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Introduction



Dick Tracy in 1946, wearing a voice activated video phone (Chester Gould)

Digital wireless and cellular roots go back to the 1940s when commercial mobile telephony began. Compared with the furious pace of development today, it may seem odd that mobile wireless hasn't progressed further in the last 60 years. Where are our video watch phones? There were many reasons for this delay but the most important ones were technology, cautiousness, and federal regulation.

As the loading coil and vacuum tube made possible the early telephone network, the wireless revolution began only after low cost microprocessors and digital switching became available. The Bell System, producers of the finest landline telephone system in the world, moved hesitatingly and at times with disinterest toward wireless. Anything AT&T produced had to work reliably with the rest of their network and it had to make economic sense, something not possible for them with the few customers permitted by the limited frequencies available at the time. Frequency availability was in turn controlled by the Federal Communications Commission, whose regulations and unresponsiveness constituted the most significant factors hindering radio-telephone development, especially with cellular radio, delaying that technology in America by perhaps 10 years.

In Europe and Japan, though, where governments could regulate their state run telephone companies less, mobile wireless came no sooner, and in most cases later than the United States. Japanese manufacturers, although not first with a working cellular radio, did equip some of the first car mounted mobile telephone services, their technology equal to whatever America was producing. Their products enabled several first commercial cellular telephone systems, starting in Bahrain, Tokyo, Osaka, Mexico City.

Wireless and Radio Defined

Communicating wirelessly does not require radio. Everyone's noticed how appliances like power saws cause havoc to A.M. radio reception. By turning a saw on and off you can communicate wirelessly over short distances using Morse

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code, with the radio as a receiver. But causing electrical interference does not constitute a radio transmission. Inductive and conductive schemes, which we will look at shortly, also communicate wirelessly but are limited in range, often difficult to implement, and do not fulfill the need to reliably and predictably communicate over long distances. So let's see what radio is and then go over what it is not.

Weik defines radio as:

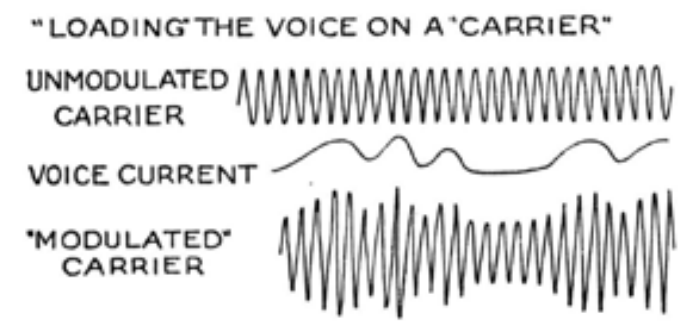
"1. A method of communicating over a distance by modulating electromagnetic waves by means of an intelligence bearing-signal and radiating these modulated waves by means of transmitter and a receiver. 2. A device or pertaining to a device, that transmits or receives electromagnetic waves in the frequency bands that are between 10kHz and 3000 GHz."

Interestingly, the United States Federal Communications Commission does not define radio but the U.S. General Services Administration defines the term simply:

1. Telecommunication by modulation and radiation of electromagnetic waves. 2. A transmitter, receiver, or transceiver used for communication via electromagnetic waves. 3. A general term applied to the use of radio waves.

http://fts.gsa.gov/library/glossary/glossary_r.htm

Radio thus requires a modulated signal within the radio spectrum, using a transmitter and a receiver. Modulation is a two part process, a current called the carrier, and a signal bearing information. We generate a continuous, high frequency carrier wave, and then we modulate or vary that current with the signal we wish to send. Notice how a voice signal varies the carrier wave below:



This technique to modulate the carrier is called amplitude modulation. Amplitude means strength. A.M. means a carrier wave is modulated in proportion to the strength of a signal. The carrier rises and falls instantaneously with each high and low of the conversation. The voice current, in other words, produces an immediate and equivalent change in the carrier.

For voice this is exactly the same way a telephone works, using the essential principle of [variable resistance](#). A voice in telephony modulates the current of a telephone line. Compared to a telephone line, the unmodulated carrier in radio is simply the steady and continuous current the transmitter generates. When you talk the radio puts, superimposes, or impresses your conversation's signal on the current the radio is transmitting. Conversation causes the current's resistance to go up and down, that is, your voice varies or modulates the carrier. I illustrate this

[1880: The Photophone and the first voice radio-telephone call](#)

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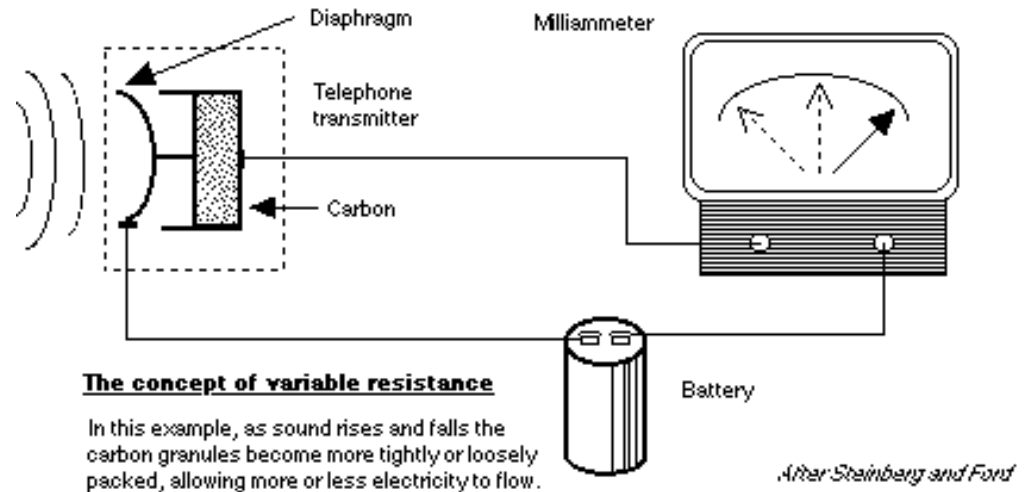
[1990: North America goes digital: IS-54](#)

[Principles of Modern Communications Technology \(external link to Amazon\)](#) (Artech House) Professor A. Michael Noll



This .pdf file is from Noll's book described above: it is a short, clear introduction to

idea with the diagram below. The only difference between a telephone and radio is that we call the transmitter a microphone. Now that we've quickly looked at radio, let's go on to its early development.



Pre-History

As we can tell already, and as [with the telephone](#), a radio is an electrical instrument. A thorough understanding of electricity was necessary before inventors could produce a reliable, practical radio system. That understanding didn't happen quickly. Starting with the work of Oersted in 1820 and continuing until and beyond Marconi's successful radio system of 1897, dozens of inventors and scientists around the world worked on different parts of the radio puzzle. In an era of poor communication and non-systematic research, people duplicated the work of others, misunderstood the results of other inventors, and often misinterpreted the results they themselves had achieved. While puzzling over the mysteries of radio, many inventors worked concurrently on power generation, telegraphs, lighting, and, later, telephones. We should start at the beginning.

In 1820 Danish physicist Christian Oersted discovered electromagnetism, the critical idea needed to develop electrical power and to communicate. In a famous experiment at his University of Copenhagen classroom, Oersted pushed a compass under a live electric wire. This caused its needle to turn from pointing north, as if acted on by a larger magnet. Oersted discovered that an electric current creates a magnetic field. But could a magnetic field create electricity? If so, a new source of power beckoned. And the principle of electromagnetism, if fully understood and applied, promised a new era of communication .



Michael Faraday
1791 to 1867

In 1821 Michael Faraday reversed Oersted's experiment and in so doing discovered [induction](#). He got a weak current to flow in a wire revolving around a permanent magnet. In other words, a magnetic field caused or *induced* an electric current to flow in a nearby wire. In so doing, Faraday had built the world's first electric generator. Mechanical energy could now be converted to electrical energy. Is that clear? This is a very important point. The simple act of moving ones' hand caused current to flow. Mechanical energy into electrical energy. But current was produced only when the magnetic field was in motion, that is, when it was changing.

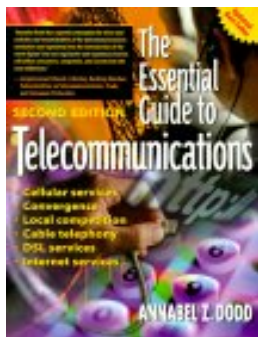
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[The Essential Guide to Telecommunications by Annabel Z. Dodd, a good, affordable \(about \\$25.00\) book on telecom fundamentals](#) (external link to Amazon.com)



[Excellent, free chapter on telecom fundamentals from the book above by Dodd \(168K, 34 page in .pdf.\) Please read.](#)

Faraday worked through different electrical problems in the next ten years, eventually publishing his results on induction in 1831. By that year many people were producing electrical dynamos. But electromagnetism still needed understanding. Someone had to show how to use it for communicating.

In 1830 the great American scientist Professor Joseph Henry transmitted the first practical electrical signal. A short time before Henry had invented the first efficient electromagnet. He also concluded similar thoughts about induction before Faraday but he didn't publish them first. Henry's place in electrical history however, has always been secure, in particular for showing that electromagnetism could do more than create current or pick up heavy weights -- it could communicate.

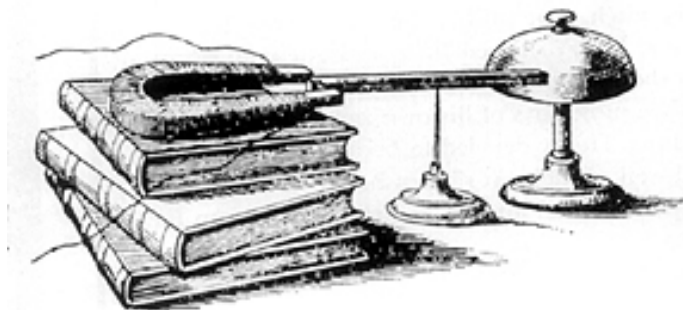
In a stunning demonstration in his Albany Academy classroom, Henry created the forerunner of the telegraph. Henry first built an electromagnet by winding an iron bar with several feet of wire. A pivot mounted steel bar sat next to the magnet. A bell, in turn, stood next to the bar. From the electromagnet Henry strung a mile of wire around the inside of the classroom. He completed the circuit by connecting the ends of the wires at a battery. Guess what happened? The steel bar swung toward the magnet, of course, striking the bell at the same time. Breaking the connection released the bar and it was free to strike again. And while Henry did not pursue electrical signaling, he did help someone who did. And that man was Samuel Finley Breese Morse.



Joseph Henry
1797 to 1878

For more information on Joseph Henry, visit the Joseph Henry Papers Project at:

<http://www.si.edu/organiza/offices/archive/ihd/jhp/index.htm>



From the December, 1963 American Heritage magazine, "a sketch of Henry's primitive telegraph, a dozen years before Morse, reveals the essential components: an electromagnet activated by a distant battery, and a pivoted iron bar that moves to ring a bell."

In 1837 Samuel Morse invented the first practical telegraph, applied for its patent in 1838, and was finally granted it in 1848. Joseph Henry helped Morse build a

telegraph relay or repeater that allowed long distance operation. The telegraph united the country and eventually the world. Not a professional inventor, Morse was nevertheless captivated by electrical experiments. In 1832 he had heard of Faraday's recently published work on inductance, and was given an electromagnet at the same time to ponder over. An idea came to him and Morse quickly worked out details for his telegraph.

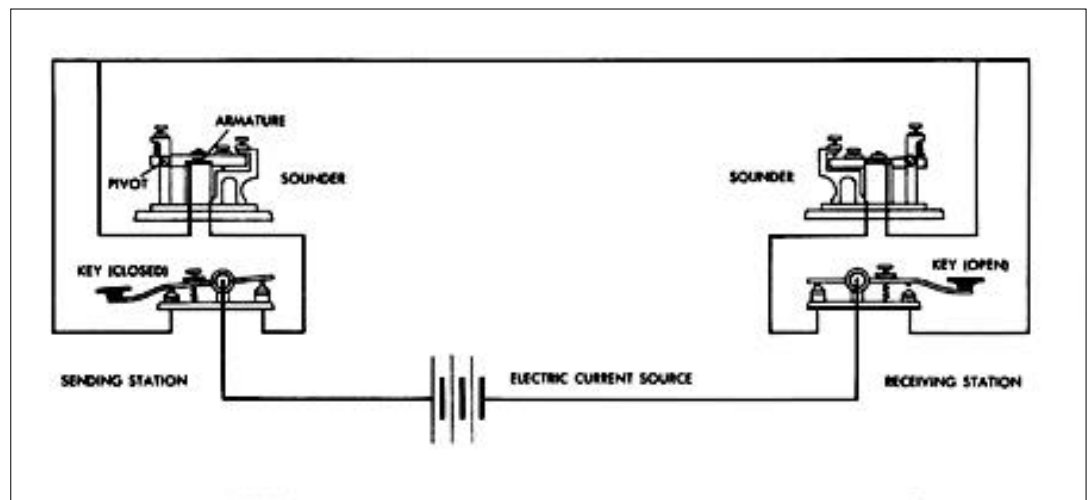


Samuel Morse
1791 to 1872

As depicted below, his system used a key (a switch) to make or break the electrical circuit, a battery to produce power, a single line joining one telegraph station to another and an electromagnetic receiver or sounder that upon being turned on and off, produced a clicking noise. He completed the package by devising the Morse code system of dots and dashes. A quick key tap broke the circuit momentarily, transmitting a short pulse to a distant sounder, interpreted by an operator as a dot. A more lengthy break produced a dash.

Telegraphy became big business as it replaced messengers, the Pony Express, clipper ships and every other slow paced means of communicating. The fact that service was limited to Western Union offices or large firms seemed hardly a problem. After all, communicating over long distances instantly was otherwise impossible. Morse also experimented with wireless, but not in a way you might think. Morse didn't pass signals though the atmosphere but through the earth and water. Without a cable.

[\(please see next page-->\)](#)



This site has a small page on Samuel Morse:

<http://web.mit.edu/invent/www/inventorsI-Q/morse.html>

abebooks.com 

The best selection of used books on the web is at <http://www.abe.com>. Period. No argument. Advanced Book Exchange is an association of hundreds and hundreds of independent book sellers. I do not get a commission from them because they do not have an affiliate program yet. But I've used and recommended them since late '95; you will be very happy with them.

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I'm presenting a work in progress to let you contribute. Please send any comments to me by [clicking here](#). Spelling errors, dead links, unclear writing, lack of coverage on a topic -- whatever. I might not agree with your suggestion but I read and respond to all of my mail. BTW, the best writing on cellular and PCS is R.C. Levine's lecture on [Digital Switching](#). It's a 368 k .pdf file that doesn't take too long to download. It expands using Acrobat 4.0 to 1.1 meg and the file is nearly 100 pages long. If you are tired of waiting for me to get this article done, please download his article. Happy reading!

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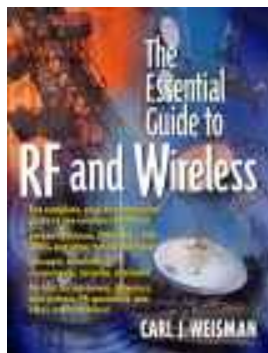
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Digital Wireless Basics

by [Tom Farley](#), KD6NSP

This work is in progress and subject to change, my [cellular basics article](#) is my most current and accurate writing

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I. Introducing wireless

A. Abstract

This article discusses digital wireless basics. It covers [wireless history](#) along with [basic radio principles and terms](#). Digital building blocks like bits, frames, slots, and channels are explained along with details of entire operating systems. Building on my [analog cellular article](#), digital cellular gets treated along with the newest service: [personal communication systems or PCS](#).

I. A general introduction -- where we are now

Wireless has gone digital, enabling services that analog couldn't easily provide. Like better eavesdropping protection, increased call capacity, decreased fraud, e-mail delivery, and text messaging. But digital has its drawbacks, especially poor coverage. We'll compare newer digital systems like GSM and PCS1900 with systems like analog and early digital cellular. We'll better understand where wireless is today and where it's headed.

New and existing wireless services share much in common. They all provide coverage using a cellular like network of radio base stations and antennas. They all use mobile switches to manage that network, allowing calls, arranging handoffs between cells, and so on. They all use one of two microwave frequency bands. Sometimes both. They all use digital to some extent. But aside

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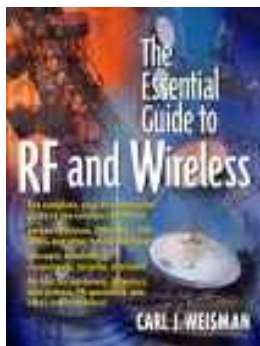
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from providing basic voice and data handling, the many services differ greatly in features and how they provided. Here's a quick, completely oversimplified list to get us going. More information follows:

AMPS: Advanced Mobile Phone service. Conventional cellular service. Mostly analog, with some digital signals providing call setup and management. A first generation service, now only installed in remote regions.

IS-95: All digital cellular using CDMA, a spread spectrum technique. Sprint PCS uses this technology. Sometimes called by its trade name of PCS 1900. A second generation or early digital service.

IS-136: D-AMPS 1900. Feature rich cellular. Mostly digital, although backward compatible with analog based AMPS. AT&T uses it for their nationwide cellular network. Uses time division multiple access or TDMA. Incorporates the old standard IS-54, an early second generation system at the time. IS-136 operates at either 800 Mhz or 1900 Mhz. AT&T is moving to a transitional technology whereby three standards, in some form, will work together: IS-136, GSM, and the newer General Packet Radio Service or GPRS. Eventually AT&T will stop using IS-136, replace it with GSM, and eventually replace that with a wideband CDMA system.

GSM. European cellular come to North America at 1900 Mhz. Fully digital with advanced features. Each mobile has intelligence within the phone, using a smart card. Uses TDMA. Among others, Pacific Bell uses GSM. Will migrate in a few years to a wideband CDMA technology.

iDEN: Proprietary cellular scheme devised by Motorola and used nationwide by NEXTEL. Combines a cell phone with a business radio. TDMA based.

We'll look soon at each service. For right now, though, to give us some orientation, let's go over recent mobile telephone history. It is quite a LONG history, so feel free to skip over that series and go on to the next topic, which is about standards.



[Click here for this free chapter from Professor Noll's book described below](#), the selection is an excellent, simple introduction to cellular. (32 pages, 204K in .pdf)

[More info on Introduction to Telephones and Telephone Systems \(external link to Amazon\)](#) (Artech House) Professor A. Michael Noll

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IV. Basic wireless principles

Cellular defined

Four key components make up most cellular radio systems: the cellular layout itself, a carefully engineered network of radio base stations and antennas, base station controllers which manage several base stations at a time, and a mobile switch, which gathers traffic from dozens of cells and passes it on to the public switched telephone network.

All analog and digital mobiles use a network of base stations and antennas to cover a large area. The area a base station covers is called a cell, the spot where the base station and antennas are located is called a [cell site](#). Viewed on a diagram, the small territory covered by each base station appears like a cell in a honeycomb, hence the name cellular. Cell sizes range from sixth tenths of a mile to thirty miles in radius for [cellular](#) (1km to 50km). GSM and PCS use much smaller cells, no more than 6 miles (10km) across. A large carrier may use hundreds of cells.

Each cell site's radio base station uses a computerized 800 or 1900 megahertz transceiver with an antenna to provide coverage. Each base station uses carefully chosen frequencies to reduce interference with neighboring cells. Narrowly directed sites cover tunnels, subways and specific roadways. The area served depends on topography, population, and traffic. In some PCS and GSM systems, a base station hierarchy exists, with pico cells covering building interiors, microcells covering selected outdoor areas, and macrocells providing more extensive coverage to wider areas. See the Ericsson diagram below.

The macro cell controls the cells overlaid beneath it. A macro cell often built first to provide coverage and smaller cells built to provide capacity.

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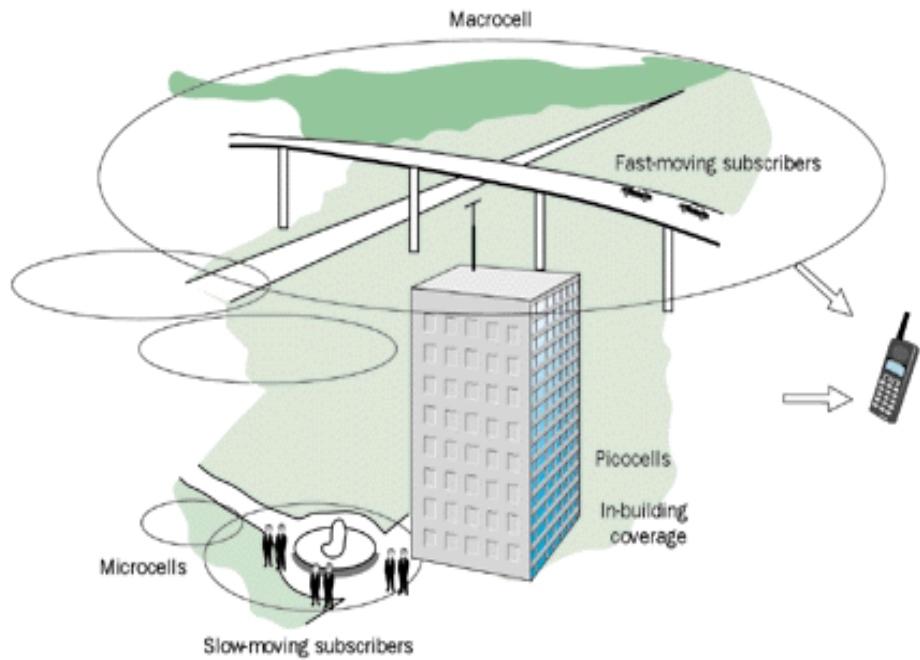
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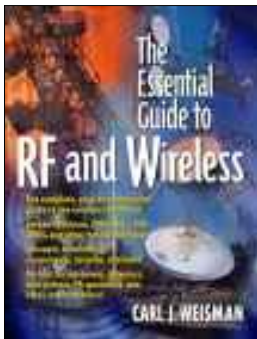
[Cellular and PCS frequencies chart](#)



Macario describes a business park or college campus as a typical situation. In those cases a macrocell provides overall coverage, especially to fast moving mobiles like those in cars. A microcell might provide coverage to slow moving people between large buildings and a piconet might cover an individual lobby or the floor of a convention center.

Steve Punter, of the excellent Steve's Toronto Area Cellular/PCS Site Guide, <http://www.arcx.com/sites/> ([external link](#)) says that typically microcells are employed along the sides of busy highways or on street corners. Steve sent in pictures of two typical microcells in the Toronto area:

[\[Microcell 1 \(70K\)\]](#) [\[Microcell2 \(71K\)\]](#)



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Base station equipment by itself is nothing without a means to manage it. In GSM and PCS 1900 that's done by a base station controller or BSC. As Nokia puts it, a base station controller "is a high-capacity switch which provides total overview and control of radio functions, such as handover, management of radio network resources and handling of cell configuration data. It also controls radio frequency power levels in the RBSs, and in the mobile phones. Base station controllers also set transceiver configurations and frequencies for each cell." Depending on the complexity and capacity of a carrier's system, there may be several base station controllers.

These BSCs react and coordinate with a mobile telecommunication switching office or MTSO, sometimes called, too, a MSC or mobile switching center. With AMPS or D-AMPS, however, the mobile switch controls the entire network. In either case, the mobile switch interacts with distant databases and the public switched telephone network or PSTN. It checks that a customer has a valid account before letting a call go through, delivers subscriber services like Caller ID, and pages the mobile when a call comes in. Among many other administrative duties. Learn more about cellular switches by [checking out this small graphic](#).

Also, if you want to see pictures of a "mobile" mobile switching center, (a Motorola EMX 100 Plus Cellular Switch) go to Michael Hart's excellent site

(external link)[Link not working right now]

How does this work out in the real world? Consider Omnipoint's PCS network for the greater New York city area. To cover the 63,000-square-mile service area, Ericsson says Omnipoint installed over 500 cell sites, with their attendant base stations and antennas, three mobile switching centers, one home location register, and one service control point. (The latter two are network resources.) [The New York Times](#) says the entire system cost \$680 million dollars, although they didn't say if that included Omnipoint's discounted operating license. Now that we've seen what makes up a cellular network, let's discuss the idea that makes that makes those networks possible: frequency reuse.



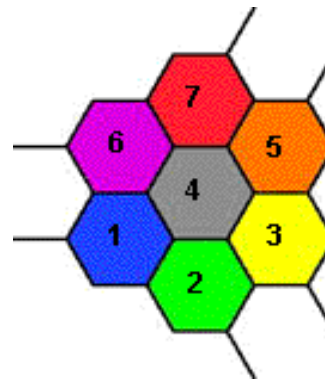
Dual band IS-136 Ericsson RBS 884 base station

B. Frequency reuse

The heart and soul, the inner core, the *sine qua non* of cellular radio is frequency reuse. The same frequency sets are used and reused systematically throughout a carrier's coverage area. If you have frequency reuse you have cellular. If you don't, well, you don't have cellular. Frequency reuse distinguishes cellular from [conventional mobile telephone service](#), where only a few frequencies are used over a large area, with many customer's competing to use the same channels. Much like a taxi dispatch operation, older style radio telephone service depended on a high powered, centrally located transmitter which paged or called mobiles on just a few frequencies.

Cellular instead relies on a distributed network of cells, each cell site with its own antenna and radio equipment, using low power to communicate with the mobile. In each cell the same frequency sets are used as in other cells. But the cells with those same frequencies are spaced many miles apart to reduce interference. Thus, in a 21 cell system a single frequency may be used several times. The lone, important exception to this are CDMA systems which we will cover later. In those, the same frequencies are used by every cell.

Each base station, in addition, controls a mobile's power output, keeping it low enough to complete a circuit while not high enough to skip over to another cell. ([back to Cell Basics article](#))



The frequency reuse concept. Each honeycomb represents a cell. Each number represents a different set of channels or paired frequencies. A cellular system separates each cell that shares the same channel set. This minimizes interference while letting the same frequencies be used in another part of the system. This is frequency reuse. Note, though, that CDMA based systems can use, in theory, all frequencies in all cells, substantially increasing capacity. For review, a channel is a pair of frequencies, one for transmitting on and one for receiving. Frequencies are described by their place in the radio spectrum, such as 900mHZ, whereas channels are described by numbers, such as channels 334 through 666. [Illustration from the CDC](#)

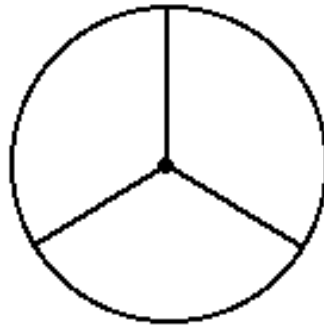
([back to Cellular basics article](#))

[Click here to go to another frequency resuse explanation](#) in my Cellular Baiscs Article -- it contains a large graphic from an early AT&T journal.

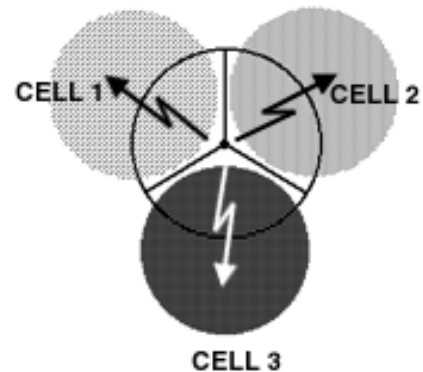
C. Adding cells and cell sectorizing

Adding cells and sectoring cells allows cellular expansion. Don't have enough circuits in a crowded cell? Too many customers? Then add to that cell by providing smaller cells like micro and pico cells, underneath and controlled by the existing and larger macro cell. As Steve Punter puts it, "By placing these short-range microcells along busy highways or at busy street corners, you effectively reduce the strain on the primary macrosites by a substantial margin.

Splitting a single cell does not mean that it is broken into smaller cells, like a dividing amoebae, but rather into sectors. A previously omnidirectional base station antenna, radiating equally in all directions, is replaced by several directional antennas on the same tower. This "sectorizing" thus divides the previously homogeneous cell into 3 or 6 distinct areas (120 and 60 degrees around the site respectively). Each sector gets its own frequencies to operate on.



WRONG!



RIGHT!

A cell site does not lie at the center of a cell, rather it lies at the edge of several cells. The pie shaped pieces represent sectors, cell areas covered by directional antennas at the cell site, using different frequencies than the other sectors and cells. Notice how adjacent cell sites would sectorize nearby cells?

As Fernando Lepe-Casillas neatly puts it, "We sector cells to reduce interference between similar cells in adjacent clusters. Cell splitting is done to increase traffic capacity." Still confused by all of this? I understand. I give another, I think somewhat clearer, [explanation at this link](#).

According to [Telephony Magazine](#), AT&T began splitting their macrocell based New York City network in 1994. (They use IS-136 at both 800 and 1900 MHz.) Starting in Midtown Manhattan, the \$30 million-plus project added 55 microcells to the three square mile area by 1997, with 10 more on the way. Lower Manhattan got a "few dozen." Microcells in lower Manhattan sought to increase signal quality, while Midtown improvements tried to increase system capacity. An AT&T engineer said "a macrocell costs \$500,000 to \$1 million to build, a microcell one-third as much and you don't have to build a room around it." AT&T used Ericsson base stations, with plans to use Ericsson 884 base stations as pictured above in the future. Camouflaged antennas got placed on buildings between 25 and 50 feet above street level.

Resources

Keiser, Bernhard, and Eugene Strange. Digital Telephony and Network Integration. 2d ed. New York, 1995 ([back to text](#))

Landler, Mark. "Yipes! Invasion of the 9-inch antennas! A new form of wireless phone service is in the works for New York City. (Omnipoint Communications to offer wireless personal communications services)" (Company Business and Marketing) New York Times v145 (August 19, 1996):C1(N), D1(L).

Luxner, Larry. "The Manhattan Project: AT&T Wireless invades the Big Apple with microcells" Telephony, Feb 24, 1997, 232(8):20. 1997

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VIII Wireless categories

II. Introducing the five main digital wireless categories

We'll cover three of the following wireless categories:

Personal Communications Services

Cellular

Paging ([Finally, some information on paging!](#))

Wireless Data

New or proposed services

(Categories adopted from Quent Cassen of the [IEEE\(external link\)](#) Orange County Communications and Computer Society)

I find [paging](#) and wireless data boring and I won't discuss them. But I will provide a quick overview of them with a few links for going further. What follows then are quick snapshots of the different categories and their services. I'll have further information in later sections.

Before describing wireless communication types and what sets them apart, we must remember what they have in common. As we've [discussed](#), and [as we have seen](#), PCS, GSM, and cellular systems use the following:

1. A distributed network of . . .
2. Cell sites, encompassing a low powered radio base station transceiver, a base station controller, and an antenna which . . .
3. Provide coverage in small geographical areas called cells . . .
4. Calls from those cells being managed by . . .
5. The base station controller and mobile switches, the . . .
6. Mobile switch and its connected databases providing an . . .

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[Frames, slots and channels](#)

[IS-54: D or Digital AMPS](#)

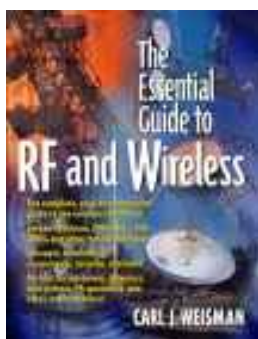
[IS-136: TDMA based cellular](#)

[Call processing](#)

[Appendix](#)

[Wireless' systems chart](#)

[Cellular and PCS frequencies chart](#)



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7. Interface between the wireless network and the wired or landline telephone network.

Think of these systems as cellular radio. That all encompassing term describes best what makes up modern radio-telephony. Keep it in mind as we roll around in many different terms. Let's look now at details and see how these mostly incompatible technologies provide similar services in different ways.



(For a comprehensive treatment on cellular radio, including GSM/PCS, [click here for Levine's most excellent 100 page .pdf file](#))

A. Personal Communications Services (PCS)

Personal communications services started as another choice to conventional cellular, and possibly as an improvement to it. As I noted in the [history section](#), PCS started in America in the mid 1990s. The FCC had previously licensed only two cellular carriers for each metropolitan area. But by 1994 more channels were needed since many carriers serving densely populated cities were at their system capacity. After much study the FCC began auctioning space in the newly designated [PCS band](#), from December 5, 1994 to January 14, 1997. [[The FCC \(external link\)](#)] A convoluted set of rules resulted in several carriers being licensed in each metropolitan area. A new group of wireless offerings in the new, higher frequency band would allow more companies to compete for the mobile customer and possibly lower wireless rates overall. Or so the FCC thought.

In each area new services and new carriers did develop to compete against conventional cellular and its existing carriers. Prices did not lower, though, and in many areas conventional cellular is now cheaper than PCS. Personal communication services, though, had been born, the most different offerings being IS-95, a spread spectrum system, which Sprint PCS uses, and the European derived GSM, a smart card technology, which many carriers now use across the United States.

Most importantly, perhaps, most PCS services started from scratch, with no older phones or handsets to accommodate analog routines. They could be an all digital service from the start. Unlike existing cellular carriers which had to accommodate even the most simple analog phone, the PCS carriers didn't worry about servicing customers with older equipment. That's because there were no new customers yet. They could build a whole new network including handsets, exactly the way they wanted.

In the United States, therefore, personal communication systems or PCS means products or services using the Federal Communication Commission's two designated PCS radio bands. Equipment like multi-purpose phones, advanced pagers, "portable facsimile and other imaging devices, new types of multi-function cordless phones, and advanced devices with two-way data capabilities." [[FCC \(external link\)](#)]

By regulation the FCC says PCS are "Radio communications that encompass mobile and ancillary fixed communication that provide services to individuals and

businesses and can be integrated with a variety of competing networks." [[47 CFR 24.5 9 \(external link\)](#)] Just about, in other words, any high tech wireless gadget or service imaginable. PCS includes many present wireless services, too, like conventional cellular, modified for the higher, newly allotted PCS frequencies. An example is AT&T's PCS offering, "Pure Digital PCS, more precisely known as IS-136. It's the foundation for their digital one rate plan. Sprint uses a technology called IS-95, which is CDMA based.

Outside the United States, and sometimes even within, defining PCS further gets trickier. Mobility Canada says they "don't believe that PCS can be defined as a technology, a radio spectrum, or a market. It is whatever the wireless communications customer wants it to be." Perhaps. But their quote reminds me of Humpty Dumpty's exhortation that "When I use a word, it means just what I choose it to mean -- neither more nor less."

Calling something PCS is now sexy and it implies that your technology, however old and dusty it may be compared to the competition, is actually happening and cutting edge. AT&T, in fact, deliberately planned to "[blur the distinction between cellular and PCS" \(external link\)](#) when they called their cellular service PCS. This debate is not purely semantical, at least to the lawyers. Roseville Telephone and AirTouch Cellular are in a [lawsuit \(external link\)](#) that hinges on the definition of PCS and Cellular.

Let's remember two things. One, that cellular radio best describes most modern radio-telephone systems, while names like AMPS and GSM refer to the operating system itself. Secondly, PCS in the States generally refers to digital cellular radio operating at a higher frequency. Those services can include different technologies, like IS-136, IS-95, and GSM.

a. The two PCS types or divisions

Two PCS types exist: narrowband and broadband. Narrowband does data and wideband does voice. Mostly. PCS narrowband uses 900 megahertz (MHz) frequencies for many advanced paging services. Broadband uses 2 gigahertz (GHz) frequencies for voice, data, and video services.

In general broadband PCS systems use higher frequencies, lower power, smaller cells and more of them, than conventional cellular at 800 MHz. That reflects the spectrum's properties: higher frequency waves are shorter, travel less distance than low frequency signals, and thus need more base stations spaced more closely together. Base station requirements are, in fact, 50% to 100% more than 800 MHz cellular. [[IEEE-OCCS](#)] These characteristics, in turn, reflect the main problem with PCS systems: lack of coverage! Until PCS networks are completely built out in America, conventional cellular service will continue to lead in coverage and lack of dropped calls.

b. The five main PCS systems

David Crowe of the outstanding [Cellular Networking Perspectives](#), says five PCS systems exist, along with a smaller, more different group of three, which we won't discuss. By way of explanation, 'upband' means a wireless service operating at a higher frequency than it normally does.

PCS1900 Upbanded GSM (A TDMA system)
TIA IS-136 Upbanded [TDMA digital cellular](#)
TIA IS-95 Upbanded [CDMA digital cellular](#)
TIA IS-88 Upbanded [NAMPS narrowband analog cellular](#) (Now defunct)
TIA IS-91 Upbanded [Plain old analog cellular](#)

As anyone can see, the major players are all existing cellular radio systems put at higher frequencies. And since they are all cellular, it makes sense to discuss them in the cellular radio discussion. Am I clear on this? PCS in America is just cellular radio put at a higher frequency. Okay? Perhaps another diagram?

The Five Major Cellular Radio Systems

AMPS -- Mostly analog

These three default to AMPS operation

- IS-54 -- First digital service -- TDMA based
(IS-54 and IS 136 are now considered one system)
- IS-136 -- Newest digital service -- TDMA based
- IS-95 -- Digital service -- CDMA based

GSM -- Digital service incompatible with above systems. Uses TDMA.

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XIII. Call Processing

This is the last page of the digital basic series. There's much more on radio in [my cellular telephone basic series](#) and in [my radio series](#). If you think you've understood most of what I have written, and you want to go further, download and read R.C. Levine's comprehensive, somewhat easy to read work on cellular and PCS by [clicking here](#). It's a 368K download in .pdf format. About 100 pages for you to print out. It deals with PCS/GSM better than I can and in more detail than a web site permits. If you want something less extensive on PCS/GSM, but just as good, try the WebProforum at this link here: [http://www.iec.org/online/tutorials/\(external link\)](http://www.iec.org/online/tutorials/(external link)). It's a great read and you will soon be a PCS wizard.

I describe [AMPS call processing in the cellular basics series](#) I just mentioned. GSM or PCS call processing, unfortunately, is too difficult for any beginning article, but I want to give you an idea of its complexity just to make the point. The chart below, reprinted with permission from Smith, gives you an idea of the problem. This is the first chart of four (!) on his article on call processing in his latest wireless book.

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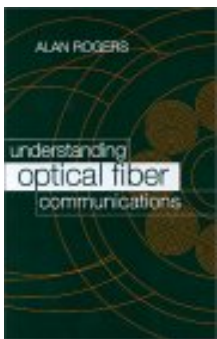
[IS-136: TDMA based cellular](#)

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Appendix

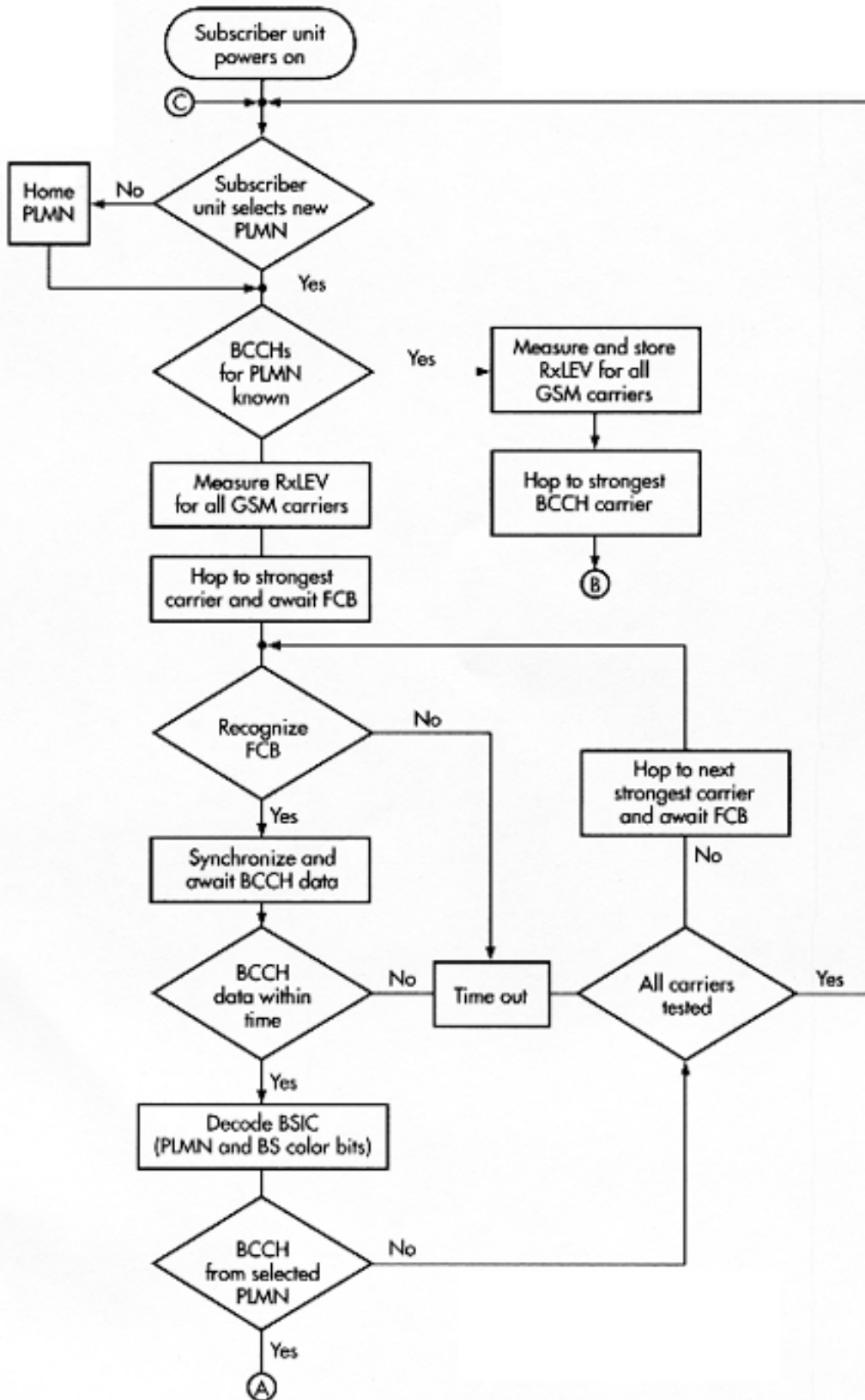
[Wireless' systems chart](#)

[Cellular and PCS frequencies chart](#)



Alan J. Rogers' [excellent introduction to electromagnetic waves, frequencies, and radio transmission](#). Really well done. (19 pages, 164K in .pdf)

[Ordering information for the book above, Understanding Optical Fiber Communications](#)

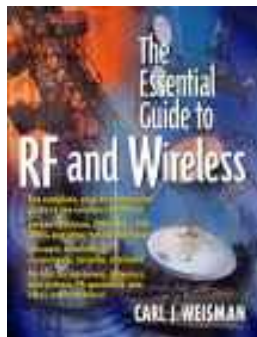


PLMN: Public land mobile network. BCCH: Broadcast Control Channel, FCB: Frequency control bursts. BSIC: Base station ID code

See how complex things get? And you have to translate his terms into something you are familiar with to have any of this make sense. Best to go to the library to search for his book. Here is a review I wrote for McGraw Hill. Anyway, I do hope you have enjoyed the series and if you know of something less complex on

[by Alan Rogers \(external link to Amazon.com\)](#)

GSM/PCS call processing on the web, [let me know](#).



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Easy to read, affordable book on wireless basics. (12 pages, 72K in .pdf)

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Clint Smith's Wireless Telecom FAQs is a necessity for wireless professionals, a requirement for those whose jobs touch on cellular radio, and a great resource for anyone working in telecom. Beginners should have a good telecom or communications dictionary when consulting this book. Those interested specifically in LMDS or other unconventional radio schemes should look elsewhere. Such as the book on LMDS that Smith also writes!

Published in 2000 by McGraw Hill, Wireless Telecom FAQs's is a desk and field reference book in one. It's set in a question and answer format and accompanied by many illustrations. Formulae and equations appear rarely and only when necessary, such as in calculating diffraction loss or figuring path clearance. Besides discussing RF, filters, and antennas, it also gives information on cellular networks, design, cell site management, traffic engineering, and system performance.

Bearing little resemblance to musty, text only internet FAQs, Smith's work features crisp diagrams, well done charts, and extensive tables. Each one seems designed for this book; all of the line art is of a piece, and beautifully presented. The GSM/PCS1900 call processing charts in particular are outstanding, as well as the IS-136 channel assignments table.

The book's layout is exemplary. Printed on brilliant white, acid free paper, a ragged right border for easy reading, and generous white space between questions and answers, the book's style opens the text, invites browsing, and leavens Smith's studied tone. An accurate, comprehensive index makes subjects easy to find. This is an excellent, practical, Q&A style book on current cellular radio practice. The list price is \$39.95 and the ISBN is 0-07-134102-1. 572 pages in hardback. Available from [McGraw Hill](#) directly or, among others, [Amazon.com](#).



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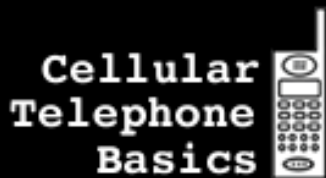
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CELLULAR TELEPHONE BASICS: AMPS & BEYOND

BY TOM FARLEY KD6NSP

with Mark van der Hoek of [WFI](#)

(Best viewed at 800 X 600)



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Please Note: Systems built on time division multiplexing will gradually be replaced with other access technologies. CDMA is the future of digital cellular radio. Time division systems are now being regarded as legacy technologies, older methods that must be accommodated in the future, but ones which are not the future itself. (Time division duplexing, as used in cordless telephone schemes: DECT and Personal Handy Phone systems might have a place but this still isn't clear.) Right now all digital cellular radio systems are second generation, prioritizing on voice traffic, [circuit](#)

► [R.B. Hill: Dial system history](#)

[switching](#), and slow data transfer speeds. 3G, while still delivering voice, will emphasize data, packet switching, and high speed access.

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[III Cell and Sector Terminology](#)

[IV Basic Theory and Operation](#)

[V Cellular frequency and channel discussion](#)

[VI. Channel Names and Functions](#)

[VII. AMPS Call Processing](#)

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[C. The SAT, Dial Tone, and Blank and Burst](#)

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[IX. Code Division Multiple Access -- IS-95](#)

[A. Before We Begin -- A Cellular Radio Review](#)

[B. Back to the CDMA Discussion](#)

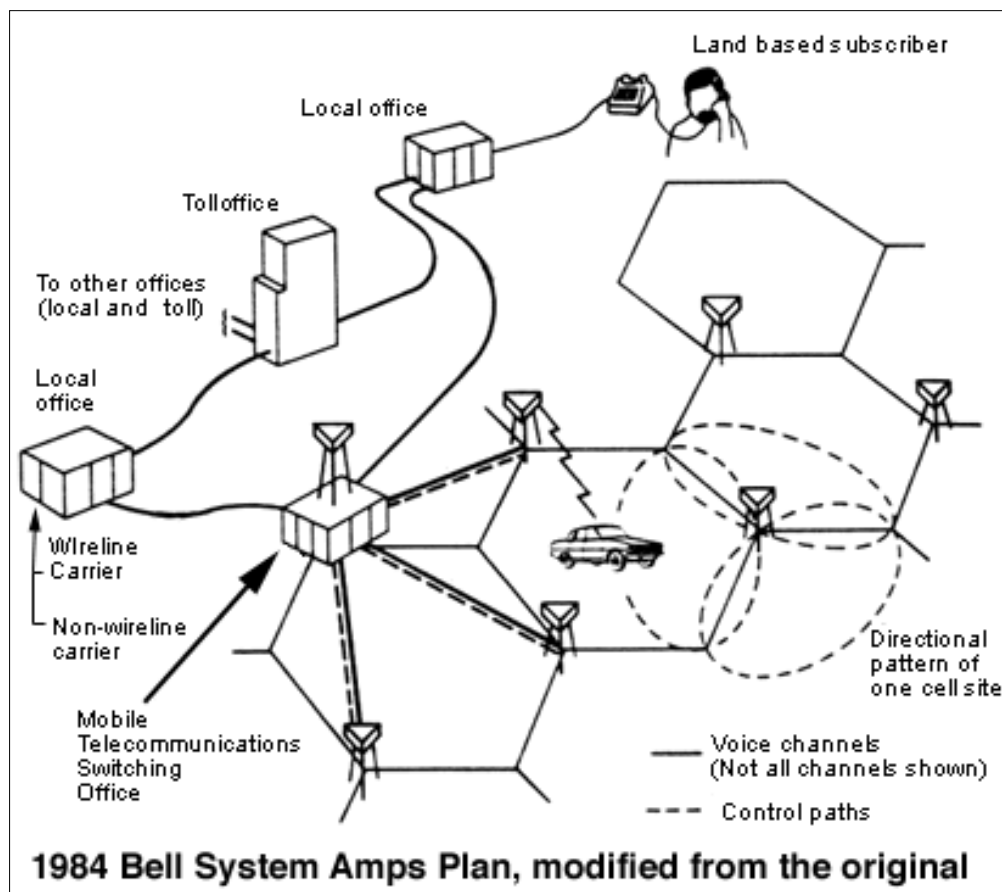
[C. A Summary of CDMA -- Another transmission technique](#)

[D. A different way to share a channel](#)

[E. Synchronization](#)

[F. What Every Radio System Must Consider](#)

Over the years, in stages hard to follow, often with 2G and 3G techniques co-existing, TDMA based [GSM\(external link\)](#) and AT&T's IS-136 cellular service will be replaced with a wideband CDMA system, the much hoped for [Universal Mobile Telephone System \(external link\)](#). Strangely, IS-136 will first be replaced by GSM before going to UMTS. Technologies like [EDGE and GPRS\(Nokia white paper\)](#) will extend the life of these present TDMA systems but eventually new infrastructure and new spectrum will allow CDMA/UMTS development. The present CDMA system, IS-95, which Qualcomm supports and the Sprint PCS network uses, is narrowband CDMA. In the Ericsson/Qualcomm view of the future, IS-95 will also go to wideband CDMA.



[A larger image of the above and a complete description of same is here](#)



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[G. CDMA Benefits](#)

[H. Call Processing -- A Few Details](#)

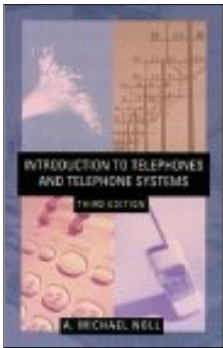
X. Appendix

[A. AMPS Call Processing Diagram](#)

[B. Land Mobile or IMTS](#)

[C. Early Bell System Overview of Amps](#)

[Introduction to Telephones and Telephone Systems \(external link to Amazon\)](#) (Artech House)
Professor A. Michael Noll



[This is from Professor Noll's book above, it is an excellent, simple introduction to cellular \(32 pages, 204K in .pdf\)](#)



[This is a sample of Professor Levine's writing, co-author of the work below. This .pdf file is a well detailed, advanced guide to cellular \(100 pages, 373K in .pdf\)](#)

I. Introduction

Cellular radio provides mobile telephone service by employing a network of [cell sites](#) distributed over a wide area. A cell site contains a [radio transceiver and a base station controller](#) which manages, sends, and receives traffic from the mobiles in its geographical area to a cellular telephone switch. It also employs a tower and its antennas, and provides a link to the distant cellular switch called a mobile telecommunications switching office. This MTSO places calls from land based telephones to wireless customers, switches calls between cells as mobiles travel across cell boundaries, and authenticates wireless customers before they make calls.

Cellular uses a principle called frequency reuse to greatly increase customers served. Low powered mobiles and radio equipment at each cell site permit the same radio frequencies to be reused in different cells, multiplying calling capacity without creating interference. This spectrum efficient method contrasts sharply with earlier mobile systems that used a high powered, centrally located transmitter, to communicate with high powered car mounted mobiles on a small number of frequencies, channels which were then monopolized and not re-used over a wide area.

Complex signaling routines handle call placements, call requests, handovers, or call transfers from one cell to another, and roaming, moving from one carrier's area to another. Different cellular radio systems use frequency division multiplexing (analog), time division multiplexing (TDMA), and spread spectrum (CDMA) techniques. Despite different operating methods, AMPS, PCS, GSM, E-TACS, and NMT are all cellular radio. That's because they all rely on a distributed network of cell sites employing frequency re-use. Is your head spinning yet? Let's ease into this cellular discussion by discussing some history first.

History

United States cellular planning began in the mid 1940s-after World War II, but trial service did not begin until 1978, and full deployment in America not until 1984. This delay must seem odd compared to today's furious pace of wireless development, but there were many reasons for it. Limited technology, Bell System ambivalence, and government regulation limited radio-telephone progress.

As the vacuum tube and the transistor made possible the early telephone network, the wireless revolution began only after low cost microprocessors, miniature circuit boards, and digital switching became available. And while AT&T personnel built the finest landline telephone system in the world, Bell System management never truly committed to mobile telephony. The U.S. Federal Communications Commission also contributed to the delay, stalling for decades on granting more frequency space. This limited the number of mobile customers, and thus prevented any new service from developing fully since serving those few customers would not make economic sense. But in Europe,



[Cellular and PCS: The Big Picture, Harte, Prokup, and Levine \(external link to Amazon.com\)](#)

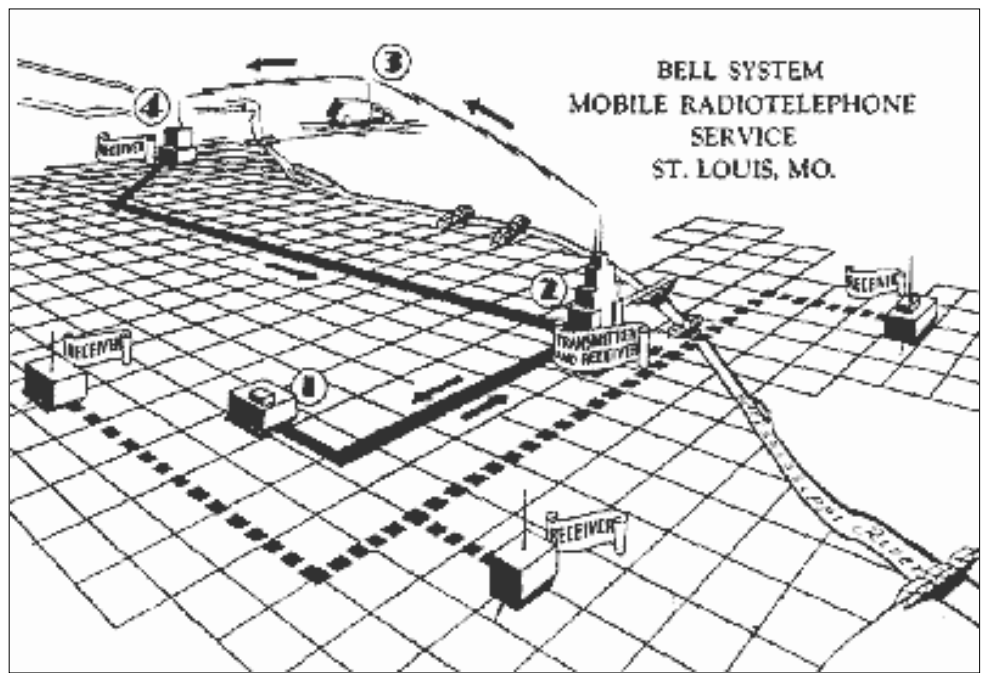
Scandinavia, Britain, and Japan, where state run telephone companies operated without competition, and where regulatory interference was minor, cellular came at the same time or later, not sooner than in America. It remains a question, then, on what the biggest factor limiting cellular development truly was.

For far more on mobile telephone history [go to my wireless history series here](#)

Although theorized for years before, Bell Laboratories' D.H. Ring articulated the cellular concept in 1947 in an unpublished company paper. W.R. Young, writing in The Bell System Technical Journal, said Ring's paper stated all of cellular's elements: a network of small geographical areas called cells, a low powered transmitter in each, traffic controlled by a central switch, frequencies reused by different cells and so on. Young states that from 1947 Bell teams "had faith that the means for administering and connecting to many small cells would evolve by the time they were needed." [Young] While cellular waited to evolve, a more simple system was used for mobile telephony, a technology that, as it finally matured, originated some practices that cellular radio later employed.

On June 17, 1946 in Saint Louis, Missouri, AT&T and Southwestern Bell introduced the first American commercial mobile radio-telephone service. It was called simply Mobile Telephone Service or [MTS](#). Car drivers used newly issued vehicle radio-telephone licenses granted to Southwestern Bell by the FCC. These radios operated on six channels in the 150 MHz band with a 60 kHz channel spacing, twice the size of today's analog cellular. [Peterson] Bad cross channel interference, something like cross talk in a landline phone, soon forced Bell to use only three channels. In a rare exception to Bell System practice, subscribers could buy their own radio sets and not AT&T's equipment.

Installed high above Southwestern Bell's headquarters at 1010 Pine Street, a centrally located antenna transmitting 250 watts paged mobiles when a call was for them. Automobiles responded not by transmitting to the headquarters building but to a scattering of receiving sites placed around the city, usually atop neighborhood central switching offices. That's because automobiles used lower powered transmitters and could not always get a signal back to the middle of town. These central offices relayed the voice traffic back to the manually operated switchboard at the HQ where calls were switched. So, although the receiver sites were passive, merely collecting calls and passing them on, they did presage the cellular network of distributed, interactive cell sites.



[A much larger and clearer image of the above can be had by clicking here. Warning!](#)
 -- 346K

One party talked at a time with MTS. You pushed a handset button to talk, then released the button to listen. This eliminated echo problems which took years to solve before natural, full duplex communications were possible. This is not simplex operation as many people say it was. Simplex, used in business radio, shares a single frequency for both people talking. In MTS and IMTS transmitting and receiving frequencies were different, and offset from each other to prevent interference. Base to mobile might be on 152 MHz and mobile to base might be on 158. This is what we call half duplex, whereby different frequencies for transmit and receive are employed, but only one party talks at a time.

Operators placed all calls so a complex signaling routine wasn't required. The Bell System was not interested in automatic dial up and call handling until decades later, instead, independent wireless companies or Radio Common Carriers, pioneered these techniques.

On March 1, 1948 the first fully automatic radiotelephone service began operating in Richmond, Indiana, eliminating the operator to place most calls. [\[McDonald\]](#) The Richmond Radiotelephone Company bested the Bell System by 16 years. AT&T didn't provide automated dialing for most mobiles until 1964, lagging behind automatic switching for wireless as they had done with landline telephony. Most systems, though, RCCs included, still operated manually until the 1960s.

In 1964 the Bell System began introducing Improved Mobile Telephone

Service or [IMTS](#), a replacement to the badly aging Mobile Telephone System. But some operating companies like Pacific Bell didn't implement it until 1982, at the dawn of cellular. IMTS worked in full-duplex so people didn't have to press a button to talk. Talk went back and forth just like a regular telephone. Echo problems had been solved. IMTS also permitted direct dialing, automatic channel selection and reduced bandwidth to 25-30 kHz. [\[Douglas\]](#). Operating details foreshadowed analog cellular routines, the complexity of which we will see soon enough. Here's how AT&T described automatic dialing:

Control equipment at the central office continually chooses an idle channel (if there is one) among the locally equipped complement of channels and marks it with an "idle" tone. All idle mobiles scan these channels and lock onto the one marked with the idle tone. All incoming and outgoing calls are then routed over this channel. Signaling in both directions uses low-speed audio tone pulses for user identification and for dialing.

[\[See the Bell System description for more details\]](#)

[\[Or check out my pages on IMTS and come back here later\]](#)

In January, 1969 the Bell System employed [frequency reuse](#) in a commercial service for the first time. On a train. From payphones. As we've mentioned before, frequency re-use is the defining principle or concept of cellular. "[D]elighted passengers" on Metroliner trains running between New York City and Washington, D.C. "found they could conveniently make telephone calls while racing along at better than 100 miles an hour." [\[Paul\]](#) Six channels in the 450 MHz band were used again and again in nine zones along the 225 mile route. A computerized control center in Philadelphia managed the system. The main elements of cellular were finally coming into being, and would result in a fully functional system in 1978.

For a detailed look at mobile wireless history, go here:

<http://www.TelecomWriting.com/PCS/history.htm>

Let's not dismiss early radio systems too quickly, especially since we need to contrast them with cellular radio, to see what makes cellular different. IMTS or the Improved Mobile Telephone System equipment (and its variants) may still be around, serving isolated and rural areas not well covered by cellular. Larger telcos, though, have abandoned it, Pacific Bell dropping IMTS in 1995. Cellular service may be in 90% of urban areas, but it only reaches 30% to 40% of the geographical area of America. [\[See IMTS\]](#) Most IMTS equipment operated in the UHF band. Again, it used a centrally located transmitter and receiver serving a wide area with a relatively few frequencies and users. Only in larger areas would you have additional receiving sites like in Saint Louis. A single customer could drive 25 miles or more from the transmitter, however, only one person at a time could use that channel.

[Go to the end of this article for a Bell System overview of IMTS and Cellular](#)

This limited availability of frequencies and their inefficient use were two main reasons for cellular's development. The key to the system, to be offensively

repetitive, is the concept of frequency reuse. It is the chief difference between IMTS and cellular. In older mobile telephone services a single frequency serves an entire area. In cellular that frequency is used again and again. More exactly, a channel is used again and again, a radio channel being a pair of frequencies, one to transmit on and one to receive.

[More explanation of frequency reuse](#)

Now, since we are defining cellular so much, let's look at the terminology and structure of cells.

[Next page--->](#)

Notes

[IMTS] Fike, John L. and George E. Friend. Understanding Telephone Electronics SAMS, Carmel 1990 268 ([back to text](#))

[Appendix: Early Bell System overview of IMTS and cellular](#) // [Appendix: Call processing diagram](#) // [Pages in This Article](#)

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Bits & Bytes

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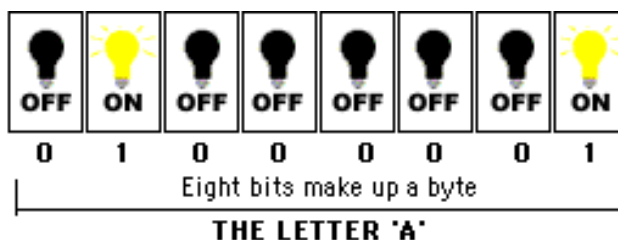
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Bits and Bytes, It's all Done By Code

A computer processes information by turning electricity on and off. It is amazing that everything a computer does is grounded in either the presence or absence of extremely small amounts of electricity. On or off. That's it. Now, you might say that this sounds daft, that your word processor, spreadsheet, or internet browser program, cannot possibly work because of little charges turning on and off like Christmas lights. But in fact that is true. Those little charges, like little acorns, grow indeed to be big things.

We can do quite a bit by turning electricity on and off. [Morse code](#), that system of dots and dashes, uses short or long electrical bursts to represent letters and numbers. International Morse code represents the letter "A" with a dot, electricity turned on for a small amount of time, a space, electricity absent for a short amount of time, and a dash, a longer electrical burst than the dot. Different combinations of dots and dashes stand for other letters. Good telegraphers can send fifty words or more per minute using Morse code. Teletype machines sent information even faster using the Baudot code. All done by turning electricity on and off.



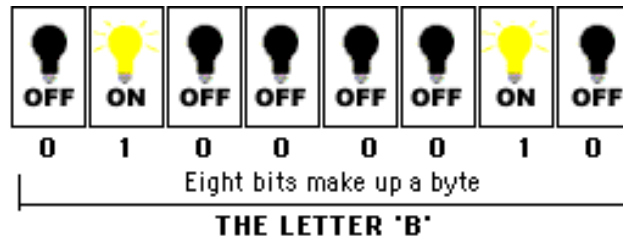
With computers we use a different kind of code, the most common being something called ASCII, which stands for, hold your breath, the American National Standard Code for Information Interchange. Of course. Eight parts make up all ASCII characters, each part called a bit. A bit can be a charge of electricity or a lack of electricity. That's a big difference than Morse Code.

With Morse different characters like A, B, or C, are made up of differing amounts. Three parts make up the letter A like we showed above, while the letter V is made up of seven parts: dot, space, dot, space, dot, space, dash. In ASCII all characters make up the same amount, eight bits which we call a byte. Also, Morse code has three states: electricity on for a short amount of time, electricity on for a longer amount of time, and, of course, electricity off. With ASCII we have two states, a binary code; electricity only on or off. Which works out fine.

When you punch in "A" or "B" on your computer keyboard a microprocessor doesn't recognize those letters as such, instead it responds to 0s and 1s, bits, pulses

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which make up a byte. Bits and bytes are the building blocks of digital.



You're probably wondering how all these 0s and 1s stay together and not get lost. That's a big concern -- we must be sure that what we sent is what got across. A bank wouldn't want their automated teller machine to hand out a thousand dollars when only a hundred was intended. So what do we do? We add a bit to our code and use a simple routine to automatically check our byte or digital character.

The extra bit we is called the parity bit, the watch guard for the letter. A newer, better method exists to check data integrity, known as a cyclic redundancy check. Let's look at bit parity checking instead, since you'll find so many references to it. It is elegantly simple but difficult to grasp on the first read. Here's Jade Clayton's presentation, from his excellent [McGraw Hill Illustrated Telecom Dictionary](#). Read it once or twice and you will get it:

"Bit Parity: A way to check that transmitted data is not corrupted or distorted during transmission. . . Take a bit stream that will be transmitted, add all the bits as binary numbers mathematically, and the resulting number is odd or even. Add a 1 at the end of the stream if the number is even and a 0 if the number is odd.

When the bits are received at the other end, they are added up and compared to the last bit. If they add up to be an even number, then the last bit should be a 1. If they add up to be an odd number they should be a 0. If the case for either does not hold true, the receiving end sends a request to retransmit the stream of bits. They are retransmitted, with the parity bit attached all over again.

For example, a computer sends a bit stream of 10101011. Simply adding the bits gives a sum of $1+0+1+0+1+0+1+1=5$. This is an odd number so add a 0 to the end of the stream to make it 101010110. The bits are received at the other end, added together, and compared to the parity bit the same way. There are new and more sophisticated ways of checking for errors in data transmission, such as cyclic redundancy checking." [Jade Clayton, writing in the McGraw Hill Telecom Dictionary](#)

Get it? Parity check adds or sums the bits in a byte. If it is an odd number a 0 is tacked onto the end of the group and if it is an even number a 1 gets put on. Once received, Mr. Computer adds up the original eight bits. It then looks at the parity bit, to see if it agrees with the sum. If not, retransmit and try again!

More coming soon! Questions? [E-mail me: tom@TelecomWriting.com](mailto:tom@TelecomWriting.com)

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Introducing circuit and packet switching

"Thanks to more capable electronics for handhelds, communications companies are scrambling to deploy so called 2.5G (for generation 2.5) networks more attuned to the world of data. In earlier networks, whether analog or digital, each call creates a circuit that reserves a channel between two parties for the entire session. The 2.5G devices are the first to use Internet-style packet switched networks; they send bursts of data only when needed. Because these devices don't hog an entire circuit, they can be "always on."

John Ueland, writing in the article 'Internet Everywhere', from the September/October issue of MIT's [Technology Review \(external link\)](#).

There's much talk about the coming mobile internet, about how people will have a wireless, always on connection to the web. How will that come about? In two words, packet switching, a fundamental, elemental change between how wireless was delivered in the past and how it will be presented in the future.

Conventional cellular radio and landline telephony use circuit switching. A service like Cellular Digital Packet Data or CDPD, by contrast, employs packet switching. Wireless services now developing such as General Packet Radio Service or GPRS, [Bluetooth](#), and [3G](#), will use packet switching as well.

Circuit switching dominates the public switched telephone network or PSTN. Network resources set up calls over the most efficient route, even if that means a call to New York from San Francisco goes through switching centers in San Diego, Chicago, and Saint Louis. But no matter how convoluted the route, that path or circuit stays the same throughout the call. It's like having a dedicated railroad track with only one train, your call, permitted on the track at a time.

Before we go on, let's talk about digital. Voice and data from the [local loop](#) goes digital once it hits the local telephone switch. Traffic between American telephone offices is nearly all digital, you know, 1s and 0s. Bits. That includes most circuit switched traffic, like we just discussed. All these bits get packaged into small

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[Early dial systems by R.B. Hill](#)

[Early Years of the Strowger System by R.B. Hill](#)

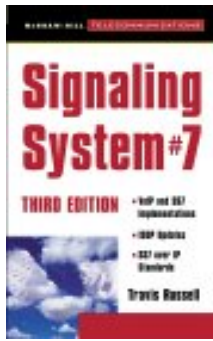
[Gilder, Page 1](#)

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[Packet switching](#)

[Sounds of a step by step switch](#)

[Strowger memorabilia \(275K\)](#)



[Signaling System #7 by Travis Russell, McGraw Hill \(external link to Amazon.com\)](#) I am puzzled by the reviews at Amazon on this book, check out the .pdf file below. I think it is quite clear, moves logically, and is well written. What am I missing?



[Good background on the present telephone system structure by Travis Russell. These are pages 1 through 8 \(8 pages, 203K, .in .pdf\)](#)



[Background article continues here, explaining circuit switching and why the present telephone network needs to change. Pages 9 through 19. \(11 pages, 275K, .in .pdf\)](#)

groups called packets, frames, blocks, or cells. [TCP/IP](#), X.25, [ATM](#), [frame relay](#), pick your packet switched technology, all traffic gets put into one form of packet or another. But simply packetizing data does not mean a call is packet switched.

TDMA and CDMA in wireless, [T-Carrier](#) and [SONET](#) in wireline networks, are transmission methods, transport mechanisms that carry information from one point to another across the telephone network. They packetize data but do not in general switch that data. According to their own protocol or standard, they package up data sent to them in the most efficient way possible, without interfering in switching. If my laptop is connected to the internet over a cellular modem, for example, then I am using TCP/IP to surf the net, while the modem may be using TDMA or CDMA to actually transport the call. Read more in the Ericsson quote below, where voice over the internet is sent using wideband CDMA. I don't mean to confuse anyone here, I just want to point out the difference between packets in switching and packets in certain transmission technologies. If you really want to get confused, know that some packet technologies like [TCP/IP](#) combine elements of both transmission and switching. But stay with the discussion.

Packet switching dominates data networks like the internet. A data call or communication from San Francisco to New York is handled much differently than with circuit switching. With circuit, all packets go directly to the receiver in an orderly fashion, one after another on a single track. Like the train we mentioned before, hauling one boxcar after another. With packet switching routers determine a path for each packet or boxcar on the fly, dynamically, ordering them about to use any railroad track available to get to the destination. Other packets from other calls race upon these circuits as well, making the most use of each track or path, quite unlike the circuit switched calls that occupy a single single path to the exclusion of all others.

Upon getting to their destination, the individual packets get put back into order by a packet assembler. That's because the different routes practically ensures that packets will arrive at different times. This approach is acceptable when calling up a web page or downloading a file, since a tiny delay is hardly noticed. But one notices even the tiniest delay with voice. This point is really important. Circuit switching guarantees the best sounding call because all packets go in order. No delay. Delays in packet switching for voice causes voice quality to fall apart, as anyone who has talked over the internet can tell you.

As technology gets better with time, voice over packet switched networks will get better, indeed, Bell Labs says that the problems with sending voice over [packet switched networks have been overcome \(external link\)](#). They don't talk, though, about sending voice over packet switched networks in a cellular radio context. Ericsson is confident about the 'air interface' as the following shows:

"Recently, Ericsson and Japan Telecom . . . successfully completed the world's first field trial of Voice-over-IP [using] wideband CDMA. The field trial results prove that voice can be efficiently transported over an IP-based mobile network. This includes the cellular air-interface, to mobile terminals, with full quality of voice service as well as full quality of other service features such as data, without loss of capacity. . . The field trial was conducted in July and August, 2000 with Japan Telecom at its network center in Chiba, Japan. . . The

trend in today's telecoms industry is towards 'all-IP' transport networks," says Håkan Eriksson, Vice President and General Manager, Ericsson Research. "Operators want to be able to use the same network for all services; data, voice and video. The field trial conducted together with Japan Telecom has proven that it is possible to transport voice over an IP-based mobile network, without compromising quality or system performance."

Some companies like [Caspian Networks \(external link\)](#) are developing router like devices which will recognize packet types and prioritize accordingly, thus speeding up packet delivery and reducing lag time with voice and video. As Josh McHugh writes about Caspian's optical IP superswitch, in the May 2001 Wired, "It can identify packet types (voice, text, video, et cetera) and priorities, allowing it to determine one packet's relation to others, and expedite traffic in a way that's impossible today. For example, the Aperio will recognize all portions of a video stream and label them as a part of a greater whole so they can be more efficiently slotted and moved to their ultimate destination." We shall see.

Packet switched networks exist for the data communication needs of education, business, and government throughout the United States. These networks rely on telephone lines, of course, but the circuits are so arranged that they retain a permanent connection with their customers. The Public Data Network or Packet Switched Network, stands as the data counterpart to the Public Switched Telephone Network. I used to dial a local number to access Delphi, a now defunct internet service provider. CompuServe and Prodigy used the same telephone number. All three used the same packet network, which you accessed when your computer dialed and logged in. An identification number directed your traffic to the right ISP, no matter where in the country it was. If you logged out but did not hang up the modem, you could enter numbers at the prompt on your screen and connect to, among other services, the NASA packet switching network. But I wander from the point I wanted to make.



I will probably get sued but I wanted you to see this nice graphic from Warner Brothers and [Packet Video \(external link\)](#). Packet Video is promising video clips at 60Kbs over conventional circuit switched cellular radio channels, indeed, they say they are platform independent, that is, their technology will work over whatever radio technology a carrier

is using. I saw T.V. screen based demo at WirelessIT2000 in Santa Clara, CA recently, although a working device wasn't present.

Unlike circuit switching, no one call takes up an entire channel for an entire session. Bits get sent only when traffic goes on, when people actually speak. During pauses in a conversation a channel gets filled with pieces of other conversations. Because your call doesn't hog an entire circuit the telephone system can permit an always on connection. You might pay a flat monthly charge or by the bandwidth or bits you actually use. Whether wireless operators can afford to do so is difficult to decide. Too many customers means building many more expensive cell sites. Even if technology permits we may stay with a per minute charge.

If packet switching is so efficient, why hasn't the landline public switched telephone network converted to it? The answer is time and money. Replacing circuit switched switches with packet switches accross the country would be a monumental task, requiring billions of dollars over years and years. The legacy of circuit switching will be around for quite a long time, following us far into the new century. Still, traffic engineers must think about changing, with lengthy dial up calls to the internet placing huge demands on switches that were never planned for, circuits now tied up longer than ever imagined. But change has to come at some point, and the internet's traffic now motivates engineers to move toward a unified switching method in the PSTN. As Bell Labs puts it "Telecommunications companies and Internet providers view these new problems as opportunities to move from separate voice and data networks to converged packet-switched voice and data networks."

[DSL](#) and ASDL and cable modem connections will either speed or retard this transistion; a local telephone company directs this broadband traffic to a packet switch, bypassing the existing local, circuit based switch. As broadband users increase call holding times should decrease, as dial up modems are taken out of service. The local switch should not be as overwhelemed as many currently are. A telco may then decide to delay a transistion to packet switching.

While the PSTN creeps towards convergence, many telecom companies are looking at placing calls over packet switched local area networks the internet. John Quain notes in the October,2000 Computer Shopper that GTE is partners with [Dialpad.com \(external link\)](#), a net based service allowing computer to landline telephone calls, while AT&T owns 30 percent of [Net2Phone \(external link\)](#), which permits free computer to computer calls. This is voice over internet protocol technology, or [VoIP \(Jade Clayton's quick article at TelecomWriting.com\)](#). Calls sound poor at times, reminding me of short wave. But free is good, especially if you are an American who needs to talk with another computer user in New Zealand. Panasonic will soon debut a cordless phone with a Net2Phone button, push it before making a call and the cordless will place the connection over the net, with no need for a computer. Call setup may take a while, of course, but Panasonic hopes a 3.9 cent a minute toll charge to anywhere in the country will mollify users. I'm not so sure. Quain also says Netscape's 6.0 browser has Net2Phone built in but does not say if there is a Macintosh version. A complete lack of Mac compatible VoIP systems has prevented me from playing with this technology.

Call quality differs from the PSTN for many reasons: slow speed internet connections, feedback from poor microphone placement, low grade transmitters and receivers. Companies using packet switching to place voice calls over their high speed local and wide area networks don't suffer from these problems as much. Quain says companies like 3Com market systems to small firms which funnel inbound calls to the packet switch for a company. Once packetized the call goes directly to whatever phone number was being dialed. This eliminates the traditional office switch and allows software, not hardware, to enable features like conferencing and call forwarding. Even video conferencing if the number being dialed at the office is to a computer and not a desk telephone. That's simpler than it sounds.

When a call comes into your computer over such a system a graphic or an image comes up, saying you have a call. An keypad image lets you point and click on the numbers to make a call. Your computer or the one for the company enables voice mail and stores telephone directories. A company with a packet based switch will allow you to eventually store all of your e-mail and pages and faxes and voice calls on a single computer which also acts as your phone. See where convergence is taking us? And how getting away from circuit switching will help? The drive toward unified packet switching will enable a brand new future for the public telephone system.

Some people say that Bell System engineers had good ideas for developing packet switching for voice traffic on the PSTN but I will have to do more research to confirm this. The following article, written by George Gilder, gives some clues but no specific references or dates. But for now, knowing the difference between circuit switching and packet switching will, I hope, make understanding the new wireless data services a little easier.

For outstanding information on packet switching, please visit the site at Bell Labs:

<http://www.bell-labs.com/technology/packet/>

More reading here!

George Gilder's '[Inventing the Internet](#)' was first published in Forbes in June, 1997. It describes the beginning of packet switched networks and the start of the internet. Later on it describes future wireless technologies. It makes for excellent reading, putting my preliminary article on circuit switching and packet switching into context. I've put the article up at TelecomWriting.com since Gilder permitted its free distribution. Keep in mind a few things while you read.

Gilder does not address the voice delay problem inherent in packet switching, leaving the reader thinking that there are no drawbacks to voice over packet. That would be wrong, especially at the beginning of the 1970's. The second problem is that Gilder quotes a central figure in the article, a man who says a Bell System employee told him that packet switching would never work. But we cannot tell whether this AT&T employee was discussing data networks or voice networks. If the man said packet switching wouldn't work for data, well, that man would be wrong. But if he maintained that packet could not be substituted for circuit switching in the PSTN because of call quality, well, that man would be right, especially for the times. Aside from these two points, Gilder writes well and you

will learn much. [---->](#)



Voice and data come together when telephone calls get put over the internet. For a good explanation on voice over the internet, [click here for a free selection](#) from Carrier Grade Voice Over IP by Daniel Collins (20 pages, 860K in .pdf)

[For ordering information, click here](#) (external link to Amazon.com)

[On to Gilder's article --->](#)

Packet Switching Types: [ATM](#), [Frame Relay](#), [TCP/IP](#), [X.25](#)

Transmission: [SONET](#), [T-Carrier](#)

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Wireless by Conduction

On October 18, 1842, Morse laid wires between Governor's Island and Castle Garden, New York, a distance of about a mile. [\[For a complete description click here\]](#) Part of that circuit was under water, indeed, Morse wanted to show that an underwater cable could transmit signals as well as a copper wire suspended on poles. But before he could complete this demonstration a passing ship pulled up his cable, ending, it seemed, his experiment. Undaunted, Morse proceeded without the cable, passing his telegraph signals through the water itself. This is wireless by conduction.

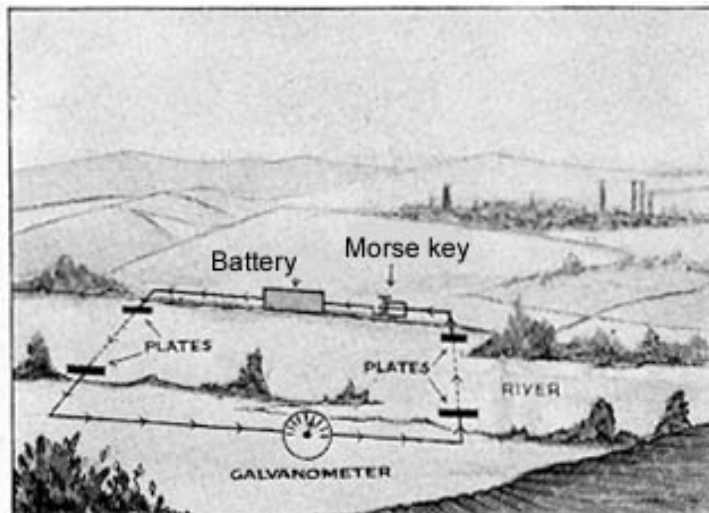


Fig. 1. Radio by conduction. How Morse's experiment in transmitting a message across a river was carried out.

Over the next thirty years most inventors and developers concentrated on wireline telegraphy, that is, conventional telegraphy carried over wires suspended on poles. Few tinkered exclusively with wireless since basic radio theory had not yet been worked out and trial and error experimenting produced no consistent results. Telegraphy did produce a good understanding of [wireless by induction](#), however, since wires ran parallel to each other and often induced rouge currents into other lines. University research and some field work did continue, though, with many people making contributions.

Early Electromagnetic Research

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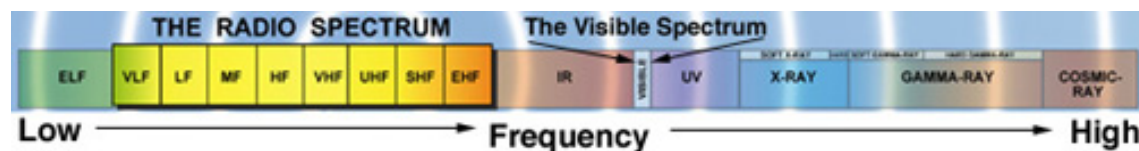
[1990: North America goes digital: IS-54](#)

In 1843 Faraday began intensive research into whether space could conduct electricity. In April, 1846 he reported his findings in a speech called "Thoughts on Ray-vibrations." He continued work in this area for many years, with inventors and academicians closely following his discoveries and theories. James Clerk Maxwell, whom we today would call a theoretical physicist, pondered constantly over Faraday's findings, translating and interpreting these field results into a set of mathematical equations. Maxwell often wove these equations into the many papers he published on electricity and magnetism. Scientists knew that light was a wave but they didn't know what made it up. Maxwell figured it out.

In 1864 Maxwell released his paper "Dynamical Theory of the Electromagnetic Field" which concluded that light, electricity, and magnetism, were all related, all worked hand in hand, and that these electromagnetic phenomena all traveled in waves. As he put it "[W]e have strong reason to conclude that light itself -- including radiant heat, and other radiations if any -- is an electromagnetic disturbance in the form of waves . . ." Maxwell found further. If electricity rapidly varied in amount then electromagnetic waves could be produced at will; they would *radiate* in waves to a distant point. At least he said so. There was no method yet to prove that "other radiations" existed, to demonstrate that waves other than light occurred. How could one see, produce, or detect an invisible wave?

Visible light is only one small part of the omnipresent electromagnetic field or spectrum, that great, universal energy force that constantly [washes over and through us](#). [\(Illustration, 244K\)](#) [All matter is in fact a wave](#). Radio waves as well as infrared waves lie below the visible spectrum. Things like X-Rays lie above. And because light is a radiated electromagnetic emission, lasers and all things optical qualify, strictly speaking, as a radio transmission.

Maxwell's equations also stated that radiation increased dramatically with frequency, that is, many more radio waves are generated at high frequencies than low, given the same amount of power. Experimenting with generating high frequency waves thus began. This wasn't an easy task since it isn't until 90,000 cycles per second, or 9kHz, that radio begins. The familiar A.M. radio band starts around 560 kHz, or 560,000 cycles a second, with all present day radio-telephone services far, far above this. If you want to define radio, generating a rapidly oscillating, high frequency electromagnetic wave is certainly a prerequisite.



Radio spectrum not to scale, Diagram above modified from here:
<http://www.jsc.mil/images/speccht.jpg>

Need a different perspective on the spectrum? I have archived a nice NASA diagram. [Click here](#).

Got Java enabled in your browser? Most folks do. Then try this URL for an excellent demonstration of an electromagnetic wave, it correctly portrays how electric and magnetic fields travel at right angles to each other:

<http://micro.magnet.fsu.edu/primer/java/electromagnetic/index.html>

[Principles of Modern Communications Technology](#) (external link to Amazon) (Artech House) Professor A. Michael Noll



This .pdf file is from Noll's book pictured above: it is a short, clear introduction to signals and will give you background to what you are reading here.



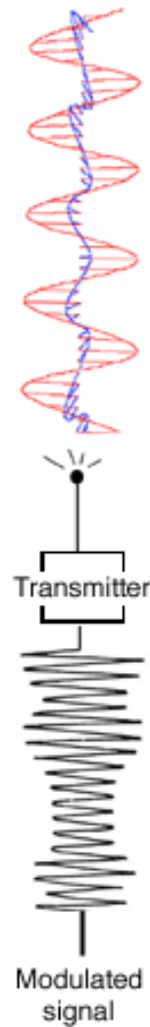
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[Excellent, free chapter on telecom fundamentals from the book above by Dodd \(168K, 34 page in .pdf.\) Please read.](#)



Blue stands for the electric field and red for the magnetic field. An electrical current or signal always has a magnetic field associated with it, either in a wire or out in space when it is radiated from an antenna. This modulated signal does NOT go straight up, rather, these big and small loops of electrical energy, depending on how low or high the frequency, are whipped out 360 degrees from an omnidirectional antenna such as the one above. Or focused like a light beam from a directional antenna.

Let's review before we look at how early radio developers developed high frequency waves. At the top of this page we saw how Morse used conduction, to wirelessly pass a signal without using the atmosphere. The second way is to do wireless is by induction, where one wire induces current to flow in another. The third way is radiation, where high frequency, rapidly moving waves get generated by electricity and radiate from a fixed point like an antenna. I want to cover induction just a bit more, to better let us understand the difference between this method and what we now know as true radio.



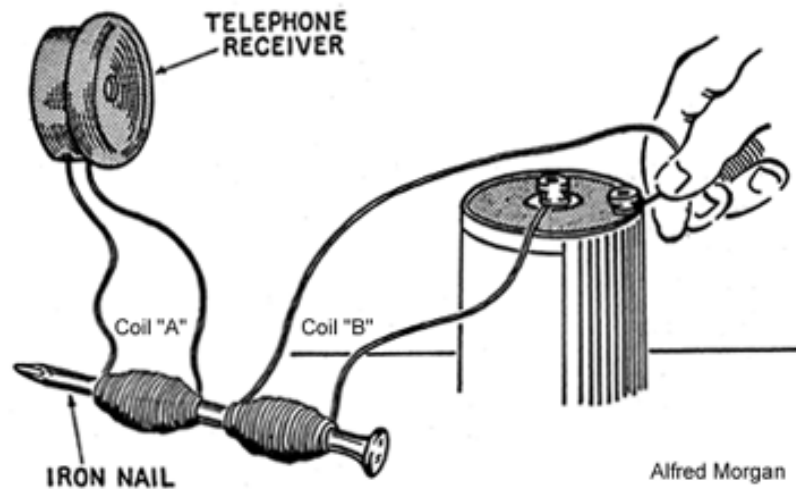
Don't be put off with phrases like "lines of force" and "electro-magnetic fields." The above is a simple bar magnet with its lines of force. Wrap some wire around it, connect the wire to a battery and you will have an electromagnetic field. Communications often use complex words for simple subjects. For an excellent, authoratative look at electricity and magnetism, visit the

IEEE site below:

http://www.ieee.org/organizations/history_center/general_info/lines_menu.html#eandm

Wireless by Induction

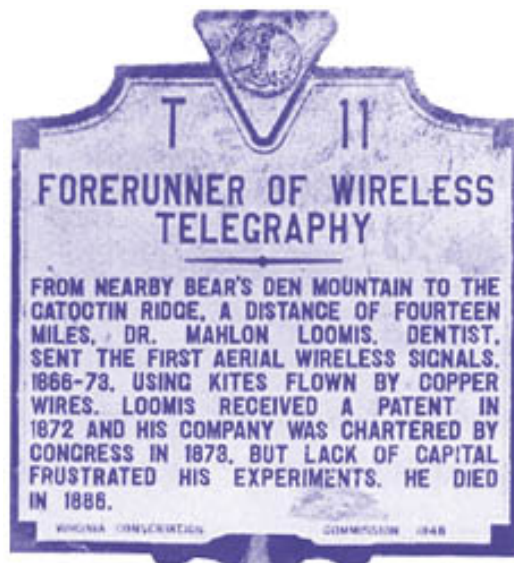
We can define radio as the transmission and reception of signals by means of high frequency electrical waves without a connecting wire. And as we noted before, true radio requires that a signal modulate a carrier wave. Early induction schemes operated at low frequencies and possessed no modulating signal. As I stated above induction was well known to telegraphy, since signals often jumped from one line to another. This same tendency is known as "cross talk" in telephone lines, where one conversation may be heard on another line. In this case the wires are not physically crossed with each other, rather, induction *induces* one signal to travel on the wire of a nearby line.



An experiment in electromagnetic induction: Two separate but closely set coils of wire are wrapped around a nail. The coils are insulated from the nail itself by several pieces of paper, which you cannot see in the drawing. When the battery is connected current steadily flows in one direction and no sound is produced. Remove a lead from the battery and a clicking noise sounds from the receiver. Current in one wire has been induced to flow in the second wire. Only when the current is turned on or off do you get a change in the electromagnetic field and, consequently, a corresponding click. This is induction.

Induction and The Risky Dr. Loomis

In 1865 the dentist Dr. Mahlon Loomis of Virginia may have been the first person to communicate wirelessly through the atmosphere. Between 1866 and 1873 he transmitted telegraphic messages a distance of 18 miles between the tops of Cohocton Mountain and Beorse Deer Mountain, Virginia. Perhaps taking inspiration from Benjamin Franklin, at one location he flew a metal framed kite on a metal wire. He attached a telegraph key to the kite wire and sent signals from it. At another location a similar kite picked up these signals and noted them with a galvanometer. No attempt was made to generate high frequency, rapidly oscillating waves, rather, signals were simply electrical discharges, with current turned off and on to represent the dots and dashes of Morse code. He was granted U.S. patent number 129,971 on July 30, 1872 for an "Improvement in Telegraphing," but for financial reasons did not proceed further with his system.



The text of this sign reads: "T-11: Forerunner of Wireless Telegraphy. From nearby Bear's Den Mountain to the Catoclin Ridge, a distance of fourteen miles, Dr. Mahlon Loomis, Dentist, sent the first aerial wireless signals, 1866-73, using kites flown by copper wires. Loomis received a patent in 1872 and his company was chartered by Congress in 1873. But lack of capital frustrated his experiments. He died in 1866. Virginia Conservation Commission 1848."

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Early Radio Discoveries

Over the next thirty years different inventors, including Preece and Edison, experimented with various induction schemes. You can [read about many of them by clicking here](#). The most successful systems were aboard trains, where a wire atop a passenger car could communicate by induction with telegraph wires strung along the track. A typical plan for that was William W. Smith's idea, contained in U. S. Pat. No. 247,127, which was granted on Sept 13, 1881. Edison, L. J. Phelps, and others came out later with improved systems. In 1888 the principle was successfully employed on 200 miles of the Lehigh Valley Railroad. Now, let's get back to true radio and Maxwell's findings, which lead to intense experimenting.

Maxwells' 1864 conclusions were distributed around the world and created a sensation. But it was not until 1888 that Professor Heinrich Hertz of Bonn, Germany, could reliably produce and detect radio waves. Before that many brushed close to detecting radio waves but did not pursue the elusive goal. The most notable were Edison and David Edward Hughes, who became the first person to take a call on a mobile telephone.

On November 22, 1875, while working on acoustical telegraphy, a science close to telephony, Thomas Alva Edison noticed unusual looking electro-magnetic sparks. Generated from a so called vibrator magnet, Edison had seen similar sparks from other electric equipment before and had always thought they were due to induction. Further testing ruled out induction and pointed to a new, unknown force. Although unsure of what he was observing, Edison leapt to amazing, accurate conclusions. This etheric force as he now named it, might replace wires and cables as a way to communicate. Under deadline to complete other inventions Edison did not pursue this mysterious force, although in later years he returned to consider it. Edison's vibrating magnet had in fact set up crude, oscillating electromagnetic waves, although these were too weak to detect at much distance. [Josephson]

An on-line Edison biography which touches on this subject is here. It is a 376K(!) file:
<http://www.bookrags.com/books/ehlai/PART32.htm>

Basic Radio Principles

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Introducing wireless systems

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D.E. Hughes and the first radio-telephone reception

From 1879 to 1886, London born David Hughes discovered radio waves but was told incorrectly that he had discovered no such thing. Discouraged, he pursued radio no further. But he did take the first mobile telephone call. Hughes was a talented freelance inventor who had at only 26 designed an all new printing telegraph ([external link](#)). Like Edison and [Elisha Gray](#) he often worked under contract for Western Union. He went on to invent what many consider the first true microphone, a device that made the telephone practical, a transmitter as good as the one Edison developed.



Hughes noted many unusual electrical phenomena while experimenting on his microphone, telephone, and wireless related projects. The telephone, by the way, [had been invented in 1876](#) and plans for constructing them had circulated around the world. Hughes noticed a clicking noise in his home built telephone each time he worked used his induction balance, a device now often used as a metal detector.

From the illustration and explanation [on the previous page](#) we know that turning current on and off to an induction coil *can* produce a clicking sound on another wire. It would seem then that Hughes was receiving an inductively produced sound, not a signal over radio waves. But Hughes noticed something more than just a click. In looking over the balance Hughes saw that he hadn't wired it together well, indeed, the unit was sparking at a poorly fastened wire. What would Sherlock Holmes have said? "Come, Watson, come! The game is afoot."



When enough electrical pressure builds up between the two points or spheres a spark will jump across the gap.

The spark we see isn't the radio signal, instead, it is light from energy released by excited or charged atoms between the spheres. And the spark does not indicate a single current flowing in one direction, but rather it is a set of oscillating, back and forth currents, too fast to observe.

Fixing the circuit's loose contact stopped the signal. Hughes correctly deduced that radio waves, electromagnetic, radiated emissions, were produced by the coil of wire in his induction balance and that the gap the spark raced across marked the point they radiated from. He set about making all sorts of equipment to test his hypothesis. Most ingenious, perhaps, was a clockwork transmitter that interrupted the circuit as it ticked, allowing Hughes to walk about with his telephone, now aided by a specially built receiver, to test how far each version of his equipment would send a signal.

At first Hughes transmitted signals from one room to another in his house on Great Portland Street, London. But since the greatest range there was about 60 feet, Hughes took to the streets of London with his telephone, intently listening for

[radio-telephone reception](#)

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[1990: North America goes digital: IS-54](#)

the clicking produced by the tick, tock of his clockwork transmitter. Ellison Hawks F.R.S., quoted and commented on Hughes' accounting, published years later in 1899:

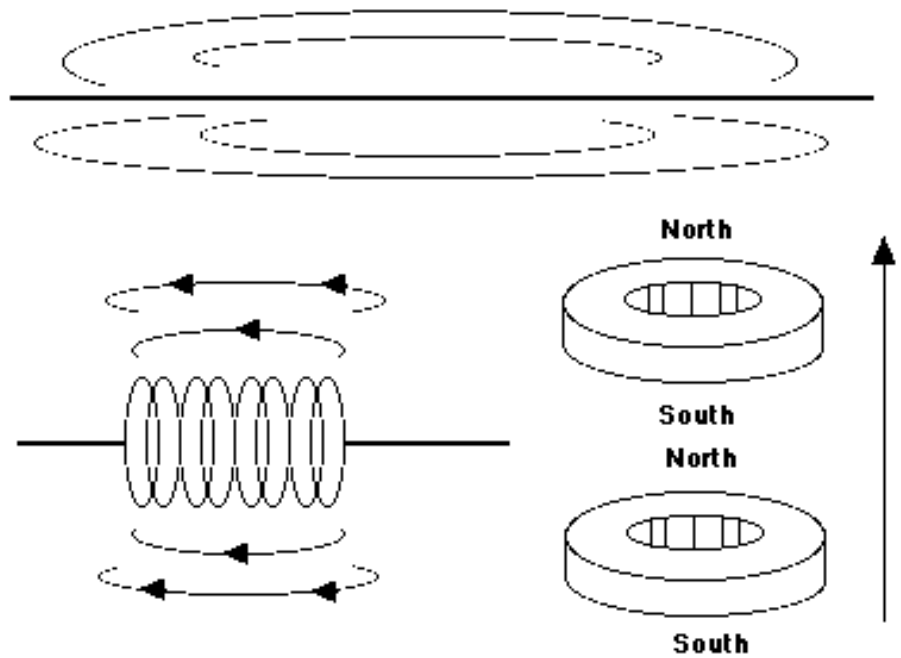
"He obtained a greater range by setting 'the transmitter in operation and walking up and down Great Portland Street with the receiver in my hand and with the telephone to my ear.' We are not told what passers-by thought of the learned scientist, apparently wandering aimlessly about with a telephone receiver held to his ear, but doubtless they had their own ideas. Hughes found that the strength of the signals increased slightly for a distance of 60 yards and then gradually diminished until they no longer could be heard with certainty." [\[Hawks\]](#)

Since Hughes moved his experimenting from the lab to the field he had truly gone mobile. Although these clicks were not voice transmissions, I think it fair to credit Hughes with taking the first mobile telephone call in 1879. That's because his sparking induction coil and equipment put his signal into the radio frequency band, thus fulfilling part of [our radio definition](#). Modulation, the act of putting intelligence onto a carrier wave such as the one he generated, would have to wait for others. This was an important first step, though, even though his clockwork mechanism signaled simply by turning the current on and off, like inductance and conductance schemes before.

Hughes' experimenting was profound and well researched, it was *not* accidental discovery. Click here to [see a picture of all his radio apparatus](#).

Now, we can signal using a spark transmitter without a coil. This would be just like a car spark plug. When spark plugs fire up they spew electrical energy across the electromagnetic spectrum; this noise wreaks havoc in nearby radios. It's typical of all unmodulated electrical energy called, appropriately enough, RFI, for radio-frequency interference. Light dimmers, electrical saws, badly adjusted ballast in fluorescent light bulbs, dying door bell transformers, and so on, all generate RFI. If you turn the source of RFI on and off you could communicate over short distances using Morse code. But only by interfering with true radio services and causing the wrath of your neighbors. By contrast to spuriously generated electrical noise, Hughes deliberately formed electromagnetic waves which easily travelled a great distance, were tuned to more or less a specific frequency, and were picked up by a receiver designed to do just that.

The electromagnetic field around a straight piece of energized wire is fairly simple.



The electromagnetic field around a charged induction coil is complex. Lines of force reinforce each other, much as magnets of like poles attach to each other, increasing strength as they collect.

How Radio Signals Work by Jim Sinclair

Chapter 1: Rules of the Game.

Chapter 2: Spectra.

Chapter 3: How Energy is Coupled.

Chapter 4: Modulation: The Intelligent Message.

Chapter 5: How Signals Get There.

Chapter 6: How the Bands are Used.

Chapter 7: Radiating Structures, Aerials and Antennas.

Chapter 8: An Example of Each Type of Aerial.

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Chapter 11: Strange Beaties.

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Appendix.Glossary.

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Beginning in 1879 Hughes started showing his equipment and results to [Royal Society \(external link\)](#) members. On February 20, 1880 Hughes was sufficiently confident in his findings to arrange a demonstration before the president of the Royal Society, a Mr. Spottiswoode, and his entourage. Less knowledgeable in radio and less inquisitive than Hughes, a Professor Stokes declared that signals were not carried by radio waves but by induction. The group agreed and left after a few hours, leaving Hughes so discouraged he did not even publish the results of his work. Although he continued experimenting with radio, it was left to others to document his findings and by that time radio had passed him by.

[Principles of Modern Communications Technology \(external link to Amazon\)](#) (Artech House) Professor A. Michael Noll



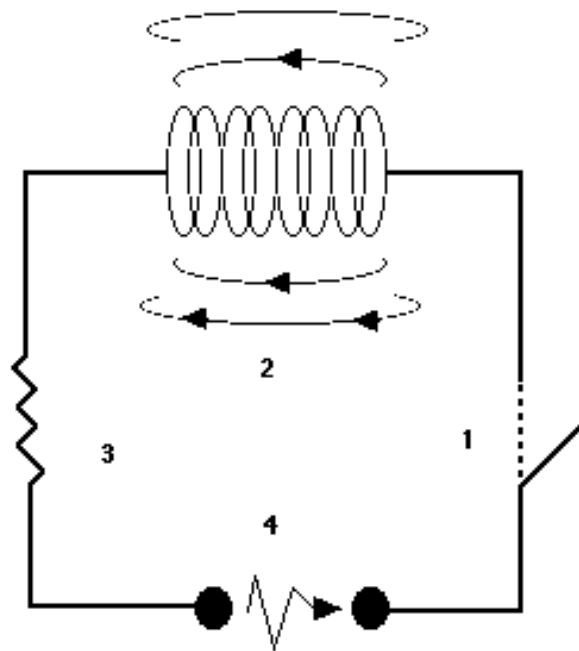


This .pdf file is from Noll's book above: it is a short, clear introduction to signals and will give you background to what you are reading here.



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No. 1 represents a switch. When closed power flows through No. 2, the coil, raising the frequency of the line and building voltage within the coil. For completeness, No. 3 represents resistance, the normal opposition to electricity in a metallic line. When enough 'pressure' builds behind No. 4, the spark gap, energy crosses the divide. What's really interesting is what happens when power is shut off, say after tapping a pulse to represent a dash in Morse Code.

An electromagnetic wave radiates from the gap microseconds after the current gets shut off. That's because the stored up energy in the coil releases itself by pushing forward on the now empty electrical path. Tapping on a telegraph key would act like a pump on the circuit, alternately priming and releasing electrical flow. This paddle like action creates the oscillating electromagnetic waves.

Coils and what makes up an oscillating electromagnetic wave

The coil Hughes used raised the audio frequency signal on his line to the lower end of the radio band, providing an essential element of our radio definition. How was the frequency raised? Voice, conversations, music, and all other acoustic sounds reside in the the audio frequency band, far below the radio frequency band. Our range of hearing extends to perhaps 20,000 cycles a second, whereas the radio band starts around 100,000 cycles per second, with normal radio frequencies much higher. When put on a wire a sound occupies the frequency it would normally take up if not on the wire, that is, if a normal conversation is taking place at around 500Hz, then the conversation would naturally set up at 500Hz if put on a wire. That's a simple example, of course, since the telephone system for several reasons limits this baseband or voice band channel on a telephone wire to around 300Hz to 3,000Hz.

As the diagram above show a wire laid flat exhibits only a simple electromagnetic field when current flows. But if you scrunch it together, start running dozens of feet of wire around a core, spacing each loop nearly on top of each other, well, now you've really changed the dynamics of that line. You might have 25 feet or more of wire on a five inch core.

Have you ever seen an A.M. radio antenna in an old style radio? All that wire, wrapped around a ferrite core, is designed to tune frequencies from around 560,000 cycles per second, to about 1,600,000 cycles per second. The length of the wire tries to represent the length of the radio wave itself, although in practice it may be a quarter wavelength in size or less. The closer in size your antenna comes

to the size of the wavelength you want to listen to, the better your chances are of receiving it. If you took that same antenna, no core needed, and wired it into a telephone line, you will probably raise the signal on the baseband channel into the low end of the radio band.

Modern radios don't use this principle to produce a high frequency carrier wave, of course, but the point I am making is that an induction coil to produce electromagnetic radio waves was an element which distinguished Hughe's work from more primitive schemes.

So who did complete the first radio telephone call using voice? None other than Alexander Graham Bell, the man who invented the telephone and of course made the first call on a wired telephone to Thomas Watson. Bell was also first with radio, although in a way you probably wouldn't imagine.

Time out for terms!

Inductive reactance is the proper term for opposition to current flow through a coil. Resistance of a circuit *and* inductive reactance, both measured in Ohms, makes up impedance. The other confusing term in radio is AC.

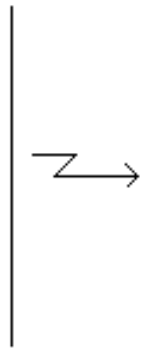
In many radio discussions AC does not mean the alternating current that powers your appliances, rather, it means the way audio signals alternate in a wave like fashion. Huh? As we've just seen above and on the [on the previous page](#), we need a change in current flow through a coil to get radiation. Current must go on and off to release the electromagnetic energy stored within the coil.

AC in radio means the natural alternating current of a voice signal, that is, the [normal up and down waveform](#) of the analog signal. In this case the rise and fall of a signal above a median point, that is, the top and bottom of a wave. Alternating current. Get it? A battery powered walkie talkie illustrate the difference between AC signaling current and AC power current.

A battery powered radio transmitter uses direct current to do all things. Including converting your voice, through the microphone, into a signal it can transmit. But the signal it transmits is not called a DC signal but an AC signal. That's because the radio rapidly oscillates (or alternates) the original signal, the needed step to get the signal high enough in the frequency band that it will radiate from the antenna. AC, in this case, is not the power coming out of a wall outlet, it is the alternating current formed by waves of acoustical energy in the voice band converted into electrical waves by the radio circuitry. These terms get clearer as you read more. But if you are really mystified, read [this little tutorial on how basic radio circuits work](#). I think it will help you a great deal and you can always come back here to continue.

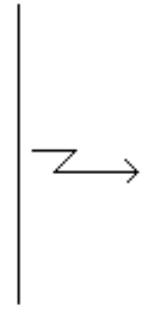
Communicating Without Wires:

Inductance



Inducing a current to flow in another wire

Conductance



Conducting signals through a substance that is *not* the atmosphere

Radiation



Radio

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Resources

[Hawks] Hawks, Ellison, Pioneers of Wireless Arno Press, New York (1974) 172. This is a reprint of the original work which was published by Methuen & Co. Ltd. in London in 1927. ([back to text](#))

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The first voice radio-telephone call



On February 22, 1880 Alexander Graham Bell and his cousin Charles Bell communicated over the Photophone, a remarkable invention conceived of by Bell and executed by Sumner Tainter. [\[Grosvenor\]](#) This device transmitted voice over a light beam. A person's voice projected through a glass test tube toward a thin mirror which acted as a transmitter. Acoustical vibrations caused by the voice produced like or sympathetic vibrations in the mirror.

Sunlight was directed onto the mirror, where the vibrations were captured by a parabolic dish. The dish focused the light on a photo-sensitive selenium cell, in circuit with a telephone. The electrical resistance of the selenium changed as the strength of the received light changed, [varying the current flowing through the circuit](#). The telephone's receiver then changed these fluctuating currents into speech.

Although not related to the mobile telephony of today, Bell's experimenting was a first: radiated electromagnetic waves had carried the human voice. Despite Bell's brilliant achievement, optical transmission had obvious drawbacks, [only now being overcome by firms like TeraBeam](#). Most later inventors concentrated instead on transmitting in the radio bands, with the period from 1880 to 1900 being one of tremendous technological innovation.

For ruminations on the Photophone and how to improve it go here:
http://jefferson.village.virginia.edu/~meg3c/id/id_edin/ph/ph1.html

[For a fascinating look at how ham radio operators can communicate optically click here](#)

Mobile Phone History Table of

1888 on: Radio development begins in earnest

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In 1888 the German Heinrich Hertz conclusively proved [Maxwell's prediction](#) that electricity could travel in waves through the atmosphere. Unlike Hughes, the extensive and systematic experiments into radio waves that Hertz conducted were recognized and validated by inventors around the world. Now, who would take these findings further and develop a true radio?

Dozens and dozens of people began working in the field after Hertz made his findings. It is a miserable job to decide what to report on from this period, with people like Tesla, Branly, and yes, even folks like [Nathan B. Stubblefield \(external link\)](#), claiming to have invented radio. Typical of these events is [Jagadis Chandra Bose \(external link -- 817K!\)](#) demonstrating in 1895 electromagnetic waves "by using them to ring a bell remotely and to explode some gunpowder." While not inventing radio, any more than Edison invented the incandescent light bulb, Marconi did indeed establish the first successful and practical radio system. Starting in 1894 with his first electrical experiments, and continuing until 1901 when his radio telegraph system sent signals across the Atlantic ocean, Marconi preserved against every kind of discouragement and deserves lionizing for making radio something reliable and useful.

Ships were the first wireless mobile platforms. In 1901 Marconi placed a radio aboard a Thornycroft steam powered truck, thus producing the first land based wireless mobile. (Transmitting data, of course, and not voice.) Arthur C. Clarke says the vehicle's cylindrical antenna was lowered to a horizontal position before the the wagon began moving. Marconi never envisioned his system broadcasting voices, he always thought of radio as a wireless telegraph. That would soon change.



Visit Arthur C. Clarke's Time Line of Communication at <http://www.acclarke.co.uk/1900-1909.html> This link no longer seems to be working.

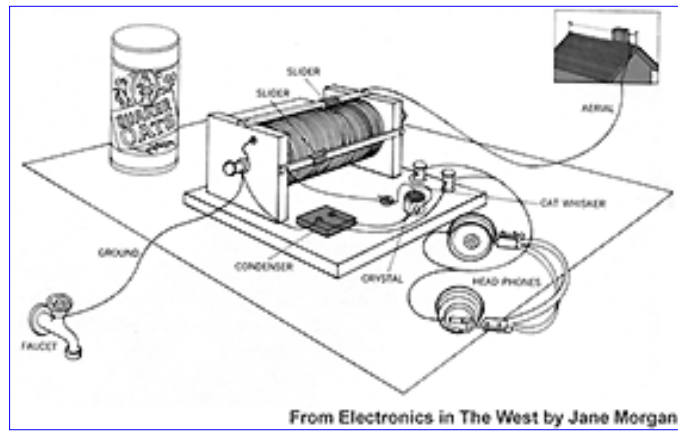
On December 24, 1906, the first radio band wave communication of human speech was accomplished by Reginald Fessenden over a distance of 11 miles, from Brant Rock, Massachusetts, to ships in the Atlantic Ocean. Radio was no longer limited to telegraph codes, no longer just a wireless telegraph. This was quite a milestone, and many historians regard the radio era as beginning here, at the start of the voice transmitted age.

[multinational cellular system](#)

[Table of Analog or First Generation Cellular Systems](#)

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Coils of wire, induction at work, changing the frequency of a line, crystal receivers demonstrate many electrical principles. I've built small crystal sets myself and you can find the kits in many places. They are fascinating, operating not off of a battery but only by the energy contained in the captured radio wave. Just the power of a received radio wave, nothing more.

As Morgan put it, "Radio receivers with sensitive, inexpensive crystal detectors, such as this double slide tuner crystal set, appeared as early as 1904, and were used by most amateurs until the early Thirties, when vacuum tubes replaced crystals. An oatmeal box was a favorite base upon which to wind the wire coils." [\(Click here for a much clearer, larger image.\)](#)

[An entire site on crystal radios is here: http://www.midnightscience.com/](http://www.midnightscience.com/); it relates well to the previous pages in this series

The first car-telephone



From 1910 on it appears that Lars Magnus Ericsson and his wife Hilda regularly worked the first car telephone. Yes, this was the man who founded [Ericsson in 1876](#). Although he retired to farming in 1901, and seemed set in his ways, his wife Hilda wanted to tour the countryside in that fairly new contraption, the horseless carriage. Lars was reluctant to go but soon realized he could take a telephone

along. As Meurling and Jeans relate,

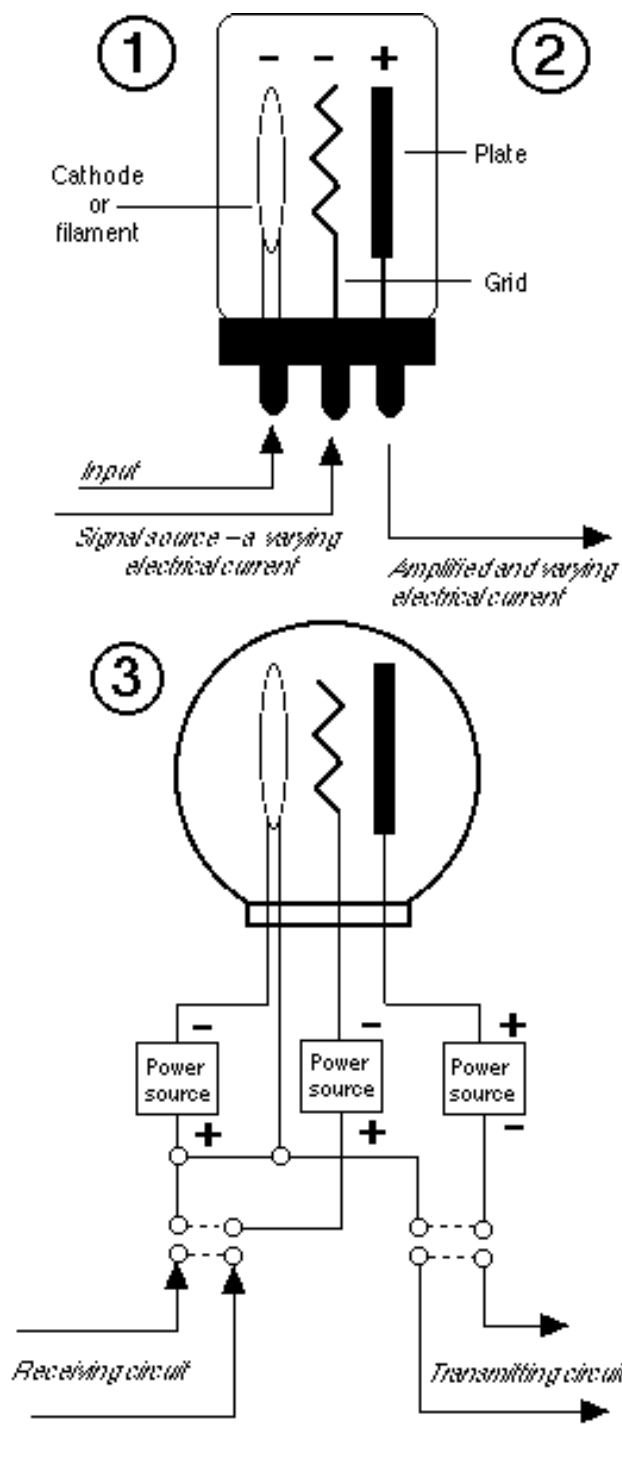
"In today's terminology, the system was an early 'telepoint' application: you could make telephone calls from the car. Access was not by radio, of course -- instead there were two long sticks, like fishing rods, handled by Hilda. She would hook them over a pair of telephone wires, seeking a pair that were free . . . When they were found, Lars Magnus would crank the dynamo handle of the telephone, which produced a signal to an operator in the nearest exchange." [\[Meurling and Jeans\]](#)

Thus we have the founder of [Ericsson \(external link\)](#), that Power of The Permafrost, bouncing along the back roads of Sweden, making calls along the way. Now, telephone companies themselves had portable telephones before this, especially to test their lines, and armed forces would often tap into existing lines while their divisions were on the move, but I still think this is the first regularly occurring, authorized, civilian use of a mobile telephone. [More on mobile working below.](#)

Around the middle teens the triode tube was developed, allowing far greater signal strength to be developed both for wireline and wireless telephony. No longer passive like a crystal set, a triode was powered by an external source, which provided much better reception and volume. Later, with Armstrong's regenerative circuit, tubes were developed that could either transmit or receive signals. They were the answer to developing high frequency oscillating waves; tubes were stable and powerful enough to carry the human voice and sensitive enough to detect those signals in the radio spectrum.

[More on how a triode works and its history is here](#)

How does a triode work?



How does a triode work?

Vacuum tubes revolutionized electronics and communications. Television, radio, recording equipment, radar, telephone repeaters and a thousand other things were either improved or made possible with a variety of tubes. The triode was the most important.

Diagram one shows a triode's parts.

Diagram two shows an external power source sending current to a filament or cathode, heating it tremendously. That causes the glow you see in a tube. In a vacuum a cathode so heated boils off huge amounts of negative electrons. The positively charged plate draws the negative electrons to it. An electrical field is created, with electrons leaping across the gap.

Diagram three shows a simplified repeater circuit. A third part called the grid carries, in our case, a weak phone conversation. It sits between the cathode and the plate, the circuit so built that the grid is negatively charged. As the positively charged plate collects electrons the negatively charged stream from the cathode washes over the grid. This impresses the signal on the stream.

Armstrong's regenerative circuit fed back the input signal into the circuit over and over again, amplifying the signal far more than original designs, building great wireless and wireline transmission signal strength. The feedback circuit could also be overdriven, fed back so many times that supplying a small current to the circuit would develop in it an extremely high frequency, so high it could resonate at the frequency of a radio wave, letting the triode receive or detect signals, not just transmit them. You had a tunable electronic tuning fork, of sorts, a device which detected and amplified the rhythmic energy of the radio wave when set to the frequency desired.

In 1919 three firms came together to develop a wireless company that one day would reach around the world. Heavy equipment maker ASEA, boiler and gas equipment maker AGA, and telephone manufacturer LM Ericsson, formed SRA Radio, the forerunner of Ericsson's radio division. Svenska Radio Aktiebolaget,

known simply as SRA, was formed to build radio receivers, broadcasting having just started in Scandinavia. (Aktiebolaget, by the way, is Swedish for a joint stock company or corporation.)

Much unregulated radio experimenting was happening world wide at this time with different services causing confusion and interference with each other. In many countries government regulation stepped in to develop order. In the United States the Radio Act of 1912 brought some order to the radio bands, requiring station and operator licenses and assigning some spectrum blocks to existing users. But since anyone who filed for an operating license got a permit many problems remained and others got worse.

In 1921 United States mobile radios began operating at 2 MHz, just above the present A.M. radio broadcast band. For the most part law enforcement used these frequencies. [Young] The first radio systems were one way, sometimes using Morse Code, with police getting out of their cars and then calling their station house on a wired telephone after being paged. As if to confirm this, a reader recently e-mailed me this paragraph. The reader did not include the author's name or any references, however, the content is quite similiar to Bowers in *Communications for a Mobile Society*, Sage Publications, Cornell University, Beverley Hills (1978):

"Until the 1920s, mobile radio communications mainly made use of Morse Code. In the early 1920s, under the leadership of William P. Rutledge, the Commissioner of Detroit Police Department, Detroit, Michigan police carried out pioneering experiments to broadcast radio messages to receivers in police cars. The Detroit police department installed the first land mobile radio telephone systems for police car dispatch in the year 1921. [With the call sign KOP!, ed.] This system was similar to the present day paging systems. It was one-way transmission only and the patrolmen had to stop at a wire-line telephone station to call back in. On April 7, 1928, the first voice based radio mobile system went operational. Although the system was still one-way, its effectiveness was immediate and dramatic."

A detailed article on the pioneering efforts of the Detroit Police Department with wireless mobile is here: <http://www.detroitnews.com/history/police/police.htm>

The first car mounted radio-telephone

Police and emergency services drove mobile radio pioneering, therefore, with little thought given to private, individual telephone use. Equipment in all cases was chiefly experimental, with practical systems not implemented until the 1940s, and no interconnection with the the land based telephone system.[FCC: ([external link](#))] Having said this, [Bell Laboratories \(external link\)](#) does claim inventing the first version of a mobile, two way, voice based radio telephone in 1924 and I see nothing that contradicts this, indeed, the photo below from their site certainly

seems to confirm it!



[Visit Lucent and Bell Labs' site soon!](http://www.bell-labs.com/history/75/gallery.html)
<http://www.bell-labs.com/history/75/gallery.html>

For the difficulty involved in dating radio history, consider this page:
<http://members.aol.com/jeff560/chrono1.html>

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Resources

[Grosvenor] Grosvenor, Edwin S. and Morgan Wesson. Alexander Graham Bell : The Life and Times of the Man Who Invented the Telephone Abrams, New York (1997) p.102.

Editor's note: The Photophone photograph that accompanies the text is from Grosvenor's excellent book. I never take pictures from books still in print but I have been unable to find any accurate picture of the Photophone on the net. I will immediately remove this image once I do. ([back to text](#))

[Meurling and Jeans] Meurling, John and Richard Jeans. The Mobile Phone Book: The Invention of The Mobile Phone Industry Communications Week International, London, on behalf of Ericsson Radio Systems (1994) p. 43. ISBN Number 0952403102 ([back to text](#))

Young, W.R. "Advanced Mobile Phone Service: Introduction, Background, and

Objectives." Bell System Technical Journal January, 1979: 7 ([back to text](#))

More on mobile working: Johan Hauknes points out that "L.M. Ericsson had already developed telephones for military purposes in the field -- mobile -- I would guess of the same kind as Meurling and Jeans describes, tapping into fixed systems. That's according to according to Ericsson's Centennial History which is written in Swedish."

"LME [sold] a large number of transportable field telephones and so called cavalry telephones to South Africa during the Boer War from 1899 to 1902. Several types of transportable telephones for military purposes had been developed by LME during the 1890s, bought by the Swedish Military. This according to Messrs A. Attman, J. Kuuse, and U. Olsson, in LM Ericsson 100 år Band 1 Pionjärtid - Kamp om koncessioner - Kris - 1876-1932 (vol. 1 of 3), published. by LM Ericsson in 1976."

"Finally, the first transportable phone documented in the centennial volume is from 1889 - primarily for 'railroad and canal works, military purposes etc.' There's a facsimile of an ad of this in vol. 3: C. Jakobaeus, LM Ericsson 100 år Band III Teleteknisk skapandet 1876-1976.) Railroad related maintenance and repair work, such as for signbased telegraph systems, was a major source of income for LME in the first years." ([back to text](#))

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The best selection of used books on the web is at <http://www.abe.com>. Period. No argument. Advanced Book Exchange is an association of hundreds and hundreds of independent book sellers. I do not get a commission from them because they do not have an affiliate program yet. But I've used and recommended them since late '95; you will be very happy with them.

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[\(Packet switching\)](#)

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- ▶ [Levine's GSM/PCS .pdf file](#)

- ▶ [Telephone history series](#)
- ▶ [Mobile telephone history](#)
- ▶ [Telephone manual](#)
- ▶ [Digital wireless basics](#)

- ▶ [Cellular telephone basics](#)

- ▶ [Seattle Telephone Museum](#)
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- ▶ [Cell phones and plans](#)

[Digital Wireless Basics:](#)

On September 25, 1928, Paul V. Galvin and his brother Joseph E. Galvin incorporated the Galvin Manufacturing Corporation. We know it today as [Motorola \(external link\)](#).

In 1927 the United States created a temporary five-member [Federal Radio Commission \(external link\)](#), an agency it was hoped would check the chaos and court cases involving radio. It did not and was quickly replaced by the F.C.C. just a few years later. In 1934 the United States Congress created the Federal Communications Commission. In addition to regulating landline telephone business, they also began managing the radio spectrum. The federal government gave the F.C.C. a broad public interest mandate, telling it to grant licenses if it was in the "public interest, convenience, and necessity" to do so. The FCC would now decide who would get what frequencies.

Founded originally as part of Franklin Roosevelt's liberal New Deal Policy, the Commission gradually became a conservative, industry backed agent for the interests of big business. During the 1940s and 1950s the agency became incestuously close to the broadcasting industry in general and in particular to RCA, helping existing A.M. radio broadcasting companies beat off competition from F.M. for decades. The F.C.C. also became a plodding agency over the years, especially when Bell System business was involved.

The American government had a love/hate relation with AT&T. On one hand they knew the Bell System was the best telephone company in the world. On the other hand they could not permit AT&T's power and reach to extend over every part of communications in America. Room had to be left for other companies and competitors. The F.C.C., the Federal Trade Commission, and the United States Justice Department, were all involved in limiting the Bell System's power and yet at the same time permitting them to continue. It was a difficult and awkward dance for everyone involved. And as for cellular, well, the slow action by the FCC would eventually delay cellular by at least a ten years, possibly twenty.

The FCC gave priority to emergency services, government agencies, utility companies, and services it thought helped the most people. Radio users like a taxi service or a tow truck dispatch company required little spectrum to conduct their

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business. Radio-telephone, by comparison, used large frequency blocks to serve just a few people. A single radio-telephone call, after all, takes up as much spectrum as a radio broadcast station. The FCC designated no private or individual radio-telephone channels until after World War II. Why the FCC did not allocate large frequency blocks in the then available higher frequency spectrum is still debated. Although commercial radios in quantity were not yet made for those frequencies, it is likely that equipment would have been produced had the F.C.C. freed up the spectrum.



Mobile radio?! A marine radio telephone of 1937 recently up for bid on e-bay.com The seller thought it was a Harvey Wells, Model MR-10. This beast measures 20"X 11"X 8 1/2" and weighs close to 40 pounds. This was probably compact for its time. The tube based radio also needed a big and heavy power supply. The present day [SEA digital radiotelephone](#), by comparison, is a far superior machine and weighs in at 9.1 pounds, and measures only 4" by 10.5" It draws just 13 volts. As is clearly evident, much progress in radio had to await microprocessors and miniaturization.

[IMTS authority Geoff Fors](#) checked in recently:

"Tom. Get this -- I just looked at some of your material on your website on early mobile phone history, and saw you have a photo of my Harvey Wells 1941 marine radio telephone! I bought that unit on eBay, I don't recall if anyone else even bid on it, it was very cheap. The seller just threw it in a box with some wadded newspapers, and when it arrived the microphone was smashed to bits along with the porcelain insulators and everything protruding from the rear panel, the cabinet was caved in on top, and there was a baggie with the smashed up knobs in it lying INSIDE the cabinet. I don't know how the knobs were shown in the photo on eBay but then wound up inside the cabinet for shipping. They were shot anyway. It does actually work, although the cabinet was painted a horrible yellow color and should have been wrinkle burgundy. I have already straightened, stripped and primed the cabinet and have a replacement mike lined up from a friend. There is some consternation whether the set is pre or post-war. It uses metal octal tubes, which suggests postwar use, although those tubes were available before 1946. It is definitely pre-1950, in any case."

(Editor's note: I don't mean to confuse you, but these are both principally short wave radios, able to place a phone call through an operator, but they aren't units dedicated to

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[Early Radio Discoveries](#)

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Hewlett Packard forms in 1939, at first building an audio oscillator, one of many precise

telephony. "Phone" is an old radio term for voice transmission, it doesn't mean, necessarily, that you have a radio-telephone. Photographs simply illustrate radio size.)

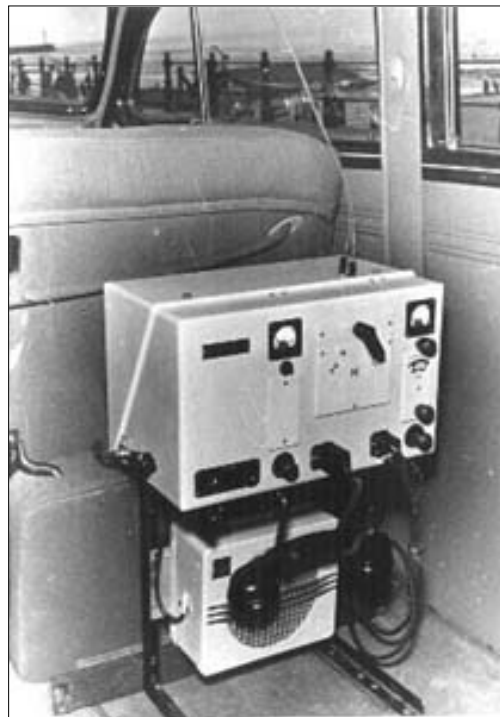
Early conventional radio-telephone development and progress towards miniaturization

Radio-telephone work was ongoing throughout the world before the war. This excellent photograph shows a Dutch Post Telegraph and Telephone mobile radio. As the excellent Mobile Radio in the Netherlands web site explains it:

"The NSF Type DR38a transmitter receiver was the first practical mobile radio telephone in Holland. The set was developed in 1937 from PTT specifications and saw use from 1939 onwards. It operates in the frequency range between 66-75 MHz having a RF power output of approximately 4-5 Watts. Change-over from receive to transmit is effected by the large lever on the front panel. The transmitter is pre-set on a single frequency while the receiver is tuneable over the frequency range." I do not know if this set actually connected to their public switched telephone network. It may have been called a radio-telephone, just like the marine radio-telephone described above.

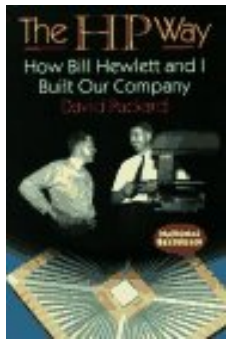
More good details are here. Their page does take a long time to load:

<http://home.hccnet.nl/l.meulstee/mobilophone/mobilophone.html>



During World War II civilian commercial mobile telephony work ceased but intensive radio research and development went on for military use. While RADAR

measuring instruments they would manufacture, eventually becoming the world leader in that field. HP was crucial to the war effort and advanced the radio art greatly. As Jane Morgan correctly put it when discussing HP in Electronics in the West, "Without such [measuring] tools, electronics could never have progressed beyond a crude experimental stage to become a science."



The HP Way : How Bill Hewlett and I Built Our Company by David Packard, David Kirby (Editor), Karen Lewis (Editor)

[Ordering information from Amazon.com \(external link\)](#)

was perhaps the most publicized achievement, other landmarks were reached as well. "The first portable FM two-way radio, the "walkie-talkie" backpack radio," [was] designed by Motorola's Dan Noble. It and the "Handie-Talkie" handheld radio become vital to battlefield communications throughout Europe and the South Pacific during World War II." [[Motorola \(external link\)](#)] For those researching this time period, [see my comments for reading](#) below.

In the July 28, 1945 Saturday Evening Post magazine, the commissioner of the F.C.C., E.K. Jett, hinted at a cellular radio scheme, without calling it by that name. (These systems would first be described as "a small zone system" and then cellular.) Jett had obviously been briefed by telephone people, possibly Bell Labs scientists, to discuss how American civilian radio might proceed after the war.

What he describes below is frequency reuse, the defining principle of cellular. In this context frequency reuse is not enabled by a well developed radio system, but simply by the high frequency band selected. Higher frequency signals travel shorter distances than lower frequencies, consequently you can use them closer together. And if you use F.M. you have even less to worry about, since F.M. has a capture effect, whereby the nearest signal blocks a weaker, more distant station. That compares to A.M. which lets undesired signals drift in and out, requiring stations be located much further apart:

"In the 460,000-kilocycle band, sky waves do not have to be taken into account, day or night. The only ones that matter are those parallel to the ground. These follow a line of sight path and their range can be measured roughly by the range of vision. The higher the antenna, the greater the distance covered. A signal from a mountain top or from an airplane might span 100 miles, by one from a walkie talkie on low ground normally would not go beyond five miles, and one from a higher powered fixed transmitter in a home would not spread more than ten to fifteen miles. There are other factors, such as high buildings and hilly terrain which serve as obstacles and reduce the range considerably."

"Thanks to this extremely limited reach, the same wave lengths may be employed simultaneously in thousands of zones in this country. Citizens in two towns only fifteen miles apart -- or even less if the terrain is especially flat -- will be able to send messages on the same lanes at the same time without getting in one another's way."

"In each zone, the Citizen' Radio frequencies will provide from 70 to 100 different channels, half of which may be used simultaneously in the same area without any overlapping. And each channel in every one of the thousands of sectors will on average assure adequate facilities for ten or twenty, or even more "subscribers," because most of these will be talking on the ether only a very small part of the time. In each locality, radiocasters will avoid interference with one another by listening, before going on the air, to find out whether the lane is free. Thus the 460,000 to 470,000 kilocycle band is expected to furnish enough room for millions of users. . . "

The article was deceptively titled "Phone Me by Air"; no radio-telephone use was envisioned, simply point to point communications in what was to become the

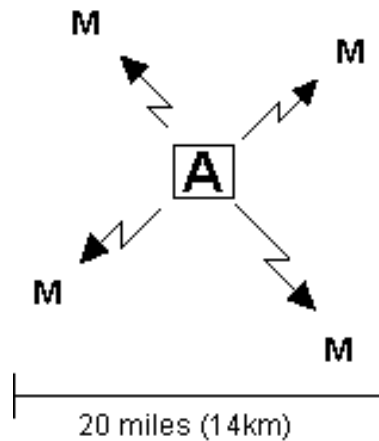
Citizens' Radio Band, eventually put at the much lower 27Mhz. Still, the controlling idea of cellular was now being discussed, even if technology and the F.C.C. would not yet permit radio-telephones to use it.

In 1946, the very first circuit boards, a product of war technology, became commercially available. Check out the small board in the lower right hand corner. It would take many years before such boards became common. The [National Museum of American History \(external link\)](#) explains this photo of a 'midget radio set' like this: "Silver lines replace copper wires in the 'printed' method developed for radio circuits . . . One of the new tiny circuits utilizing midget tubes is shown beside the same circuit as produced by conventional methods." These tiny tubes were called "acorn tubes" and were generally used in lower powered equipment. Car mounted mobile telephones used much larger tubes and circuits.



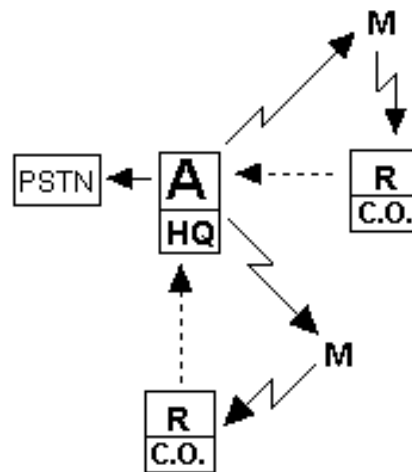
The first commercial American radio-telephone service

On June 17, 1946 in Saint Louis, Missouri, AT&T and Southwestern Bell introduced the first American commercial mobile radio-telephone service to private customers. Mobiles used newly issued vehicle radio-telephone licenses granted to Southwestern Bell by the FCC. They operated on six channels in the 150 MHz band with a 60 kHz channel spacing. [\[Peterson\]](#) Bad cross channel interference, something like cross talk in a landline phone, soon forced Bell to use only three channels. In a rare exception to Bell System practice, subscribers could buy their own radio sets and not AT&T's equipment.



A simplified picture of Radio Telephone Service -- A Non-Zoned System

The diagram above shows a central transmitter serving mobiles over a wide area. One antenna serves a wide area, like a taxi dispatch service. While small cities used this arrangement, radio telephone service was more complicated, using more receiving antennas as depicted below. That's because car mounted transmitters weren't as powerful as the central antenna, thus their signals couldn't always get back to the originating site. That meant, in other words, you needed receiving antennas throughout a large area to funnel radio traffic back to the switch handling the call.. This process of keeping a call going from one zone to another is called a handoff.



The 1946 Bell System Mobile Telephone Service in St. Louis -- A Zoned System

M: mobile R:receiver. PSTN: Public switched telephone network.

As depicted above, in larger cities the Bell System Mobile Telephone Service used a central transmitter to page mobiles and deliver voice traffic on the downlink. Mobiles, based on a signal to noise ratio, selected the nearest receiver to transmit their signal to. In other words, they got messages on one frequency from the central transmitter but they sent their messages to the nearest receiver on a separate frequency.

Placed atop distant central offices, these receivers and antennas could also "be

installed in buildings or mounted in weather proof cabinets or poles." They collected the traffic and passed it on to the largest telephone office, where the main mobile equipment and operators resided. [\[Peterson2\]](#)

Installed high above Southwestern Bell's headquarters at 1010 Pine Street, a centrally located antenna transmitting 250 watts paged mobiles and provided radio-telephone traffic on the downlink or forward path, that is, the frequency from the transmitter to the mobile. Operation was straightforward, as the following describes:

How Mobile Telephone Calls Are Handled

Telephone customer (1) dials 'Long Distance' and asks to be connected with the mobile services operator, to whom he gives the telephone number of the vehicle he wants to call. The operator sends out a signal from the radio control terminal (2) which causes a lamp to light and a bell to ring in the mobile unit (3). Occupant answers his telephone, his voice traveling by radio to the nearest receiver (4) and thence by telephone wire.

To place a call from a vehicle, the occupant merely lifts his telephone and presses a 'talk' button. This sends out a radio signal which is picked up by the nearest receiver and transmitted to the operator.[\[BLR1\]](#)

The above text accompanies a [Bell Laboratories Record illustration \(346K\)](#), from the 1946 article that first described the system. It gives you a good idea of how the system worked. Click on the link to view this big, but slow to load graphic.)

Simple block diagrams can be hard to follow. [Click here to see another MTS illustration](#); it is from Bell Labs and my cellular telephone basics article.)

The lower powered 20 watt mobile sets did not transmit back to the central tower but to one of five receivers placed across the city.[\[BLR2\]](#) Once a mobile went off hook all five receivers opened. The Mobile Telephone Service or MTS system combined signals from one or more receivers into a unified signal, amplifying it and sending it on to the toll switchboard. This allowed roaming from one city neighborhood to another. Can't visualize how this worked? Imagine someone walking through a house with several telephones off hook. A party on the other end of the line would hear the person moving from one room to another, as each telephone gathered a part of the sound. This was the earliest use of handoffs, keeping a call going when a caller traveled from the zone in the city to another.

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Resources

Peterson, A.C., Jr. "Vehicle Radiotelephony Becomes a Bell System Practice." Bell Laboratories Record April, 1947: 137 ([back to text](#))

Peterson2 ibid. 140 ([back to text](#))

BLR1"Telephone Service for St. Louis Vehicles." Bell Laboratories Record July, 1946: 267 ([back to text](#))

BLR2 ibid. ([back to text](#))

My comments for reading: The following three volumes chronicle American military radio development during World War II, focusing on the United States Army. They are indispensable for anyone researching radio, especially those looking at the beginning of F.M. for handheld and mobile operations. Part of a larger series, the United States' official chronicle of World War II, these should be available through any major university. Out of print, used copies exist, figure \$25 to \$30 a volume; I paid \$80 for my set. They have been reprinted a number of times, any edition is serviceable. For used books try ABE below.

Terrett, Dulany. The Signal Corps: The Emergency (to December 1941). Washington, Office of the Chief of Military History, Dept. of the Army, 1956. xiii, 383 p. illus., ports. 26 cm. Series title: United States Army in World War II. Technical services

Thompson, George Raynor. The Signal Corps: The Test (December 1941 to July 1943), by George Raynor Thompson [and others] Washington, Office of the Chief of Military History, Dept. of the Army, 1957. xv, 621 p. illus. 26 cm. Series title: United States Army in World War II : The technical services

Thompson, George Raynor. The Signal Corps: The Outcome (mid-1943 through 1945), by George Raynor Thompson and Dixie R. Harris. Washington, Office of the Chief of Military History, U.S. Army;1966. xvi, 720 p. illus., maps, ports. 26 cm. Series title: United States Army in World War II. Technical services ([back to text](#))

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[\(Packet switching\)](#)

(Next topic: [Standards](#))

One party talked at a time with Mobile Telephone Service or MTS. You pushed a handset button to talk, then released the button to listen. (This eliminated echo problems which took years to solve before natural, full duplex communications were possible.) Mobile telephone service was not simplex operation as many writers describe, but half duplex operation. Simplex uses only one frequency to both transmit and receive. In MTS the base station frequency and mobile frequency were offset by five kHz. Privacy is one reason to do this; eavesdroppers could hear only one side of a conversation. Like a citizen's band radio, a caller searched manually for an unused frequency before placing a call. But since there were so few channels this wasn't much of a problem. This does point out greatest problem for conventional radio-telephony: too few channels.

Art imitating life below. This cartoon is from the April, 1948 issue of The Bell Laboratories Record. It reads, "Hello, Mr. Bunting. I've changed my mind -- I'll take that accident policy!" Shortly after this cartoon appeared the July 1948 BLR reported that a taxi cab driver with a mobile phone reported a stuck car on a railroad crossing, thus saving the broken down car and its motorist from disaster. Possibly the first radio-telephone rescue of its kind. This incident happened at a "grade crossing of the Nickel Plate Railroad at Dunkirk, New York." I wonder if that crossing still exists and whether the county history museum knows of its place in mobile telephone history. If one of my readers can find this location I would like to see a photograph.

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- ▶ [Levine's GSM/PCS .pdf file](#)
- ▶ [Telephone history series](#)
- ▶ [Mobile telephone history](#)
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Things to come. "All equipped with telephones so that the minute you catch anything you can call all your friends and start bragging." From the September, 1950 Bell Laboratories Record.

Cellular telephone systems first discussed

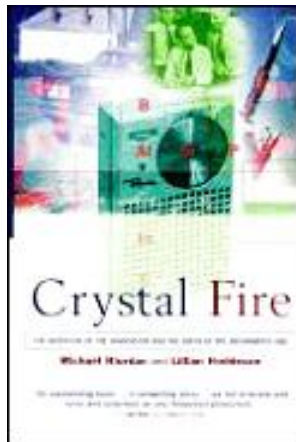
The MTS system presaged many cellular developments. In December, 1947 Bell Laboratories' D.H. Ring articulated the cellular concept for mobile telephony in an internal memorandum, authored by Ring with crucial assistance from W.R. Young. Mr. Young later recalled that [all the elements](#) were known then: a network of small geographical areas called cells, a low powered transmitter in each, the cell traffic controlled by a central switch, [frequencies reused](#) by different cells and so on. Young states that from 1947 Bell teams "had faith that the means for administering and connecting to many small cells would evolve by the time they were needed." [[Young](#)] The authors at SRI International, in their voluminous history of cell phones [[SR1](#)], put those early days like this:

[multinational cellular system](#)

[Table of Analog or First Generation Cellular Systems](#)

[1982 --> The Rise of GSM](#)

[1990: North America goes digital: IS-54](#)



Crystal Fire: The Invention of the Transistor & the Birth of the Information Age by Michael Riordan (\$15.00)

[Read two wonderful excerpts from the book by clicking here](#)

[Ordering information here \(external link to Powells.com\)](#)



Manufacturing the Future : A History of Western Electric by Stephen B. Adams, Orville R. Butler

[Ordering information \(external link to Powells.com\)](#)

"The earliest written description of the cellular concept appeared in a 1947 Bell Labs Technical Memorandum authored by D. H. Ring. [\[but see previous page, the key difference is that Ring describes true mobile telephone service, ed.\]](#) The TM detailed the concept of frequency reuse in small cells, which remained one of the key elements of cellular design from then on. The memorandum also dealt with the critical issue of handoff, stating "If more than one primary band is used, means must be provided for switching the car receiver and transmitter to the various bands." Ring does not speculate how this might be accomplished, and, in fact, his focus was on how frequencies might be best conserved in various theoretical system designs."

Here we come to an important point, one that illustrates the controlling difference between conventional mobile telephony and cellular. Note how the authors describe handoffs, a process that Mobile Telephone Service already used. The problem wasn't so much about conducting a handoff from one zone to another, but dealing with handoffs in a cellular system, one in which frequencies were used over and over again. In a cellular system you need to transfer the call from zone to zone as the mobile travels, and you need to *switch* the frequency it is placed on, since frequencies differ from cell to cell. See the difference? Frequency re-use is the critical and unique element of cellular, not handoffs, since conventional radio telephone systems used them as well. [\[Discussion\]](#) Let's get back to Young's comments, when he says that Bell teams had faith that cellular would evolve by the time it was needed.

Important conventional mobile telephone handoff patents are: Communication System with Carrier Strength Control, Henry Magunski, assignor to Motorola, Inc. U.S. 2,734,131 (1956) and Automatic Radio Telephone Switching System, R.A. Channey, assignor to Bell Telephone Laboratories, Inc. U.S. 3,355,556(1967)

While recognizing the Laboratories' prescience, more mobile telephones were always needed. Waiting lists developed in every city where mobile telephone service was introduced. By 1976 only 545 customers in New York City had Bell System mobiles, with 3,700 customers on the waiting list. Around the country 44,000 Bell subscribers had AT&T mobiles but 20,000 people sat on five to ten year waiting lists. [\[Gibson\]](#) Despite this incredible demand it took cellular 37 years to go commercial from the mobile phone's introduction. But the FCC's regulatory foot dragging slowed cellular as well. Until the 1980s they never made enough channels available; as late as 1978 the Bell System, the Independents, and the non-wireline carriers divided just 54 channels nationwide. [\[O'Brien\]](#) That compares to the 666 channels the first AMPS systems needed to work. Let's back up.

In mobile telephony a channel is a pair of frequencies. One frequency to transmit on and one to receive. It makes up a circuit or a complete communication path. Sounds simple enough to accommodate. Yet the radio spectrum is extremely crowded. In the late 1940s little space existed at the lower frequencies most equipment used. Inefficient radios contributed to the crowding, using a 60 kHz wide bandwidth to send an signal that can now be done with 10kHz or less. But

what could you do with just six channels, no matter what the technology? With conventional mobile telephone service you had users by the scores vying for an open frequency. You had, in effect, a wireless party line, with perhaps forty subscribers fighting to place calls on each channel. Most mobile telephone systems couldn't accommodate more than 250 people. There were other problems.

Radio waves at lower frequencies travel great distances, sometimes hundreds of miles when they skip across the atmosphere. High powered transmitters gave mobiles a wide operating range but added to the dilemma. Telephone companies couldn't reuse their precious few channels in nearby cities, lest they interfere with their own systems. They needed at least seventy five miles between systems before they could use them again. While better frequency reuse techniques might have helped, something doubtful with the technology of the times, the FCC held the key to opening more channels for wireless.

In 1947 AT&T began operating a "highway service", a radio-telephone offering that provided service between New York and Boston. It operated in the 35 to 44MHz band and caused interference from time to time with other distant services. Even AT&T thought the system unsuccessful. Tom Kneitel, K2AES, writing in his Tune In Telephone Calls, 3d edition, CRB Books (1996) recalls the times:

"Service in those early days was very basic, the mobile subscriber was assigned to use one specific channel, and calls from mobile units were made by raising the operator by voice and saying aloud the number being called. Mobile units were assigned distinctive telephone numbers based upon the coded channel designator upon which they were permitted to operate. A unit assigned to operate on Channel 'ZL' (33.66 Mhz base station) might be ZL-2-2849. The mobile number YJ-3-5771 was a unit assigned to work with a Channel YJ (152.63 Mhz) base station. All conversations meant pushing the button to talk, releasing it to listen."

Also in 1947 the Bell System asked the FCC for more frequencies. The FCC allocated a few more channels in 1949, but gave half to other companies wanting to sell mobile telephone service. Berresford says "these radio common carriers or RCCs, were the first FCC-created competition for the Bell System" He elaborates on the radio common carriers, a group of market driven businessmen who pushed mobile telephony in the early years further and faster than the Bell System:

"The telephone companies and the RCCs evolved differently in the early mobile telephone business. The telephone companies were primarily interested in providing ordinary, 'basic' telephone service to the masses and, therefore, gave scant attention to mobile services throughout the 1950s and 1960s. The RCCs were generally small entrepreneurs that were involved in several related businesses--telephone answering services, private radio systems for taxicab and delivery companies, maritime and air-to-ground services, and 'beeper' paging services. As a class, the RCCs were more sales-oriented than the telephone companies and won many more customers; a few became rich in the paging business. The RCCs were also highly

independent of each other; aside from sales, their specialty was litigation, often tying telephone companies (and each other) up in regulatory proceedings for years." [[Berresford External Link](#)]

As proof of their competitiveness, the RCCs serviced 80,000 mobile units by 1978, twice as many as Bell. This growth built on a strong start, the introduction of automatic dialing in 1948.

The first automatic radiotelephone service

On March 1, 1948 the first fully automatic radiotelephone service began operating in Richmond, Indiana, eliminating the operator to place most calls. [[McDonald](#)]

The Richmond Radiotelephone Company bested the Bell System by 16 years. AT&T didn't provide automated dialing for most mobiles until 1964, lagging behind automatic switching for wireless as they had done with landline telephony. (As an aside, the Bell System did not retire their last cord switchboard until 1978.) Most systems, though, RCCs included, still operated manually until the 1960s.

Some claim the Swedish Telecommunications Administration's S. Lauhrén designed the world's first automatic mobile telephone system, with a Stockholm trial starting in 1951. [[SE External link](#)] I've found no literature to support this. Anders Lindeberg of the Swedish Museum of Science and Technology points out the text at the link I provide above is "a summary from an article in the yearbook 'Daedalus' (1991) for the Swedish Museum of Science and Technology <http://www.tekmu.se/> [[External link](#)]." He goes on to say, "The Swedish original article is much more extensive than the summary" and that "The Mobile Phone Book" by John Meurling and Richard Jeans, ISBN 0-9524031-02 published by [Communications Week International](#), London in 1994 does briefly describe the "MTL" from 1951. But, again, nothing contradicts my contention that Richmond Telephone was first with automatic dialing.

On July 1, 1948 the Bell System [unveiled the transistor](#), a joint invention of Bell Laboratories scientists William Shockley, John Bardeen, and Walter Brattain. It would revolutionize every aspect of the telephone industry and all of communications. One engineer remarked, "Asking us to predict what transistors will do is like asking the man who first put wheels on an ox cart to foresee the automobile, the wristwatch, or the high speed generator." Sensitive, bulky, high current drawing radios with tubes would be replaced over the next ten to fifteen years with rugged, miniature, low drain units. For the late 1940s and most of the 1950s, however, most radios would still rely on tubes, as the photograph below illustrates, a typical radio-telephone of the time.



Visit the Telecommunication Museum of Sweden!

http://www.telemuseum.se/historia/mobtel/mobtfn_2e.html

Let's go to Sweden to read about a typical radio-telephone unit, something similar to American installations:

"It was in the mid-1950's that the first phone-equipped cars took to the road. This was in Stockholm - home of Ericsson's corporate headquarters - and the first users were a doctor-on-call and a bank-on-wheels. The apparatus consisted of receiver, transmitter and logic unit mounted in the boot of the car, with the dial and handset fixed to a board hanging over the back of the front seat. It was like driving around with a complete telephone station in the car. With all the functions of an ordinary telephone, the telephone was powered by the car battery. Rumour has it that the equipment devoured so much power that you were only able to make two calls - the second one to ask the garage to send a breakdown truck to tow away you, your car and your flat battery. . . These first carphones were just too heavy and cumbersome - and too expensive to use - for more than a handful of subscribers. It was not until the mid-1960's that new equipment using transistors were brought onto the market. Weighing a lot less and drawing not nearly so much power, mobile phones now left plenty of room in the boot - but you still needed a car to be able to move them around."

The above paragraph was taken from:
<http://www.ericsson.com/Connexion/connexion1-94/hist.html> Ericsson has since moved this page and I am working on finding the new URL.
[\[Ericsson \(external link\)\]](#)

In 1953 the Bell System's Kenneth Bullington wrote an article entitled,

"Frequency Economy in Mobile Radio Bands." [Bullington] It appeared in the widely read Bell System Technical Journal. For perhaps the first time in a publicly distributed paper, the 21 page article hinted at, although obliquely, cellular radio principles.

Time Out From Texas Instruments:

"In 1954, Texas Instruments was the first company to start commercial production of silicon transistors instead of using germanium. Silicon raised the power output while lowering operating temperatures, enabling the miniaturization of electronics. The first commercial transistor radio was also produced



in 1954 - powered by TI silicon transistors." Photo courtesy of Texas Instruments: <http://www.ti.com/> (external link)

In 1956 AT&T and the United States Justice Department settled, for a while, another anti-monopoly suit. AT&T agreed not to expand their business beyond telephones and transmitting information. Bell Laboratories and Western Electric would not enter such fields as computers and business machines. The Bell System in return was left intact with a reprieve from monopoly scrutiny for a few years. This affected wireless as well. Bell and WECO previously supplied radio equipment and systems to private and public concerns. No longer. Western Electric Company stopped making radio-telephone sets. Outside contractors using Bell System specs would make AT&T's next generation of radio-telephone equipment. Companies like Motorola, Secode, and ITT-Kellog, now CORTELCO. Also in 1956 the Bell System began providing manual radio-telephone service at 450 MHz, a new frequency band assigned to relieve overcrowding. AT&T did not automate this service until 1969.

In this same year Motorola produces its first commercial transistorized product: an automobile radio. "It is smaller and more durable than previous models, and demands less power from a car battery. An all-transistor auto radio, [it] is considered the most reliable in the industry." [Motorola (external link)]

In 1958 the innovative Richmond Radiotelephone Company improved their automatic dialing system. They added new features to it, including direct mobile to mobile communications. [McDonald2] Other independent telephone companies and the Radio Common Carriers made similar advances to mobile-telephony throughout the 1950s and 1960s. If this subject interests you, The Independent Radio Engineer Transactions on Vehicle Communications, later renamed the IEEE Transactions on Vehicle Communications, is the publication to read during these years.

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Resources

Bullington, Kenneth "Frequency Economy in Mobile Radio Bands." Bell System Technical Journal, January 1953, Volume 32: 42 et. seq. ([back to text](#))

Douglas, V.A. "The MJ Mobile Radio Telephone System." Bell Laboratories Record December, 1964: 383 ([back to text](#))

Gibson, Stephen W., Cellular Mobile Radiotelephones. Englewood Cliff: Prentice Hall, 1987. 8 ([back to text](#))

McDonald, Ramsey "'Dial Direct'" Automatic Radiotelephone System. IRE Transactions on Vehicle Communications July, 1958: 80 ([back to text](#)) As a courtesy to researchers I have scanned this article for you to download and review. These are very large files but they are readable and with some work will be decent for OCR. The first image is the title page for the IRE Transactions publication. The article starts at page 80:

<http://www.TelecomWriting.com/IRE/IREfrontpiece.jpg>

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<http://www.TelecomWriting.com/IRE/page84.jpg>

<http://www.TelecomWriting.com/IRE/page85.jpg>

[McDonald2] *ibid.* 84 ([back to text](#))

O'Brien, James "Final Tests Begin for Mobile Telephone System." Bell Laboratories Record July/August, 1978: 171 ([back to text](#))

[SRI1] David Roessner, Robert Carr, Irwin Feller, Michael McGeary, and Nils Newman, "The Role of NSF's Support of Engineering in Enabling Technological Innovation: Phase II Final report to the National Science Foundation. Arlington, VA: SRI International, 1998. ([back to text](#))

<http://www.sri.com/policy/stp/techin2/chp4.html>

[SRI2] *ibid.* ([back to text](#))

Young, W.R. "Advanced Mobile Phone Service: Introduction, Background, and Objectives." Bell System Technical Journal January, 1979: 7 ([back to text](#)) Messrs. Carr, Feller, McGeary, and Newman, of SRI, *supra*, cite the original memo describing cellular as follows: "Mobile Telephony -- Wide Area Coverage" Bell Laboratories Technical Memorandum, December 11, 1947.

[Discussion] Some might say conventional mobile telephones already employ frequency reuse since the same frequencies are used in radio-telephone service

some distance away, in other cities perhaps seventy miles or more distant. Broadcast radio and television stations use this same approach to prevent interference, where the same frequencies are used throughout the country and where each station is separated by distance or space. In cellular, though, frequency reuse goes on *within* the fixed wide area of a cellular carrier, as part of an overall operating system. Within the coverage area of an AM or FM radio station, by comparison, no other station can use the frequency of that station. And there is no connection between other stations to act as a network. ([back to text](#))

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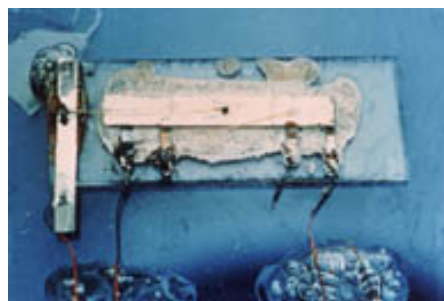
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[\(Packet switching\)](#)

(Next topic: [Standards](#))



Another TI Time Out

"In 1958 Jack Kilby invented the integrated circuit at Texas Instruments. Comprised of only a transistor and other components on a slice of germanium, Kilby's invention, 7/16-by-1/16-inches in size, revolutionized the electronics industry. The roots of almost every

electronic device we take for granted today can be traced back to Dallas more than 40 years ago." Photo courtesy of Texas Instruments.

<http://www.ti.com> ([external link](#))

As an aside, Jack Kilby assisted [Al Gross](#) with the first walkie talkie circuit board Gross developed. Al would reminisce how Jack Kilby (IC pioneer and Texas Instruments cofounder) helped him make his first walkie-talkie circuit using ceramic and bakelite materials to reduce frequency drift -- his walkie-talkies had tubes in them and operated at about 400 MHz." "Al Gross Remembered...." By Ted Rappaport, Virginia Tech,

<http://www.comsoc.org/socstr/remport.html> ([external link](#))

Images of people using 1950s' mobile telephones:

[Swedish mobile telephone \(she's very cute\)](#)

[American mobile telephone](#)

[British mobile telephone](#)

I think all photographs are in the public domain but let me know if you are the legitimate copyright owner. I think people recognize that it's fun and education that I'm interested in, not copyright infringement.

Also in 1958 the Bell System petitioned the FCC to grant 75 MHz worth of spectrum to radio-telephones in the 800 MHz band. The FCC had not yet allowed any channels below 500MHz, where there was not enough continuous spectrum to develop an efficient radio system. Despite the Bell System's forward thinking, the FCC sat on this proposal for ten years and only considered it in 1968 when requests for more frequencies became so backlogged that they could not ignore them.

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"Because it appeared that sufficient frequencies would not be allocated for mobile radio, the 1950s saw only low level R&D activity related to cellular systems. Nonetheless, this modest activity resulted in additional Technical Memoranda in 1958 and 1959, respectively, 'High Capacity Mobile Telephone System - Preliminary Considerations,' W.D. Lewis, 2/10/58; and 'Multi-Area Mobile Telephone System,' W.A. Cornell & H. J. Schulte, 4/30/59. These two memoranda discussed possible models for cellular systems and again recognized the critical nature of handoff. In the 1959 memo, the authors assert that handoff could be accomplished with the technology of the day, but they do not discuss in detail how it might be implemented." [\[SRI2\]](#)

Although the two papers cited above were chiefly limited to Bell System employees, it seems they were substantially reprinted in the [IRE Transactions on Vehicle Communications](#) the next year in 1960. This marked, I think, the first time the entire cellular system concept was outlined in print to the entire world. The abbreviated cites are: "Coordinated Broadband Mobile Telephone System, W.D. Lewis, Bell Telephone Laboratories, Incorporated, Murray Hill, New Jersey, [IRE Transactions](#) May, 1960, p. 43, and "Multi-area Mobile Telephone System, H.J. Schulte, Jr. & W.A. Cornell, Bell Telephone Laboratories, [IRE Transactions](#) May, 1960, p. 49.



In 1961 the [Ericsson \(external link\)](#) subsidiary Svenska Radio Aktiebolaget, or SRA, reorganized to concentrate on building radio systems, ending involvement with making consumer goods. This forerunner of Ericsson Radio Systems was already selling paging and land mobile radio equipment throughout Europe. Land mobile or business communication systems serviced towing, taxi, and trucking services, where a dispatcher communicated to mobiles from a central base station. These business radio systems were and continue to this day to be simplex, with one party talking at a time. SRA also sold to police and military groups.

In 1964 the Bell System began introducing Improved Mobile Telephone Service or IMTS, a replacement to the badly aging Mobile Telephone System. The IMTS field test was in Harrisburg, Pennsylvania, from 1962-1964. Improved Telephone Service worked full-duplex so people didn't have to press a button to talk. Talk went back and forth just like a regular telephone. It finally permitted direct dialing, automatic channel selection and reduced bandwidth to 25-30 kHz. [\[Douglas\]](#) Some operating companies like Pacific Bell took nearly twenty years to replace their old MTS systems, by that time cellular networks were being planned. IMTS was not cut into service in Pacific territory until mid-1982.

More on IMTS! [\(1\) Service cost and per-minute charges table/](#) [\(2\) Product literature photos/](#) [\(3\) Briefcase Model Phone /](#) [\(4\) More info on the briefcase model/](#) [\(5\) MTS and IMTS history/](#) [\(6\) Bell System Outline of IMTS](#) Take a look at a company newsletter describing the 1982 cutover:

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The Bat Phone and The Shoe Phone

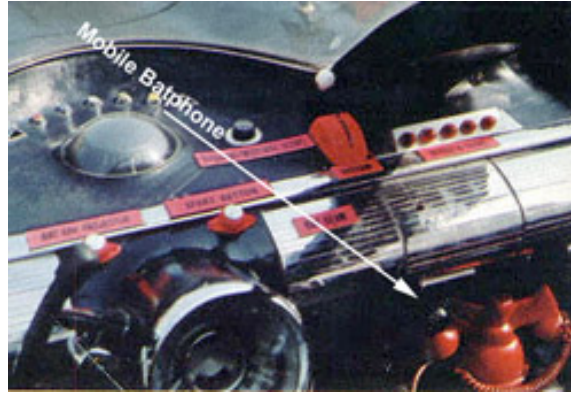
[1981: NMT -- The first multinational cellular system](#)

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In 1965 miniaturization let mobile telephony accomplish its greatest achievement to date: the fully mobile shoe phone, aptly demonstrated by Don Adams in the hit television show of the day, 'Get Smart.' Some argue that the 1966 mobile Batphone *supra*, was more remarkable, but as the photograph shows it remained solidly anchored to the Batmobile, limiting Batman and Robin to vehicle based communications.



For all things 'Get Smart' related, go here:

<http://www.hmss.com/otherspies/getsmart/>

For everything on the Batmobile, go here:

<http://www.1966batmobile.com/index.html>

For children writing reports, this section is a joke!

Across the ocean the Japanese were operating conventional mobile radio telephones and looking forward to the future as well. Limited frequencies did not permit individuals to own radio-telephones, only

government and institutions, and so there was a great demand by the public. It is my understanding that in 1967 the Nippon Telegraph and Telephone Company proposed a nationwide cellular system at 800Mhz for Japan. This proposal is supposedly contained in NTTs' Electrical Communications Laboratories Technical Journal Volume 16, No. 5, a 23 page article entitled "Fundamental problems of nation-wide mobile radio telephone system," written by K. Araki. I have not yet seen the English version of the NTT Journal in question, but it does agree with material I will go over later in this article.



What is certain is that every major telecommunications company and

manufacturer knew about the cellular idea by the middle 1960s; the key questions then became which company could make the concept work, technically and economically, and who might patent a system first.

In 1967 the Nokia group was formed by consolidating two companies: the Finnish Rubber Works and the Finnish Cable Works. Finnish Cable Works had an electronics division which Nokia expanded to include semi-conductor research. These early 1970s studies readied Nokia to develop digital landline telephone switches. Also helping the Finns was a free market for telecom equipment, an open economic climate which promoted creativity and competitiveness. Unlike most European countries, the state run Post, Telephone and Telegraph Administration was not required to buy equipment from a Finnish company. And other telephone companies existed in the country, any of whom could decide on their own which supplier they would buy from. Nokia's later cellular development was greatly helped by this free market background and their early research.

[More Nokia history: http://www.nokia.com/inbrief/history/early.html](http://www.nokia.com/inbrief/history/early.html)

Back in the United States, the FCC in 1968 took up the Bell System's now ten year old request for more frequencies. They made a tentative decision in 1970 to do so, asked AT&T to comment, and received the system's technical report in December, 1971. The Bell System submitted docket 19262, outlining a cellular radio scheme based on frequency-reuse. Their docket was in turn based on the patent Amos E. Joel, Jr. and Bell Telephone Laboratories filed on December 21, 1970 for a [mobile communication system](#). This patent was approved on May 16, 1972 and given the United States patent number 3,663,762. Six more years would pass before the FCC allowed AT&T to start a trial. This delay deserves some explaining.

Besides bureaucratic sloth, this delay was also caused, rightly enough, by the [radio common carriers](#). These private companies provided conventional wireless telephone service in competition with AT&T. Carriers like the American Radio Telephone Service, and suppliers to them like Motorola, feared the Bell System would dominate cellular radio if private companies weren't allowed to compete equally. They wanted the FCC to design open market rules, and they fought constantly in court and in administrative hearings to make sure they had equal access. And although its rollout was delayed, the Bell System was already working with cellular radio, in a small but ingenious way.

The first commercial cellular radio system

In January, 1969 the Bell System made commercial cellular radio operational by employing frequency reuse for the first time. Aboard a train. Using payphones. Frequency reuse, as I've said many times before, is the principle defining cellular and this system had it. (Some say handoffs or handovers also define cellular, which they do in part, but MTS and IMTS could use handovers as well; only frequency reuse is unique to cellular.) "[D]elighted passengers" on Metroliner trains running between New York City and Washington, D.C. "found they could conveniently make telephone calls while racing along at better than 100 miles an

hour." [\[Paul\]](#) Six channels in the 450 MHz band were used again and again in nine zones along the 225 mile route. A computerized control center in Philadelphia managed the system." Thus, the first cell phone was a payphone! As Paul put it in the Laboratories' article, ". . .[T]he system is unique. It is the first practical integrated system to use the radio-zone concept within the Bell System in order to achieve optimum use of a limited number of radio-frequency channels."

If you want another explanation of frequency reuse and how this concept differs cellular telephony from conventional mobile telephone service, [click here to read a description](#) by Amos Joel Jr., writing taken from the original cellular telephone patent.



The brilliant Amos E. Joel Jr., the greatest figure in American switching since [Almon Strowger](#). Pictured here in a Bell Labs photo from 1960, posing before his assembler-computer patent, the largest patent issued up to that date. In 1993 Joel was awarded The National Medal of Technology, "For his vision, inventiveness and perseverance in introducing technological advances in telecommunications, particularly in switching, that have had a major impact on the evolution of the telecommunications industry in the U.S. and worldwide."

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Resources

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[SRI2] David Roessner, Robert Carr, Irwin Feller, Michael McGeary, and Nils Newman, "The Role of NSF's Support of Engineering in Enabling Technological Innovation: Phase II Final report to the National Science Foundation. Arlington,

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<http://www.sri.com/policy/stp/techin2/chp4.html>

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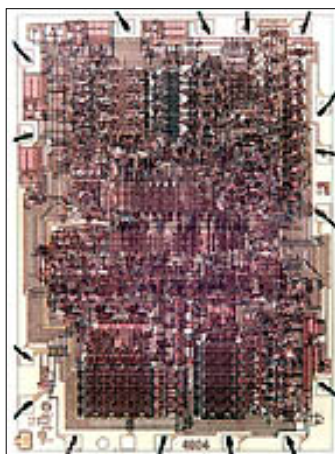
Mobile Telephone History ---- Pages: [\(1\)](#) [\(2\)](#) [\(3\)](#) [\(4\)](#) [\(5\)](#) [\(6\)](#) [\(7\)](#) [\(8\)](#) [\(9\)](#) [\(10\)](#) [\(11\)](#)

[\(Packet switching\)](#)

(Next topic: [Standards](#))

For more on early cellular and IMTS, please go to my [cellular basics article](#).

In 1971 Intel introduced the first microprocessor, the 4004. (4004B pictured here, courtesy of Intel: <http://www.intel.com> ([external link](#))) Designed originally for a desktop calculator, the microprocessor was soon improved on and quickly put into all fields of electronics, including cell phones. The original did 4,000 operations a second. According to the June, 2001 issue of Wired magazine, Gordon Moore described the microprocessor as "one of the most revolutionary products in the history of mankind." At the time Intel's chairman Andrew Grove was not so impressed. He reflected that "I was running an assembly line to build memory chips. I saw the microprocessor as a bloody nuisance." Motorola also did much to pioneer the microprocessor and semiconductor field, indeed, in their advertisements of the time, they rightly noted that Motorola circuits were on board each NASA mission since the American space program began.



In a manuscript submitted to the [IEEE Transactions On Communications](#) on September 8, 1971, NTT's Fumio Ikegami explained that his company began studying a nationwide cellular radio system for Japan in 1967. Radio propagation experiments, measuring signal strength and reception in urban areas from mobiles, were ongoing throughout this time, first at 400Mhz and then at 900Mhz. [\[Ikegami\]](#) A successful system trial may have happened in 1975 but I am unable to confirm this. What I can confirm is that Ito and Matsuzaka wrote in late 1977 that "Field

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- ▶ [Levine's GSM/PCS .pdf file](#)

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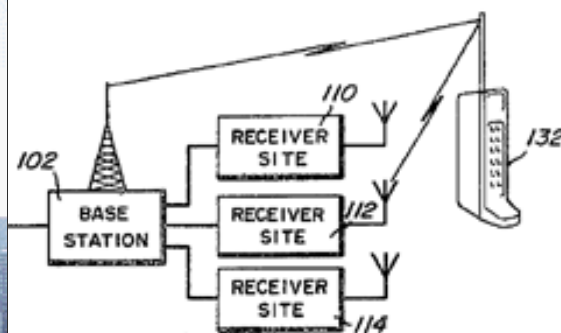
[1981: NMT -- The first multinational cellular system](#)

[Table of Analog or First Generation Cellular Systems](#)

[1982 --> The Rise of GSM](#)

tests have been carried out in the Tokyo metropolitan area since 1975 and have now been brought to a successful completion." The two authors wrote this in a major article describing how the first Japanese cellular system would work. [[Ito](#)]

The Father of the (handheld) Cell Phone



Part of one diagram in US Patent 3,906,166

On October 17, 1973, Dr. Martin Cooper for Motorola filed a patent entitled 'Radio telephone system.' It outlined Motorola's first ideas for cellular radio and was given US Patent Number 3,906,166 when it was granted on September 16, 1975. In a 1999 interview with Dr. Cooper, Marc Ferranti, writing for the IDG News Service, describes the competitiveness of that era, "While he [Dr. Cooper] was a project manager at Motorola in 1973, Cooper set up a base station in New York with the first working prototype of a cellular telephone and called over to his rivals at Bell Labs. Bell had developed cellular communications technology years earlier, but Motorola and Bell Labs in the '60s and early '70s were in a race to actually incorporate the technology into usable devices; Cooper couldn't resist demonstrating in a very practical manner who had won." [[Ferranti](#)] Thus, Cooper claims to be inventor of the cell phone. But the Metroliner service described before was working four years before Cooper placed his call and it was entirely practical. Since the Metroliner used public pay telephones, however, and judging by the photograph here, Cooper may more easily claim to be the inventor of the first personal, handheld cell phone. And that's *quite* an accomplishment!

Photograph above is from the New York Times. Dr. Cooper is now CEO of [Arraycomm.com \(external link\)](#). Their site has much more information on Cooper.

On May 1, 1974 the F.C.C. decides to open an additional 115 megahertz of spectrum, 2300 channel's worth, for future cellular telephone use. Cellular looms ahead, although no one know when FCC approval will permit its commercial rollout. American business radio and radio-telephone manufacturers begin planning for the future. Here's a chart outlining the major makers. Paul Kagan of Paul Kagan Associates developed it and it appeared in the June 10, 1974 issue of *Barrons*, in the article entitled "Go Ahead Signal: The FCC has Given One to Mobile Communications." Links below are all external and to corporate or other history sites where available. Some companies are now out of business or merged with others. Don't expect to find much on cellular or mobile telephone history :-(By the way, if you need a company history written for the web, [I can do that sort of work . . .](#)

Who's Who in Mobile Communications

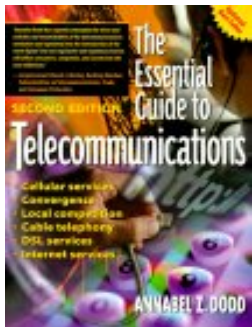
[1990: North America goes digital: IS-54](#)



[Click here for a selection from Weisman's RF & Wireless.](#)

Easy to read, affordable book on wireless basics. (12 pages, 72K in .pdf)

[Ordering information from Amazon.com \(external link\)](#)



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[Excellent, free chapter on telecom fundamentals from the book above by Dodd \(168K, 34 page in .pdf.\)](#)

	1973 Revenues in millions	% of Market
Motorola (History link)	\$350	64.2%
General Electric	80	14.7
RCA (History link)	35	6.4
E.F. Johnson	20	3.7
Harris Corp.	15	2.8
Communications Industries	11	2.0
Scope Inc.	8	1.5
Martin Marietta	6	1.1
Aerotron	3	0.5
Regency Electronics (History link)	2	0.4
All Others	15	2.8

Researchers: With IEEE permission, I have [posted two important tables](#) that give you an overview of worldwide conventional mobile telephone service. Many good details, all circa 1976, just before cellular got started. I apologize for the size of these pages (both 276K) but I had to make sure you could read the tiny type they contain.

In 1975 the FCC finally permitted the Bell System to begin a trial system. It wasn't until March, 1977, though, that the FCC approved AT&T's request to actually operate that cellular system. [\[Young\]](#) Reasons for this maddening delay was the FCC's overriding desire to control, which Berresford explains like this: "[The FCC] made a series of Solomonic compromises under its 'public interest' standard. A constant assumption in all . . . decisions was that it, the FCC, would decide the issues: whether one or more cellular systems would be allowed in each area; whether telephone companies would be allowed to operate them; who would make cellular telephones and who would sell them; and so on down to technical matters such as whether spacing between voice channels would be 25, 30, 40, or 50 kilohertz. [\[Berresford \(external link\)\]](#) This delay would cost the Bell System the chance to be the first to offer individuals cellular service. But let's back up a little.

After the 1975 trial approval the Bell System put out to bid a contract for 135 cell phones, which they'd use in their upcoming trial in Chicago, Illinois. Competing for that work were five American companies, including E.F. Johnson and Motorola. And also one Japanese company, [Oki Electric \(external link\)](#). The contract went to Oki for \$500,000, drawing bitter complaints from the losing bidders and intensifying the rancor between AT&T, now the largest company on earth, and its much smaller rivals. The contract might seem small but in today's dollars it actually works out to \$1,598,513. [\[Calculations\]](#) And it points to a more complex problem of the time.

Since 1968 Motorola was thought to have spent \$13 million dollars (\$41,561,338 in Year 2000 figures) on cellular research and development, this cost borne by them alone. Their losing \$2 million dollar bid (\$6, 394,052, converted, an astounding \$47,000 a phone) reflected some of that expense. Joseph Miller, General Manager of Motorola's Communication Division, said that, by comparison, Oki's bid represented "no inclusion of R&D costs whatsoever because these have in effect been subsidized by the Japanese government." Although this

was true, it was equally true that unlike American firms, Japan had no defense or space work to spin technology off from. But Miller went further when he said that "Japanese manufacturers, with the financial assistance of their government are now developing systems for their domestic market, but with the clear intent to invade the U.S. market." [[Business Week1](#)] One disappointed bidder maintained that by accepting their bid AT&T was further subsidizing Oki, and damaging American companies and competition. These were not just idle complaints.

The Bell System built and operated the best landline telephone service in the world. It served most medium and large sized cities in America, being the telephone company to at least 80% of the United States population. For all intents and purposes, it was *the* phone company. By 1982 it employed [over one million people](#)! Acting under the largess of a state approved monopoly it built a research and development arm far bigger than any private company like Motorola could ever afford. In the case of cellular AT&T used Bell Labs research, paid for by the Bell System's wireline telephone monopoly, to compete against privately funded wireless companies.

Although it had half-heartedly competed with the Radio Common Carriers for conventional mobile telephone service, it was never truly interested in land mobile because too few subscribers were permitted with the limited frequencies available. It didn't make economic sense for so large a company, although the RCCs managed well and treated customers with attention. With the FCC opening new frequency bands, though, cellular radio would be different, with hundreds of thousands, perhaps millions of people as potential customers. While the Bell System could properly contend they owed it to their shareholders to keep down costs, (their Chicago trials wound up costing 28 million dollars, \$89,516,728 converted), by not buying American products AT&T appeared to anti-competitive. Well, more so than usual :-) In any case they missed an important first.

First generation analog cellular systems begin

The Bahrain Telephone Company ([Batelco External link](#)) in May, 1978 began operating a commercial cellular telephone system. It probably marks the



first time in the world that individuals started using what we think of as traditional, mobile cellular radio. The two cell system had 250 subscribers, 20 channels in the 400Mhz band to operate on, and used all Matsushita equipment. (Panasonic is the name of Matsushita in the United States.) [[Gibson](#)] Cable and Wireless, now Global Crossing, installed the equipment. I have recently come across new information on this subject. [Click here to go to the footnote, under the name Gibson](#), which explains this confusing "first."

In July, 1978 Advanced Mobile Phone Service or AMPS started operating in North America. In AT&T labs in Newark, New Jersey, and most importantly in a trial around Chicago, Illinois Bell and AT&T jointly rolled out analog based cellular telephone service. Ten cells covering 21,000 square miles made up the Chicago system. This first equipment test began using 90 Bell System employees. After six months, on December 20th, 1978, a market trial began with paying customers who leased the car mounted telephones. This was called the service test. The system used the newly allocated 800 MHz band. [[Blecher](#)] Although the Bell System bought an additional 1,000 mobile phones from Oki for the lease phase, it

did place orders from Motorola and E.F. Johnson for the remainder of the 2100 radios needed. [\[Business Week2\]](#) This early network, using large scale integrated circuits throughout, a dedicated computer and switching system, custom made mobile telephones and antennas, proved a large cellular system could work.



http://park.org:8888/Japan/NTT/MUSEUM/html_ht/HT979020_e.html

"The car telephone service was introduced in the 23 districts of Tokyo in December 1979 (Showa 54). Five years later, in 1984 (Showa 59), the system became available throughout the country. Coin operated car telephones were also introduced to allow convenient calling from inside buses or taxis." NTT

Worldwide commercial AMPS deployment followed quickly. An 88 cell system in Tokyo began in December, 1979, using Matsushita and NEC equipment. The first North American system in Mexico City, a one cell affair, started in August, 1981. United States cellular development did not keep up since fully commercial systems were still not allowed, despite the fact that paying customers were permitted under the service test. The Bell System's impending breakup and a new FCC [competition requirement \(External link\)](#) delayed cellular once again. The Federal Communication Commission's 1981 regulations required the Bell System or a regional operating company, such as Bell Atlantic, to have competition in every cellular market. That's unlike the landline monopoly those companies had. The theory being that competition would provide better service and keep prices low. Before moving on, let's discuss Japanese cellular development a little more.

Growth of Japanese cellular development

At the end of World War II Japan's economy and much of its infrastructure was in ruins. While America's telecom research and development picked up quickly after the War, the Japanese first had to rebuild their country. It is remarkable that they did so much in communications so quickly. Three things especially helped. The first was re-gaining independence in 1952, allowing the country to go forward on its own path, arranging its own future. The other event was an easy patent policy AT&T adopted toward the transistor. Fearing anti-monopoly action by the U.S. States Justice department, the Bell System allowed anyone for \$25,000 to use its transistor patents. Although the first transistorized products were American, the Japanese soon displayed an inventiveness toward producing electronics that by the mid-1960s caused many American manufacturers to go out of business. This productivity was in turn helped by a third cause: a government willingness to fund research and development in electronics. Essner, writing in a Japanese Technology Evaluation Center report, neatly sums up most of the telecom situation:

"In 1944, there were 1 million telephone subscribers in Japan. By the end of the war, that number had been reduced to 400,000. NTT [Nippon Telegraph and Telephone] was established to reconstruct the Japanese telecommunication facilities and to develop the required

technology for domestic use and production. Between 1966 and 1980, NTT went through an age of growth, introducing new communication services, and the number of subscribers exceeded 10 million by 1968. From 1981 to 1990, NTT became a world class competitor, with many of its technologies, including its optical communication technologies, being used throughout the world. In 1985, NTT was converted into a private corporation." [\[JTEC\]](#)

NTT produced the first cellular systems for Japan, using all Japanese equipment. While their research benefited from studying the work of others, of course, the Japanese contributed important studies of their own. Y. Okumura's "Field Strength and its Variability in VHF and UHF Land Mobile Service," published in 1968, is cited by Roessner et. al. as "the basis for the design of several computer-modeling systems." These were "[D]eveloped to predict frequency propagation characteristics in urban areas where cellular systems were being implemented. These computer systems (the two main cellular players, Bell Labs and Motorola each developed its own) became indispensable to the design of commercial cellular systems." [\[SR3\]](#)

Often thought of as the 'Bell Labs of Japan,' NTT did not manufacture their own products, as did Western Electric for the Bell System. They worked closely instead with companies like [Matsushita Electric Industrial Co. Ltd. \(external link\)](#) (also known as Panasonic in the United States), and NEC, originally incorporated as the Nippon Electric Company, but now known simply as [NEC. \(external link\)](#) As we've seen, Oki Electric was also a player, as were Hitachi and Toshiba. The silent partner in all of this was the Japanese government, especially the Ministry of International Trade and Research, which in the 1970s put hundreds of millions of dollars into electronic research.

The Ministry of International Trade and Research, otherwise known as MITI, controls the Agency of Industrial Science and Technology. That agency traces its roots to 1882, its Electric Laboratory to 1891. Many other labs were established over the following decades to foster technological research. In 1948, MITI Ministry folded all these labs into the presently named [Agency of Industrial Science and Technology \(external link\)](#). Funded projects in the 1970s included artificial intelligence, pattern recognition, and, most importantly to communications, research into very large scale integrated circuits. [\[Business Week3\]](#) The work leading up to VLSI production, in which tens of thousands of interconnected transistors were put on a single chip, greatly helped Japan to reduce component and part size. It was not just research, which all companies were doing, but also a fanatical quality control and efficiency that helped the Japanese surge ahead in electronics in the late early to mid 1980s, just as they were doing with car building.

On March 25, 1980, Richard Anderson, general manager for Hewlet Packard's Data Division, shocked American chip producers by saying that his company would henceforth buy most of its chips from Japan. After inspecting 300,000 standard memory chips, what we now call RAM, HP discovered the American chips had a failure rate six times greater than the worst Japanese manufacturer. American firms were not alone in needing to retool. Ericsson admits it took years for them to compete in producing mobile phones. In 1987 Panasonic took over an Ericsson plant in Kumla, Sweden, 120 miles east of Stockholm to produce a handset for the Nordic Mobile Telephone network. As Meurling and Jeans

explained:

"Panasonic brought in altogether new standards of quality. They sent their inspection engineers over, who took out their little magnifying glasses and studied, say displays. And when they saw some dust, they asked that the unit should be dismantled and that dust-free elements should be used instead. Einar Dahlin, one of the original small development team in Lund, had to reach a specific agreement on how many specks of dust were permitted." [[Meurling and Jeans](#)]

America and the rest of the world responded and got better with time. Many Japanese manufacturers flourished while several companies producing cell phones at the start no longer do so. Other Japanese companies have entered the world wide market, where there now seems room for everyone. Many years ago Motorola started selling into the Japanese market, something unthinkable at the beginning of cellular. And the proprietary analog telephone system NTT first designed was so expensive to use that it attracted few customers until years later when competition was introduced and rates lowered. The few systems Japan companies sold overseas, in the Middle East or or Australia, were replaced with other systems, usually GSM, after just a few years. But now I am getting ahead of myself.

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Resources

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[Business Week3]"Japan's Bid to out-design the United States" Business Week, Industrial Edition, April 13, Number 2863: 123 ([back to text](#))

[Calculations] What is a dollar worth?: The Consumer Price Index Calculation Machine at: <http://minneapolisfed.org/economy/calc/cpihome.html>

([back to text](#))

Ferranti, Marc 'Father of cell phone eyes a revolution' IDG News Service\New York Bureau

October 12, 1999, 14:31. The article is archived below:

<http://www.idg.net/idgns/1999/10/12/WorldBeatFatherOfCellPhoneEyes.shtml>

([back to text](#))

Gibson, Stephen W., Cellular Mobile Radiotelephones. Englewood Cliff: Prentice Hall, (1987): 141, quoting information from the company Personal Communications Technology. You can view the table I cite from this book by clicking here for [the low resolution version first \(85K\)](#), and, if you are still interested, try your luck with [the original TIFF image file](#), an astounding 2.2

megabytes!

This Bahrain date was confirmed on December 5, 2000 by Mr. Ali Abdulla Sahwan, Manager, Public Relations, of the Bahrain Telecommunications Company (Batelco) in a personal correspondence to myself, Tom Farley. There is contradictory if somewhat baffling evidence from the General Manager of C&W's radio division in Bahrain at the time, a Mr. Alec Sherman. He maintains that the system was not cellular but, well, [read his own words](#) and then tell me what you think. ([back to text](#))

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(Next topic: [Standards](#))



In 1983 Texas Instruments introduced their single chip digital signal processor, operating at over five million operations a second. Though not the first to make a single chip DSP, [Lucent claiming that distinction in 1979 \(external link\)](#), TI's entry heralded the wide spread use of this technology. The digital signal processor is to cell phones what the microprocessor is to the computer.

A DSP contains many individual circuits that do different things. A properly equipped DSP chip [can compress speech so that a call takes less room in the radio bands](#), permitting more calls in the same amount of scarce radio spectrum. With a single chip DSP fully digital cellular systems like GSM and TDMA could make economic sense and come into being. Depending on design, at least three calls in a digital system could fit into the same radio frequency or channel space that a single analog call had taken before. DSP chips today run at over 35,000,000 operations a second. <http://www.ti.com> [\(external link\)](#)

In February, 1983 Canadian cellular service began. This wasn't AMPS but something different. Alberta Government Telephones, now [Telus \(external link\)](#), launched the AURORA-400 system, using GTE and NovAtel equipment. This so called decentralized system operates at 420 MHZ, using 86 cells but featuring no handoffs. As David Crowe explains, "It provides much better rural coverage, although its capacity is low." You had, in other words, a system employing frequency reuse, [the defining principle of cellular](#), but no handoffs between the large sized cells. This worked well for a rural area needing wide area coverage but it could not deliver the capacity that a system with many more small cells could offer, since more cells means more customers served.

Visit this site for an excellent timeline on American cellular development:
<http://books.nap.edu/books/030903891X/html/159.html#pagetop>

On October 12, 1983 the regional Bell operating company Ameritech began the first United States commercial cellular service in Chicago, Illinois. This was AMPS, or Advanced Mobile Phone Service, which we've discussed in previous pages. United States cellular service developed from this AT&T model, along with Motorola's analog system known as [Dyna-TAC\(external link\)](#), first introduced commercially in Baltimore and Washington D.C. by Cellular One on December 16, 1983. Dyna-Tac stood for, hold your breath, Dynamic Adaptive Total Area

[Standards](#)

Coverage. Of course.

[Basic Radio Principles](#)[Cellular defined](#)[Frequency reuse](#)[Cell splitting](#)[Cellular and PCS frequencies](#)[Transmitting digital signals](#)[Introducing wireless systems](#)[The network elements](#)[The main wireless categories](#)[Basic digital principles](#)[Modulation](#)[Turning speech into digital](#)[Frames, slots and channels](#)[IS-54: D or Digital AMPS](#)[IS-136: TDMA based cellular](#)[Call processing](#)[Appendix](#)[Wireless' systems chart](#)[Cellular and PCS frequencies chart](#)[Mobile Phone History Table of Contents:](#)[Introduction](#)[Wireless and Radio defined](#)[1820 --> Pre-history](#)[1842: Wireless by Conduction](#)[1843 --> Early Electromagnetic Research](#)[Wireless by Induction](#)[1865: Induction and Dr. Loomis](#)[Early Radio Discoveries](#)[1879: D.E. Hughes and the first](#)**Analog or First Generation Cellular Systems**

System Name or Standard	Start Date	Country of origin or region it operated in
AMPS	1979 trial, 1983 commercial	United States, then world wide
AURORA-400	1983	Alberta, Canada
C-Netz (external link, in German) (C-Netz, C-450)	Begins '81, upgraded in 1988?	Germany, Austria, Portugal, South Africa
Comvik (external link)	August, 1981	Sweden
ETACS (external link)	1987?	U.K., now world wide
JTACS (external link)	June, 1991	Japan
NAMPS (Narrowband Advanced Mobile Phone Service)	1993?	United States, Israel, ?
NMT 450 (Nordic Mobile Telephone)	1981	Sweden, Norway, Denmark, Finland, Oman; NMT now exists in 30 countries
NMT 900 (Nordic Mobile Telephone)	1986	
NTACS/JTACS (external links infra)	June, 1991	Japan
NTT (external link)	December, 1979	Japan
NTT Hi Cap (external link)	December, 1988	Japan
RadioCom (RadioCom2000) (external link) , in French	November, 1985	France
RTMS (Radio Telephone Mobile System) (external link, in Italian)	September, 1985	Italy
TACS (Total Access Communications System) (external link)	1985	United Kingdom, Italy, Spain, Austria, Ireland

NB: Some systems may still be in use, others are defunct. All systems used analog routines for sending voice, signaling was done with a variety of tones and data bursts. Handoffs were based on measuring signal strength except C-Netz which measured the round trip delay. Early C-Netz phones, most made by Nokia, also used magnetic stripe cards to access a customer's information, a predecessor to the ubiquitous SIM cards of GSM/PCS phones. [e-mail me](#) with corrections or additions, I am still working on this table. [Here is another look at an analog system table.](#)

Before proceeding further, I must take up just a little space to discuss a huge event: the breakup of AT&T. Although they pioneered much of telecom, many people thought the information age was growing faster than the Bell System could handle. Some thought AT&T stood in the way of development and competition. And the thought of any large monopoly struck most as inherently wrong.

In 1982 the Bell System had grown to an unbelievable 155 billion dollars in assets (256 billion in today's dollars), with over one million employees. By comparison, Microsoft in 1998 had assets of around 10 billion dollars. On August 24, 1982,

[radio-telephone reception](#)

[1880: The Photophone and the first voice radio-telephone call](#)

[1880 to 1900: Radio development begins in earnest](#)

[1910: The first car-telephone](#)

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[1990: North America goes digital: IS-54](#)

[Principles of Modern Communications Technology \(external link to Amazon\)](#) (Artech House) Professor A. Michael Noll

 [This .pdf file is from Noll's](#)

after seven years of wrangling with the federal justice department, the Bell System was split apart, succumbing to government pressure from without and a carefully thought up plan from within. Essentially, the Bell System divested itself.

In the decision reached, AT&T kept their long distance service, Western Electric, Bell Labs, the newly formed AT&T Technologies and AT&T Consumer Products. AT&T got their most profitable companies, in other words, and spun off their regional Bell Operating Companies or RBOCs. Complete divestiture took place on January, 1, 1984. After the breakup new companies, products, and services appeared immediately in all fields of American telecom, as a fresh, competitive spirit swept the country. The Bell System divestiture caused nations around the world to reconsider their state owned and operated telephone companies, with a view toward fostering competition in their own countries. But back to cellular.

NMT -- The first multinational cellular system

Europe saw cellular service introduced in 1981, when the Nordic Mobile Telephone System or NMT450 began operating in Denmark, Sweden, Finland, and Norway in the 450 MHz range. It was the first multinational cellular system. In 1985 Great Britain started using the Total Access Communications System or TACS at 900 MHz. Later, the West German C-Netz, the French Radiocom 2000, and the Italian RTMI/RTMS helped make up Europe's nine analog incompatible radio telephone systems. Plans were afoot during the early 1980s, however, to create a single European wide digital mobile service with advanced features and easy roaming. While North American groups concentrated on building out their robust but increasingly fraud plagued and featureless analog network, Europe planned for a digital future.



The first portable units were really big and heavy. Called transportables or luggables, few were as glamorous as this one made by Spectrum Cellular Corporation. Oki also produced a briefcase model.

The United States suffered no variety of incompatible systems. Roaming from one city or state to another wasn't difficult like in Europe. Your mobile usually worked

[book above: it is a short, clear introduction to signals and will give you background to what you are reading here.](#)



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Easy to read, affordable book on wireless basics. (12 pages, 72K in .pdf)

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[The Essential Guide to Telecommunications by Annabel Z. Dodd, a good, affordable \(about \\$25.00\) book on telecom fundamentals](#) (external link to Amazon.com)



[Excellent, free chapter on telecom fundamentals from the book above by Dodd \(168K, 34 page in .pdf.\)](#)

as long as there was coverage. Little desire existed to design an all digital system when the present one was working well and proving popular. To illustrate that point, the American cellular phone industry grew from less than 204,000 subscribers in 1985 to 1,600,000 in 1988. And with each analog based phone sold, chances dimmed for an all digital future. To keep those phones working (and producing money for the carriers) any technological system advance would have to accommodate them.

The Rise of GSM

Europeans saw things differently. No new telephone system could accommodate their existing services on so many frequencies. They decided instead to start a new technology in a new radio band. Cellular structured but fully digital, the new service would incorporate the best thinking of the time. They patterned their new wireless standard after landline requirements for ISDN, hoping to make a wireless counterpart to it. The new service was called [GSM \(external link\)](#).

[Continue reading below or go on to the next page-->](#)

-- An Evolution of Ericsson Handhelds, from Analog to Digital -- smaller and smaller, lighter and lighter

(click on photograph to bring up a bigger image)

			
1987: Curt, a converted police radio design turned into an NMT 900 phone and later a ETACS mobile. The first Ericsson handheld. Known officially as the HotLine Pocket.	1989: Olivia. Introduced originally for NMT 900 networks, followed by versions for ETACS, AMPS, and eventually GSM. The first Ericsson GSM phone and consequently its first all digital mobile.	1991: Sandra, first version in NMT 900, then ETACS, D-AMPS/AMPS, and finally GSM in 1993.	1996: Jane, D-AMPS, GSM, DCS, PCS1900/GSM. A 'slim' version appeared in a D-AMPS 1900 model as well as a PDC version.

Special thanks to James Borup, Senior Press Officer, Corporate Communications for Ericsson, who provided the book The Ugly Duckling: Mobile phones from Ericsson -- putting people on speaking terms, from which the photographs and information above were taken. I did not put in the 'Sandra' or the 'Hotline Combi' phone. The code names above were mostly "girls names because they were so small and shapely." No, I am not making that up. And Jane is after Jane Seymour but that is another story . . . for a more extended discussion on Ericsson handsets, [click here to go to the bottom of this page](#).

And for a diagrammatic look at [NTT models](#), [click here](#)

Resources

Blecher, Franklin H. "Advanced Mobile Phone Service." IEEE Transactions on Vehicle Communications, Vol. VT-29, No. 2, May, 1980 ([back to text](#))

Crowe, David "IS-41 Explained." [Cellular Networking Perspectives](#) Special Issue, 1994 ([back to text](#))

Gibson, Stephen W., Cellular Mobile Radiotelephones. Englewood Cliff: Prentice Hall, 1987. 141, quoting Personal Communications Technology ([back to text](#))

Ikegami, Fumio, "Mobile Radio Communications in Japan." IEEE Transactions On Communications Vol. Com-20 No. 4, August 1972: 744 ([back to text](#))

Johnston, William "Europe's future mobile telephony system." IEEE Spectrum October, 1998 ([back to text](#))

Ericsson handset discussion ([back to text](#))

Johann Storck recently checked in to make some comments:

"I've just read page 9 of "Mobile Telephone History" and found a picture I knew well ... the good old Ericsson GH 388 [code name Jane, ed.], one of the first really handy and still (from the size factor) small mobile phones. Just don't measure the weight! Well, you put a picture of the model 388 from 1996 on your page and I want to inform you that there was an earlier model, dating back to 1994 which had already the same size factor and nearly the same features (except SMS sending). I've included a picture of my own device manufactured in calendar week 44 in 1994. The phone measures 12.8cm (about 5 inches) in height, 4.8cm (about 1.9 inches) in width and the depth with the normal capacity battery is about 2.6cm (about 1 inch)."

"As for Ericsson getting out of the handset business, I think they were once the leading developer of mobile phones, back in the times when they made models like the 337. But they didn't learn from their design faults. Think of the small display the 337-owner had to deal with, they kept that size for several other models (377, 388 and even the latest phones like T-28 and the T-20). Or think of the fact that the menu structure was far too complicated and still is. From that point of view Ericsson could be better off giving away the mobile phone business to Flextronics because that could bring some innovations to their (technically very good) products."



"If you compare Ericsson to Nokia you see what can be done by listening to the consumer wishes. Nokia designed an easy-to-use graphical menu structure and (in some phones) eliminated the antenna to make the devices smaller and more robust. All these facts made the Nokia phones more mass-market compliant and, as a matter of fact, more people bought Nokia phones even when they weren't seen as having the same technical quality level (quality of speech transmission, battery life time, and so on, like the ones made by other companies."

Editor's note. I always liked Ericsson mobiles. They were rugged and worked. Their design philosophy seemed liked Porsche, you always knew an Ericsson phone when you saw one. There was a nice article on Ericsson design in the first issue of their publication On: <http://on.magazine.se/> (external link)

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The best selection of used books on the web is at <http://www.abe.com>. Period. No argument. Advanced Book Exchange is an association of hundreds and hundreds of independent book sellers. I do not get a commission from them because they do not have an affiliate program yet. But I've used and recommended them since late '95; you will be very happy with them.

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GSM first stood for [Groupe Speciale Mobile \(external link\)](#), after the study group that created the standard. It's now known as Global System for Mobile Communications, although the "C" isn't included in the abbreviation. GSM development began in 1982 by a group of 26 European national phone companies. [GSMWorld \(external link\)](#) This Conference of European Postal and Telecommunications Administrations or [CEPT \(external link\)](#), sought to build a uniform, European wide cellular system around 900 MHz. A rare triumph of European unity, GSM achievements became "one of the most convincing demonstrations of what co-operation throughout European industry can achieve on the global market." Planning began in earnest and continued for several years.

In the mid-1980s commercial mobile telephony took to the air. The North American terrestrial system or [NATS \(external link\)](#) was introduced by [Airfone \(external link\)](#) in 1984, the company soon bought out by GTE. The aeronautical public correspondence or APC service breaks down into two divisions. The first is the ground or terrestrial based system (TAPC). That's where aircraft placed telephone calls go directly to a ground station. The satellite-based division, which came much later, places calls to a satellite which then relays the transmission to a ground station. AT&T soon established their own TAPC network after GTE.

In December 1988 Japan's Ministry of Posts and Telecommunications ended NTT's monopoly on mobile phone service. Although technically adept, NTT was also monolithic and bureaucratic, it developed a good cellular system but priced it beyond reach, and required customers to lease phones, not to buy them. With this atmosphere and without competition cellular growth in Japan had flatlined. With rivals cellular customers did increase but it was not until April, 1994, when the market was completely deregulated, allowing price breaks and letting customers own their own phones, did Japanese cellular really take off.

In 1989 The European Telecommunication Standards Institute or [ETSI \(external link\)](#) took responsibility for further developing GSM. In 1990 the first recommendations were published. Pre-dating American PCS, the United Kingdom asked for and got a GSM plan for higher frequencies. The Digital Cellular System or DCS1800 works at 1.8 GHz, uses lower powered base stations and has greater capacity because more frequencies are available than on the continent. Aside from

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these "air interface" considerations, the system is pure GSM. The specs were published in 1991.

The late 1980s saw North American cellular becoming standardized as network growth and complexity accelerated. In 1988 the analog networking cellular standard called TIA-IS-41 was published. [\[Crowe\]](#) This Interim Standard is still evolving. IS-41 seeks to unify how network elements operate; the way various databases and mobile switches communicate with each other and with the regular landline telephone network. Despite ownership or location, all cellular systems across America need to act as one larger system. In this way roamers can travel from system to system without having a call dropped, calls can be validated to check against fraud, subscriber features can be supported in any location, and so on. All of these things rely on [network elements](#) cooperating in a uniform, timely manner.

In 1990 in-flight radio-telephone moved to digital. The FCC invited applications for and subsequently awarded new licences to operate digital terrestrial aeronautical public correspondence or TAPC services in the US. GTE Airfone, AT&T Wireless Services (previously Claircom Communications), and InFlight Phone Inc. were awarded licenses. "[T]hese U.S. service providers now have TAPC networks covering the major part of North America. The FCC has not specified a common standard for TAPC services in the US, other than a basic protocol for allocating radio channel resources, and all three systems are mutually incompatible. Currently over 3000 aircraft are fitted with one of these three North American Telephone Systems (NATS). It is estimated that the potential market for TAPC services in North America is in excess of 4000 aircraft." [\[Capway \(external link\)\]](#)

North America goes digital: IS-54

In 1990 North American carriers faced the question -- how do we increase capacity? -- do we pick an analog or digital method? The answer was digital. In March, 1990 the North American cellular network incorporated the IS-54B standard, the first North American dual mode digital cellular standard. This standard won over Motorola's Narrowband AMPS or NAMPS, an analog scheme that increased capacity by cutting down voice channels from 30KHz to 10KHz. IS-54 on the other hand increased capacity by digital means: sampling, digitizing, and then multiplexing conversations, a technique called [TDMA](#) or time division multiple access. This method separates calls by time, placing parts of individual conversations on the same frequency, one after the next. It tripled call capacity .

Using IS-54, a cellular carrier could convert any of its systems' analog voice channels to digital. A dual mode phone uses digital channels where available and defaults to regular AMPS where they are not. IS-54 was, in fact, backward compatible with analog cellular and indeed happily co-exists on the same radio channels as AMPS. No analog customers were left behind; they simply couldn't access IS-54's new features. CANTEL got IS-54 going in Canada in 1992. IS-54 also supported authentication, a help in preventing fraud. IS-54, now rolled into IS-136, accounts for perhaps half of the cellular radio accounts in this country.

I should point out that no radio service can be judged on whether it is all digital or not. Other factors such as poorer voice quality must be considered. In America GSM systems usually operate at a higher frequency than it does in most of Europe.

[1982 --> The Rise of GSM](#)

[1990: North America goes digital: IS-54](#)



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As we will see later, nearly twice as many base stations are required as on the continent, leaving gaps and holes in coverage that do not exist with lower frequency, conventional cellular. And data transfer remains no higher than 9.6 kbs, a fifth the speed of an ordinary landline modem. Tremendous potential exists but until networks are built out and other problems solved, that potential remains unfulfilled.

Meanwhile, back on the continent, commercial GSM networks started operating in mid-1991 in European countries. GSM developed later than conventional cellular and in many respects was better designed. Its North American counterpart is sometimes called PCS 1900, operating in a higher frequency band than the original European GSM. But be careful with marketing terms: in America a PCS service might use GSM or it might not. All GSM systems are TDMA based, but other PCS systems use what's known as IS-95, a CDMA based technology. Sometimes GSM at 1900Mhz is called PCS 1900, sometimes it is not. Arrgh.

Advanced Mobile Phone Service remains a contender to GSM and PCS, although its market share is now decreasing. As David Crowe puts it:

"The best known AMPS systems are in the US and Canada, but AMPS is also a de facto standard throughout Mexico, Central and South America, very common in the Pacific Rim and also found in Africa and the remains of the USSR. In summary, AMPS is on every continent except Europe and Antarctica. . . due to the high capacity allowed by the cellular concept, the lower power which enabled portable operation and its robust design, AMPS has been a stunning success. Today, more than half the cellular phones in the world operate according to AMPS standards . . . From its humble beginnings, AMPS has grown from its roots as an 800MHz analog standard, to accommodate TDMA and CDMA digital technology, narrowband (FDMA) analog operation (NAMPS), in-building and residential modifications."

"Most recently, operation in the 1800 Mhz (1.8-2.2 GHz) PCS frequency band has been added to standards for CDMA and TDMA. All of these additions have been done while maintaining an AMPS compatibility mode (known as BOA: Boring Old AMPS). It might be boring, but it works, and the AMPS compatibility makes advanced digital phones work everywhere, even if all their features are not available in analog mode." [Cellular Networking Perspectives \(external link\)](#)

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This excellent cellular handheld telephone timeline is of NTT models. This graphic is from:
http://www.nttdocomo.co.jp/corporate/rd/tech_e/base02_e.html

Year	1987	1989	1991	1993	1995
System	Large city system (April 1989) High-capacity system			Digital system (800MHz)	
Configuration of mobile station and antenna	 802B:500cc 750g	 803B:400cc 640g	 Mova:150cc 230g	 Digital 150cc Mova : 240g	 Ultra-compact 100cc mobile station:150g
Antenna technology	• Bottom end feeding 1/2λ whip	• Side-mounted built-in reverse-F antenna • Small diversity antenna	• Bottom end feeding 3/8λ whip • Retractable whip antenna on the side • Reverse-F antenna • Integrated with filter • Built-in reverse-F antenna installed at the back	• Wide-band whip antenna • Wide-band small plate antenna	

[For a look at Ericsson models click here](#)

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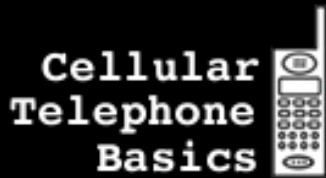
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(Page 2) Cellular telephone basics cont. . .

III Cell and Sector Terminology

With cellular radio we use a simple hexagon to represent a complex object: the geographical area covered by cellular radio antennas. These areas are called cells. Using this shape let us picture the cellular idea, because on a map it only approximates the covered area. Why a hexagon and not a circle to represent cells?



If we draw cells as circles we can't show the cells right next to each other. We get instead a confusing picture like that on the bottom right. Notice all the gaps between the circles? When showing a cellular system we want to depict an area totally covered by radio, without any gaps. Any cellular system will have gaps in coverage, but the hexagonal shape lets us more neatly visualize, in theory, how the system is laid out.



Notice the illustration below. The middle circles represent cell sites. This is where the base station radio equipment and their antennas are located. A cell

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► [R.B. Hill: Strowger switching](#)

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[Appendix: Early Bell System overview of IMTS and cellular](#)

[Appendix: Call processing diagram](#)

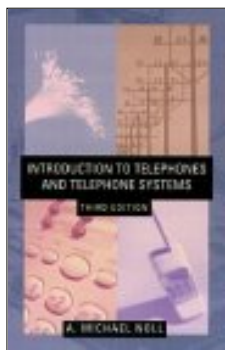
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[Introduction to Telephones and Telephone Systems \(external link to Amazon\)](#) (Artech House)

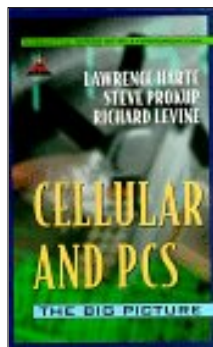
Professor A. Michael Noll



[This is from Professor Noll's book above, it is an excellent, simple introduction to cellular \(32 pages, 204K in .pdf\)](#)



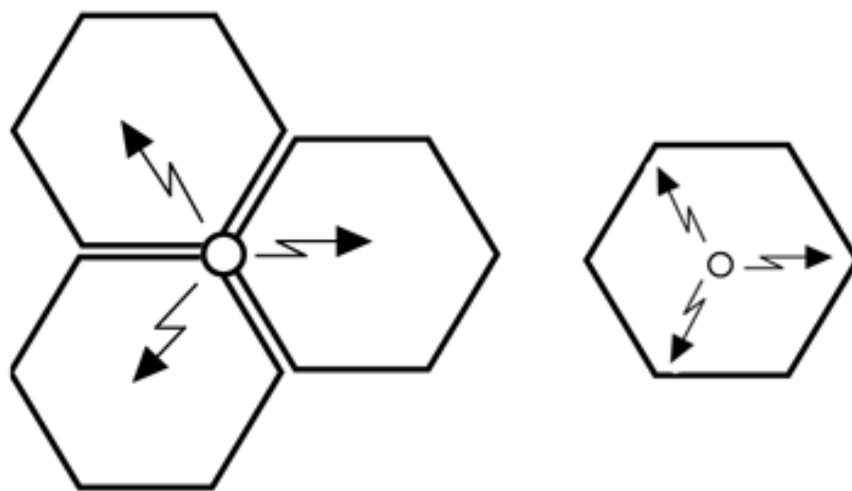
[This is a sample of Professor Levine's writing, co-author of the work below. This .pdf file is a well detailed, advanced guide to cellular \(100 pages, 373K in .pdf\)](#)



[Cellular and PCS: The Big](#)

site gives radio coverage to a cell. Do you understand the difference between these two terms? The cell site is a *location or a point*, the cell is a wide *geographical area*. Okay?

Most cells have been split into sectors or individual areas to make them more efficient and to let them to carry more calls. Antennas transmit inward to each cell. That's very important to remember. They cover a portion or a sector of each cell, not the whole thing. Antennas from other cell sites cover the other portions. The covered area, if you look closely, resembles a sort of rhomboid, as you'll see in the diagram after this one. The cell site equipment provides each sector with its own set of channels. In this example, just below , the cell site transmits and receives on three different sets of channels, one for each part or sector of the three cells it covers.



Right! 😊

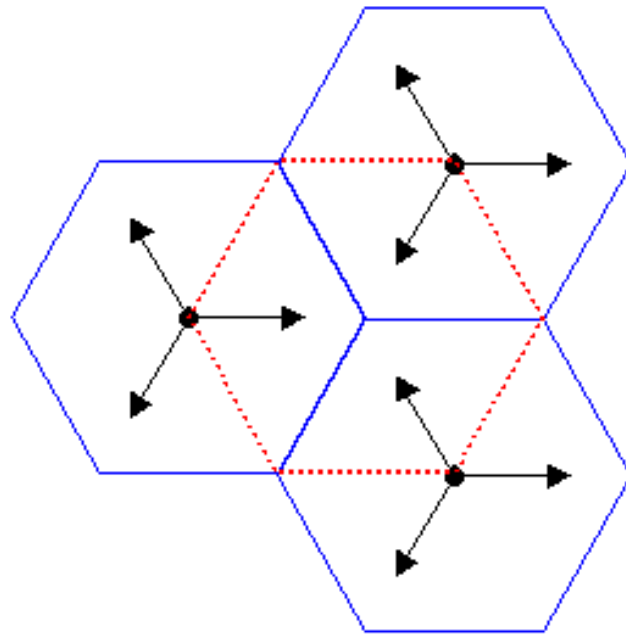
Wrong! ☹️

A cell site lies at the edge of several cells, not at the center.

Is this discussion clear or still muddy? [Skip ahead](#) if you understand cells and sectors or come back if you get hung up on the terms at some later point. For most of us, let's go through this again, this time from another point of view. Mark provides the diagram and makes some key points here:

"Most people see the cell as the blue hexagon, being defined by the tower in the center, with the antennae pointing in the directions indicated by the arrows. In reality, the cell is the **red hexagon**, with the towers at the corners, as you depict it above and I illustrate it below. The confusion comes from not realizing that a cell is a geographic area, not a point. We use the terms 'cell' (the coverage area) and 'cell site' (the base station location) interchangeably, but they are not the same thing."

[Picture, Harte, Prokup, and Levine \(external link to Amazon.com\)](#)



Click here if you want [an illustrated overview of cell site layout](#)

[WFI's](#) Mark goes on to talk about cells and sectors and the kind of antennas needed: "These days most cells are divided into sectors. Typically three but you might see just two or rarely six. Six sector sites have been touted as a Great Thing by manufacturers such as Hughes and Motorola who want to sell you more equipment. In practice six sectors sites have been more trouble than they're worth. So, typically, you have three antenna per sector or 'face'. You'll have one antenna for the voice transmit channel, one antenna for the set up or control channel, and two antennas to receive. Or you may duplex one of the transmits onto a receive. By sectorising you gain better control of interference issues. That is, you're transmitting in one direction instead of broadcasting all around, like with an omnidirectional antenna, so you can tighten up your frequency re-use"



"This is a large point of confusion with, I think, most RF or radio frequency engineers, so you'll see it written about incorrectly. While at AirTouch, I had the good fortune to work for a few months with a consultant who was retired from Bell Labs. He was one of the engineers who worked on cellular in the 60s

and 70s. We had a few discussions on this at AirTouch, and many of the engineers still didn't get it. And, of course, I had access to Dr. Lee frequently during my years there. It doesn't get much more authoritative than the guys who developed the stuff!"

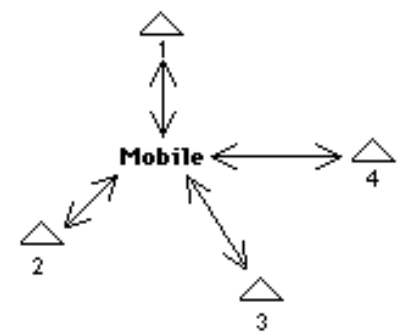
Jim Harless, a regular contributor, recently checked in regarding six sector cells. He agrees with Mark about the early days, that six sector cells in AMPS did not work out. He notes that "At [Metawave \(external link\)](#) I've been actively involved in converting some busy CDMA cells to 6-sector using our smart antenna platform. Although our technology is vendor specific, you can't use it with all equipment, it actually works quite well, regardless of the added number of pilots and increase in [soft handoffs](#). In short, six sector simply allows carriers to populate the cell with more channel elements. Also, they are looking for improved cell performance, which we have been able to provide. By the way, I think the reason early CDMA papers had inflated capacity numbers were because they had six sector cells in mind."

Mark says "I don't recall any discussion of anything like that. But Qualcomm knew next to nothing about a commercial mobile radio environment. They had been strictly military contractors. So they had a lot to learn, and I think they made some bad assumptions early on. I think they just underestimated the noise levels that would exist in the real world. I do know for sure that the 'other carrier jammer' problem caught them completely by surprise. That's what we encountered when mobiles would drive next to a competitors site and get knocked off the air. They had to re-design the phone.

IV Basic Theory and Operation

Cell phone theory is simple. Executing that theory is extremely complicated. Each cell site has a base station with a computerized 800 or 1900 megahertz transceiver and an antenna. This radio equipment provides coverage for an area that's usually two to ten miles in radius. Even smaller cell sites cover tunnels, subways and specific roadways. An area's size depends on, among other things, topography, population, and traffic.

When you turn on your phone the mobile switch determines what cell will carry the call and assigns a vacant radio channel within that cell to take the conversation. It selects the cell to serve you by measuring signal strength, matching your mobile to the cell that has picked up the strongest signal. Managing handoffs or handovers, that is, moving from cell to cell, is handled in a similar manner. The base station serving your call sends a hand-off request to the mobile switch after your signal drops below a handover threshold. The cell site makes several scans to confirm this and then switches your call to the next cell. You may drive fifty miles, use 8 different cells and never once realize that your call has been transferred.



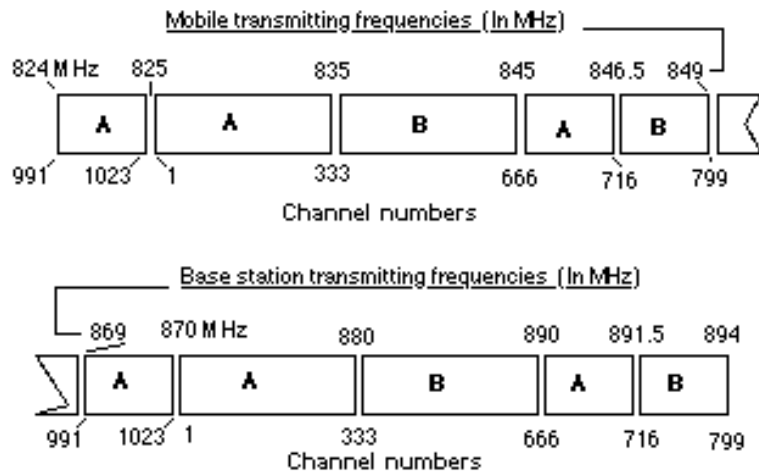
Upon turning on your phone the mobile switch gathers signal strength reports from the different cells and assigns your phone to the cell with the strongest reading. In this simplified example, 1 represents the strongest signal and 4 is the weakest. Although it is easy to say that the cell site nearest you gets your call, it may not, depending on topography and other factors.

At least, that is the goal. Let's look at some details of this amazing technology, starting with cellular's place in the radio spectrum and how it began.

The FCC allocates frequency space in the United States for commercial and amateur radio services. Some of these assignments may be coordinated with the International Telecommunications Union but many are not. Much debate and discussion over many years placed cellular frequencies in the 800 megahertz band. By comparison, PCS or Personal Communication Services technology, still cellular radio, operates in the 1900 MHz band. The FCC also issues the necessary operating licenses to the different cellular providers.

Although the Bell System had [trialed cellular in early 1978](#) in Chicago, and worldwide deployment of AMPS began shortly thereafter, American commercial cellular development began in earnest only after AT&T's breakup in 1984. The United States government decided to license two carriers in each geographical area. One license went automatically to the local telephone companies, in telecom parlance, the local exchange carriers or LECs. The other went to an individual, a company or a group of investors who met a long list of requirements and who properly petitioned the FCC. And, perhaps most importantly, who won the cellular lottery. Since there were so many qualified applicants, operating licenses were ultimately granted by the luck of a draw, not by a spectrum auction as they are today.

The local telephone companies were called the wireline carriers. The others were the non-wireline carriers. Each company in each area took half the spectrum available. What's called the "A Band" and the "B Band." The nonwireline carriers usually got the A Band and the wireline carriers got the B band. There's no real advantage to having either one. It's important to remember, though, that depending on the technology used, one carrier might provide more connections than a competitor does with the same amount of spectrum. [\[See A Band, B Band\]](#)



Mobiles transmit on certain frequencies, cellular base stations transmit on others. A and B refer to the carrier each frequency assignment has. A channel is made up of two frequencies, one to transmit on and one to receive.

[Learn more about cellular switches](#)

[Next page -->](#)

Notes:

[A Band, B Band] Actually, the strange arrangement of the expanded channel assignments put more stringent filtering requirements on the A band carrier, but it's on the level of annoying rather than crippling. Minor point. [\(back to text\)](#)

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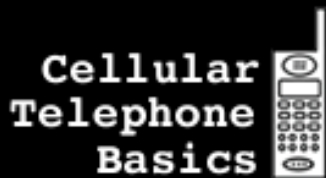
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(Page 3) Cellular telephone basics cont. . .

V. Cellular frequency and channel discussion

American cell phone frequencies start at 824.04 MHz and end at 893.7 MHz. [4] That's 69.66 megahertz worth of radio frequency spectrum. Quite a chunk. By comparison, the AM broadcast band takes up only 1.17 megahertz of space. That band, however, provides only 107 frequencies to broadcast on. Cellular may provide thousands of frequencies to carry conversations and data. This large number of frequencies and the large channel size required account for the large amount of spectrum used.

The original analog American system, AT&T's Advanced Mobile Phone Service or AMPS, now succeeded by its digital IS-136 service, uses 832 channels that are 30 kHz wide. Years ago Motorola and Hughes each tried making more spectrum efficient systems, cutting down on channel size or bandwidth, but these never caught on. Motorola's analog system, NAMPS, standing for Narrowband Advanced Mobile Service provided 2412 channels, using channels 10 kHz wide instead of 30kHz. [\[See NAMPS\]](#) While voice quality was poor and technical problems abounded, NAMPS died because digital and its inherent capacity gain came along, otherwise, as Mark puts it, "We'd have all gone to NAMPS eventually, poor voice quality or not."[\[NAMPS2\]](#)

I mentioned that a typical cell channel is 30 kilohertz wide compared to the ten kHz allowed an AM radio station. How is it possible, you might ask, that a one to three watt cellular phone call can take up a path that is three times wider than a 50,000 watt broadcast station? Well, power does not necessarily relate to bandwidth. A high powered signal might take up lots of room or a high powered signal might be narrowly focused. A wider channel helps with audio quality. An FM stereo station, for example, uses a 150 kHz channel to provide the best quality sound. A 30 kHz channel for cellular gives you great sound almost automatically, nearly on par with the normal telephone network.

I also said that the cellular band runs from 824.04 MHz to 893.97 MHz. In particular, cell phones or mobiles use the frequencies from 824.04 MHz to 848.97 and the base stations operate on 869.04 MHz to 893.97 MHz. These two

- ▶ [Bluetooth](#)
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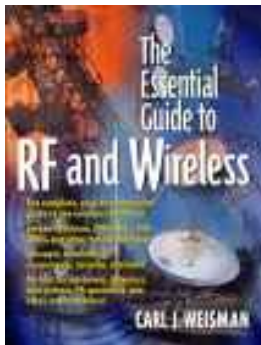
[Appendix: Early Bell System
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[Cellular and PCS: The Big
Picture, Harte, Prokup, and
Levine \(external link to
Amazon.com\)](#)

frequencies in turn make up a channel. 45 MHz separates each transmit and receive frequency within a cell or sector, a part of a cell. That separation keeps them from interfering with each other. Getting confusing? Let's look at the frequencies of a single cell for a single carrier. For this example, let's assume that this is one of 21 cells in an AMPS system:

Cell#1 of 21 in Band A (The nonwireline carrier)

Channel 1 (333) Tx 879.990 Rx 834.990

Channel 2 (312) Tx 879.360 Rx 834.360

Channel 3 (291) Tx 878.730 Rx 833.730

Channel 4 (270) Tx 878.100 Rx 833.100

Channel 5 (249) Tx 877.470 Rx 832.470

Channel 6 (228) Tx 876.840 Rx 831.840

Channel 7 (207) Tx 876.210 Rx 831.210

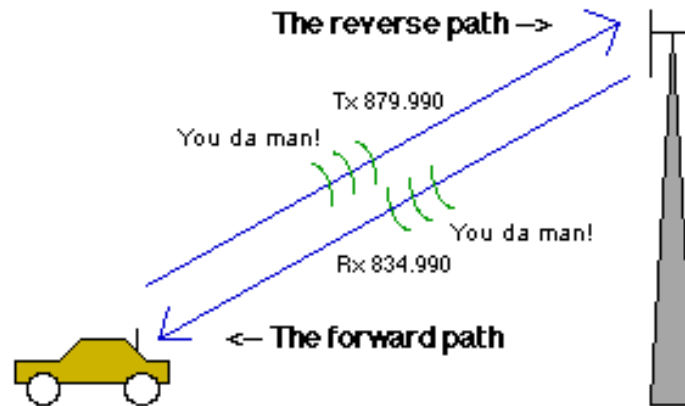
Channel 8 (186) Tx 875.580 Rx 830.580 etc., etc.,

The number of channels within a cell or within an individual sector of a cell varies greatly, depending on many factors. As Mark van der Hoek writes, "A sector may have as few as 4 or as many as 80 channels. Sometimes more! For a special event like the opening of a new race track, I've put 100 channels in a temporary site. That's called a Cell On Wheels, or COW. Literally a cell site in a truck."

Cellular network planners assign these frequency pairs or channels carefully and in advance. It is exacting work. Adding new channels later to increase capacity is even more difficult. [\[See Adding channels\]](#) Channel layout is confusing since the ordering is non-intuitive and because there are so many numbers involved. Speaking of numbers, check out the sidebar. Channels 800 to 832 are not labeled as such. Cell channels go up to 799 in AMPS and then stop. Believe it or not, the numbering begins again at 991 and then goes up to 1023. That gives us 832. Why the confusion and the odd numbering? The Bell System originally planned for 1000 channels but was given only 666 by the FCC. When cellular proved popular the FCC was again approached for more channels but granted only an extra 166. By this time the frequency spectrum and channel numbers that should have gone to cellular had been assigned to other radio services. So the numbering picks up at 991 instead of 800. Arggh!

You might wonder why frequencies are offset at all. It's so you can talk and listen at the same time, just like on a regular telephone. Cellular is not like CB radio. Citizen's band uses the same frequency to transmit and receive. What's called "push to talk" since you must depress a microphone key or switch each time you want to talk. Cellular, though, provides full duplex communication. It's more expensive and complicated to do it this way. That's since the mobile unit and the base station both need circuitry to transmit on one frequency while receiving on another. But it's the only way that permits a normal, back and

forth, talk when you want to, conversation. Take a look at the animated .gif below to visualize full duplex communication. See how two frequencies, a voice channel, lets you talk and listen at the same time?



Full duplex communication example. The two frequencies are paired and constitute a voice channel. Paths indicate direction of flow.

[Derived from Marshal Brain's How Stuff Works site \(external link\)](#)

[Miscellaneous cellular photos from Mark van der Hoek](#)

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Notes:

[Adding channels] "The channels for a particular cell are assigned by a Radio Frequency Engineer, and are fixed. The mobile switch assigns which of those channels to use for a given call, but has no ability to assign other channels. In a Motorola (and, I think, Ericsson) system, changing those assigned channels requires manual re-tuning of the hardware in the cell site. This takes several hours. Lucent equipment allows for remote re-tuning via commands input at the switch, but the assignment of those channels is still made by the RF engineer, taking into account re-use and interference issues. Re-tuning a site in a congested downtown area is not trivial! An engineer may work for weeks on a frequency plan just to add channels to one sector. It is not unusual to have to re-tune a half dozen sites just to add 3 channels to one." Mark van der Hoek. Personal correspondence. [\(back to text\)](#)

[NAMPS] Macario, Raymond. Cellular Radio: Principles and Design, McGraw Hill, Inc., New York 1997 90. A good but flawed book that's now in its second edition. Explains several cellular systems such as GSM, JTACS, etc. as well as AMPS and TDMA transmission. Details all the formats of all the digital messages. Index is poor and has many mistakes. [\(back to text\)](#)

[NAMPS2] "Only a few cities ever went with NAMPS, and it didn't replace AMPS, it was used in conjunction with AMPS. We looked at it for the Los Angeles market (where I spent 7 years with PacTel/AirTouch) but it just didn't measure up. The quality just wasn't good, and the capacity gains were not the 3 to 1 as claimed by Motorola. The reason is that you cannot re-use NAMPS channels as closely as AMPS channels. Their signal to noise ratio requirements are higher due to the reduced bandwidth. (We engineered to an 18dB C/I ratio

for AMPS, whereas we found that NAMPS required 22 dB.) [See [The Decibel](#) for more on carrier interference ratios, or [download this .pdf file from Paul Bedel](#), ed.] Also, market penetration of NAMPS capable phones was an issue. If only 30% of your customers can use it, does it really provide capacity gains? The Las Vegas B carrier loved NAMPS, though. At least, that's what Moto told us. . . though even under the best of conditions NAMPS doesn't satisfy the average customer, according to industry surveys. There's no free lunch, and you can't get 30 kHz sound from 10 kHz. But the point is moot - - NAMPS is dead." Mark van der Hoek. Personal correspondence. ([back to text](#))

[Adding channels] "The channels for a particular cell are assigned by a Radio Frequency Engineer, and are fixed. The mobile switch assigns which of those channels to use for a given call, but has no ability to assign other channels. In a Motorola (and, I think, Ericsson) system, changing those assigned channels requires manual re-tuning of the hardware in the cell site. This takes several hours. Lucent equipment allows for remote re-tuning via commands input at the switch, but the assignment of those channels is still made by the RF engineer, taking into account re-use and interference issues. Re-tuning a site in a congested downtown area is not trivial! An engineer may work for weeks on a frequency plan just to add channels to one sector. It is not unusual to have to re-tune a half dozen sites just to add 3 channels to one." Mark van der Hoek. Personal correspondence. ([back to text](#))

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(Page 4) Cellular Telephone Basics *continued* . . .

IV. Channel Names and Functions

Okay, so what do we have? The first point is that cell phones and base stations transmit or communicate with each other on dedicated paired frequencies called channels. Base stations use one frequency of that channel and mobiles use the other. Got it? The second point is that a certain amount of bandwidth called an offset separates these frequencies. Now let's look at what these frequencies do, as we discuss how channels work and how they are used to pass information back and forth.

Certain channels carry only cellular system data. We call these control channels. This control channel is usually the first channel in each cell. It's responsible for call setup, in fact, many radio engineers prefer calling it the setup channel since that's what it does. Voice channels, by comparison, are those paired frequencies which handle a call's traffic, be it voice or data, as well as signaling information about the call itself.

A cell or sector's first channel is always the control or setup channel for each cell. You have 21 control channels if you have 21 cells. A call gets going, in other words, on the control channel first and then drops out of the picture once the call gets assigned a voice channel. The voice channel then handles the conversation as well as further signaling between the mobile and the base station. Don't place too much importance, by-the-way, to the setup channel. Although first in each cell's lineup, most radio engineers place priority on the voice channels in a system. The control channel lurks in the background. [\[See Control channel\]](#) Now let's add some terms.

When discussing cell phone operation we call a base station's transmitting frequency the forward path. The cell phone's transmitting frequency, by comparison, is called the reverse path. Do not become confused. Both radio frequencies make up a channel as we've discussed before but we now treat them individually to discuss what direction information or traffic flows. Knowing what direction is important for later, when we discuss how calls are originated and how they are handled.

Once the MTSO or mobile telephone switch assigns a voice channel the two

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[Alan Bensky writes well on antennas and their transmission lines in this selection. Best for EE students or professionals. \(1.2 megs, 68 pages in .pdf.\)](#)

[\(Short-range Wireless Communication: Fundamentals of RF System Design and Application external link to Amazon.com\)](#)



[Excellent .pdf file from Paul Bedell on mobile radio basics \(280K, 14 pages in .pdf\)](#)

frequencies making up the voice channel handle signaling during the actual conversation. You might note then that a call two channels: voice and data. Got it? Knowing this makes many things easier. A mobile's electronic serial number is only transmitted on the reverse control channel. A person tracking ESNs need only monitor one of 21 frequencies. They don't have to look through the entire band.

So, we have two channels for every call with four frequencies involved. Clear? And a forward and reverse path for each frequency. Let's name them here. Again, a frequency is the medium upon which information travels. A path is the direction the information flows. Here you go:

--> Forward control path: Base station to mobile

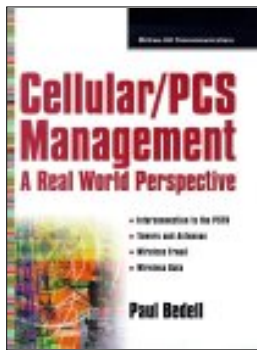
<-- Reverse control path: Mobile to base station

--> Forward voice path: Base station to mobile

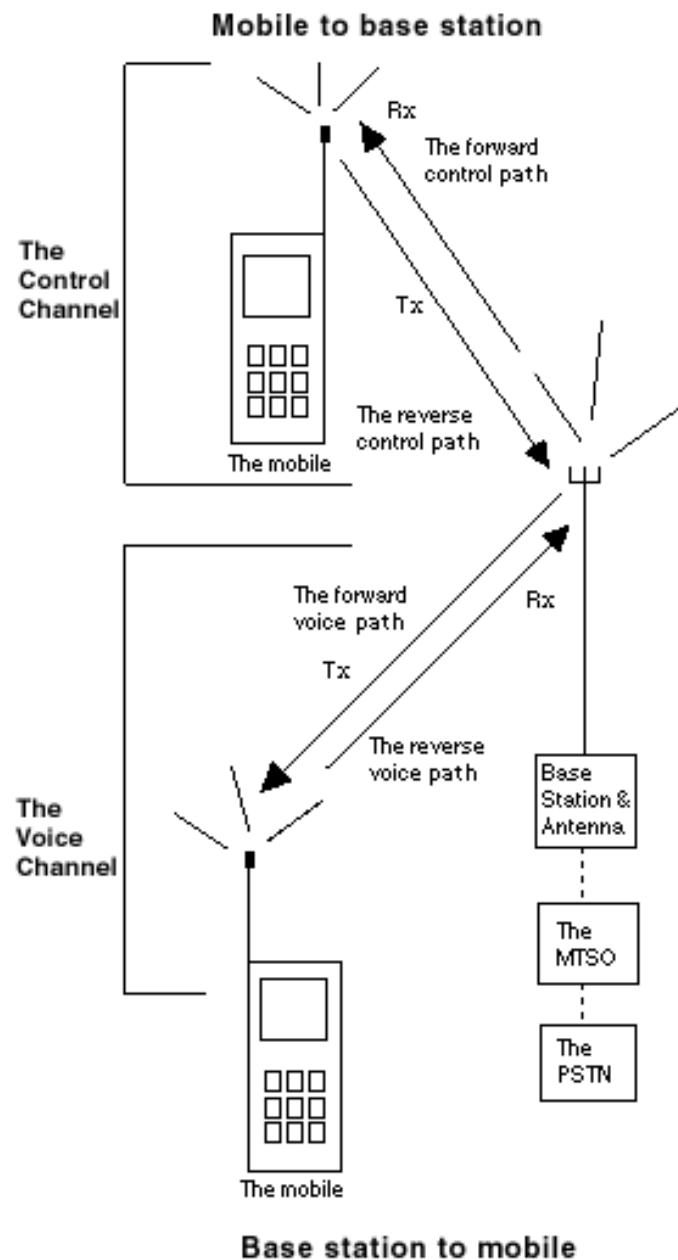
<-- Reverse voice path: Mobile to base station

One last point at the risk of losing everybody. You'll hear about dedicated control channels, paging channels, and access channels. These are not different channels but different uses of the control channel. Let's clear up this terminology confusion by looking at call processing. We'll look at the way AMPS sets up calls. Both analog and digital cellular (IS-136) use this method, CDMA cellular (IS-95) and GSM being the exceptions. We'll also touch on a number of new terms along the way.

Still confused about the terms channels, frequency, and path?, and how they relate to each other? I understand. Click here for more: [See channels, frequencies, and paths.](#)



[The file above is from his book Cellular/PCS Management. More information and reviews are here \(external link to Amazon.com\)](#)



The control channel and the voice channel, paired frequencies upon which information flows. Paths indicate direction of flow.

Notes:

[Control channel] "Is the control channel important? Actually, I can't think of a case where it would not be. But we don't think of it that way in the business. We have a set-up channel and we have voice channels. They are so different (both in function and in how they are managed) that we never think of the set-up channel as the first of the cell's channels -- it's in a class by itself. If you ask an engineer in an AMPS system what channels he has on a cell, he'll automatically give you the voice channels. Set up channel is a separate question. Just a matter of mindset. You might add channels, re-tune partially or completely, and never give a thought to the set-up channel. If asked how many channels are on a given cell, you'd never think to include the set-up channel in

the count." Mark van der Hoek. Personal correspondence.[\(back to text\)](#)

Channels, frequencies, and paths: Cellular radio employs an arcane and difficult terminology; many terms apply to all of wireless, many do not. When discussing cellular radio, which comprises analog cellular, digital cellular, and PCS, frequency is a single unit whereas channel means a pair of frequencies, one to transmit on and one to receive. (See the diagram above.) The terms are not interchangeable although many writers use them that way. Frequencies are measured or numbered by their order in the radio spectrum, in Hertz, but channels are numbered by their place in a particular radio plan. Thus, in cell #1 of 21 in a cellular carrier's system, the frequencies may be 879.990 Hz for transmitting and 834.990 Hz for receiving. These then make up Channel 1 in that cell, number 333 overall. Again, in cellular, a channel is a pair of frequencies. The frequencies are described in Hz, the channels by numbers in a plan. Now, what about path?

Path, channel, and frequency, depending on how they are used in wireless working, all constitute a communication link. In cellular, however, path does not, or should not, describe a transmission link, but rather the direction in which information flows. The forward path denotes information flowing from the base station to the mobile. The reverse path describes information flowing from the mobile to the base station. With frequency and channel we talk about the physical medium which carries a signal, with path we discuss the direction a signal is going on that medium. Is this clear?

[\(back to text\)](#)

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(Page 5) Cellular Telephone Basics *continued* . . .

VII AMPS Call Processing

[AMPS call processing diagram -- Keep track of the steps!](#)

Let's look at how cellular uses data channels and voice channels. Keep in mind the big picture while we discuss this. A call gets set up on a control channel and another channel actually carries the conversation. The whole process begins with registration. It's what happens when you first turn on a phone but before you punch in a number and hit the send button. It only takes a few hundred milliseconds. Registration lets the local system know that a phone is active, in a particular area, and that the mobile can now take incoming calls. What cell folks call pages. If the mobile is roaming outside its home area its home system gets notified. Registration begins when you turn on your phone.

Registration -- Hello, World!

A mobile phone runs a self diagnostic when it's powered up. Once completed it acts like a scanning radio. Searching through its list of forward control channels, it picks one with the strongest signal, the nearest cell or sector usually providing that. Just to be sure, the mobile re-scans and camps on the strongest one. Not making a call but still on? The mobile re-scans every seven seconds or when signal strength drops before a pre-determined level. After selecting a channel the phone then identifies itself on the reverse control path. The mobile sends its phone number, its electronic serial number, and its home system ID. Among other things. The cell site relays this information to the mobile telecommunications switching office. The MTSO, in turn, communicates with different databases, switching centers and software programs.

The local system registers the phone if everything checks out. Mr. Mobile can now take incoming calls since the system is aware that it is in use. The mobile then monitors paging channels while it idles. It starts this scanning with the initial paging channel or IPCH. That's usually channel 333 for the non-wireline carrier and 334 for the wireline carrier. The mobile is programmed with this information and 21 channels to scan when your carrier programs your phone's directory number, the MIN, or mobile identification number. Again, the paging

- ▶ [Bluetooth](#)
- ▶ [Cell phones on airplanes](#)
- ▶ [Cellular reception problems](#)

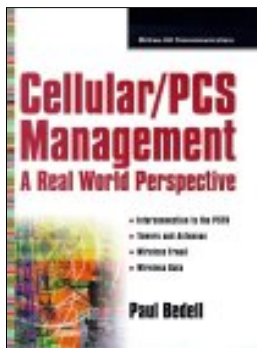
[Appendix: Early Bell System overview of IMTS and cellular](#)

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[More information on this title here \(external link to Amazon.com\)](#)



[More on the MTSO from Paul Bedell \(223K, 6 pages in .pdf\)](#)



[Alan J. Rogers' excellent introduction to electromagnetic waves, frequencies, and radio transmission.](#) Really well done. (19 pages, 164K in .pdf)

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channel or path is another word for the forward control channel. It carries data and is transmitted by the cell site. A mobile first responds to a page on the reverse control channel of the cell it is in. The MTSO then assigns yet another channel for the conversation. But I am getting ahead of myself. Let's finish registration.

Registration is an ongoing process. Moving from one service area to another causes registration to begin again. Just waiting ten or fifteen minutes does the same thing. It's an automatic activity of the system. It updates the status of the waiting phone to let the system know what's going on. The cell site can initiate registration on its own by sending a signal to the mobile. That forces the unit to transmit and identify itself. Registration also takes place just before you call. Again, the whole process takes only a few hundred milliseconds.

AMPS, the older, analog voice system, not the digital IS-136, uses frequency shift keying to send data. Just like a modem. Data's sent in binary. 0's and 1's. 0's go on one frequency and 1's go on another. They alternate back and forth in rapid succession. Don't be confused by the mention of additional frequencies. Frequency shift keying uses the existing carrier wave. The data rides 8kHz above and below, say, 879.990 MHz. Read up on the earliest kinds of modems and FSK and you'll understand the way AMPS sends digital information.

Data gets sent at 10 kbps or 10,000 bits per second from the cell site. That's fairly slow but fast enough to do the job. Since cellular uses radio waves to communicate signals are subject to the vagaries of the radio band. Things such as billboards, trucks, and underpasses, what Lee calls local scatters, can deflect a cellular call. So the system repeats each part of each digital message five times. That slows things considerably. Add in the time for encoding and decoding the digital stream and the actual transfer rate can fall to as low as 1200 bps.

Remember, too, that an analog wave carries this digital information, just like most modems. It's not completely accurate, therefore, to call AMPS an analog system. AMPS is actually a hybrid system, combining both digital and analog signals. IS-136, what AT&T now uses for its cellular network, and IS-95, what Sprint uses for its, are by contrast completely digital systems. [next page-->](#)

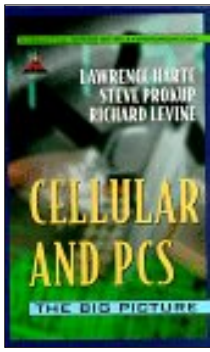
Get a refresher below in the notes on digital: bits, frames, and slots

Notes:

Bits, frames, slots, and channels: How They Relate To Cellular

Here's a little bit on digital; perhaps enough to understand the accompanying Cellular Telephone Basics article. This writing is from my [digital wireless series](#):

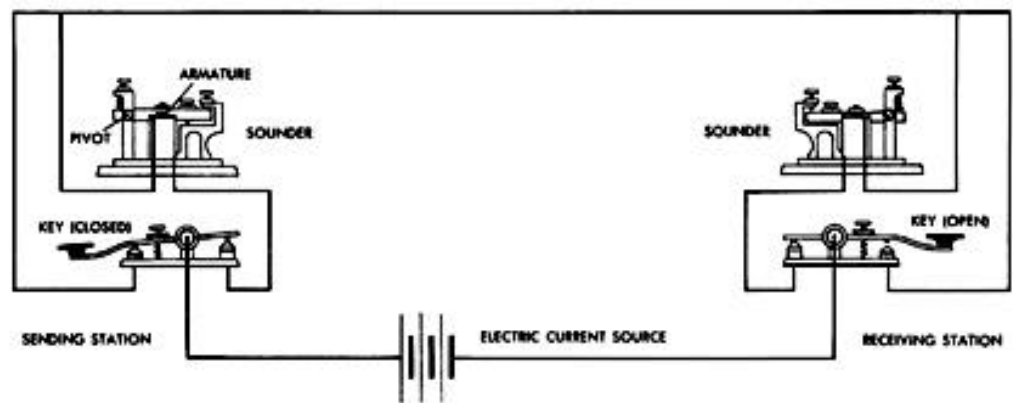
Frames, slots, and channels organize digital information. They're key to understanding cellular and PCS systems. And discussing them gets really complicated. So let's back up, review, and then look at the earliest method for organizing digital information: Morse code.



[Cellular and PCS: The Big Picture, Harte, Prokup, and Levine \(external link to Amazon.com\)](#)

You may have seen in the rough draft of digital principles how information gets converted from sound waves to binary numbers or bits. It's done by pulse code modulation or some other scheme. This binary information or code is then sent by electricity or light wave, with electricity or light turned on and off to represent the code. 10101111, for example, is the binary number for 175. Turning on and off the signal source in the above sequence represents the code.

Early digital wireless used a similar method with the telegraph. Instead of a binary code, though, they used Morse code. How did they do that? Landline telegraphs used a key to make or break an electrical circuit, a battery to produce power, a single line joining one telegraph station to another and an electromagnetic receiver or sounder that upon being turned on and off, produced a clicking noise.



A telegraph key tap broke the circuit momentarily, transmitting a short pulse to a distant sounder, interpreted by an operator as a dot. A more lengthy break produced a dash.. To illustrate and compare, sending the number 175 in American Morse Code requires 11 pulses, three more than in binary code. Here's the drill: dot, dash, dash, dot; dash, dash, dot, dot; dash, dash, dash. Now that's complicated! But how do we get to wireless?

Let's say you build a telegraph or buy one. You power it with, say, two six volt lantern batteries. Now run a line away from the unit -- any length of insulated wire will do. Strip a foot or two of insulation off. Put the exposed wire into the air. Tap the key. Congratulations. You've just sent a digital signal. (An inch or two.) The line acts as an antenna, radiating electrical energy. And instead of using a wire to connect to a distant receiver, you've used electromagnetic waves, silently passing energy and the information it carries across the atmosphere.

Transmitting binary or digital information today is, of course, much more complicated and faster than sending Morse code. And you need a radio transmitter, not just a piece of wire, to get your signal up into the very high radio spectrum, not the low baseband frequency a signal sets up naturally when placed on a wire. But transmission still involves sending code, represented by

turning energy on and off, and radio waves to send it. And as American Morse code was a logical, cohesive plan to send signals, much more complicated and useful arrangements have been devised.

We know that 1s and 0s make up binary messages. An almost unending stream of them, millions of them really, parade back and forth between mobiles and base stations. Keeping that information flowing without interruption or error means keeping that data organized. Engineers build elaborate data structures to do that, digital formats to house those 1s and 0s. As I've said before, these digital formats are key to understanding cellular radio, including PCS systems. And understanding digital formats means understanding bits, frames, slots, and channels. Bits get put into frames. Frames hold slots which in turn hold channels. All these elements act together. To be disgustingly repetitive and obvious, here's the list again:

Frames

Slots

Channels

Bits

We have a railroad made not of steel but of bits. The data stream is managed and built out of bits. Frames and slots and channels are all made out of bits, just assembled in different ways. Frames are like railroad cars, they carry and hold the slots which contains the channels which carry and manage the bits. Huh? Read further, and bear with the railroad analogy.

A frame is an all inclusive data package. A sequence of bits makes up a frame. Bit stands for binary digit, 0s and 1s that represent electrical impulses. (Go back to the [previous discussion](#) if this seems unclear.) A frame can be long or short, depending on the complexity of its task and the amount of information it carries. In cellular working the frame length is precisely set, in the case of digital cellular, where we have time division multiplexing, every frame is 40 milliseconds long. That's like railroad boxcars of all the same length. Many people confuse frames with packets because they do similar things and have a similar structure. Without defining packets, let just say that frames can carry packets, but packets cannot carry frames. Got it? For now?

A frame carries conversation or data in slots as well as information about the frame itself. More specifically, a frame contains three things. The first is control information, such as a frame's length, its destination, and its origin. The second is the information the frame carries, namely time slots. Think of those slots as freight. These slots, in turn, carry a sliced up part of a multiplexed conversation. The third part of a frame is an error checking routine, known as "error detection and correction bits." These help keep the data stream's integrity, making sure that all the frames or digital boxcars keep in order.

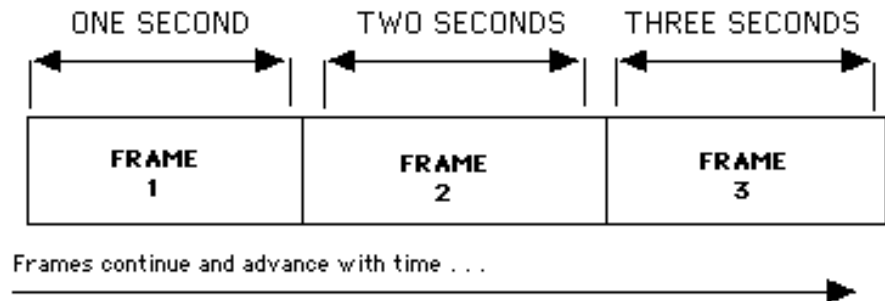
The slots themselves hold individual call information within the frame, that is, the multiplexed pieces of each conversation as well as signaling and control data. Slots hold the bits that make up the call. frequency for a predetermined amount of time in an assigned time slot. Certain bits within the slots perform

error correction, making sure sure that what you send is what is received. Same way with data sent in frames on telephone land lines. When you request \$20.00 from your automatic teller machine, the built in error checking insures that \$2000.00 is not sent instead. The TDMA based IS-136 uses two slots out of a possible six. Now let's refer to specific time slots. Slots so designated are called channels, ones that do certain jobs.

Channels handle the call processing, the actual mechanics of a call. Don't confuse these data channels with radio channels. A pair of radio frequencies makes up a channel in digital IS-136, and AMPS. One frequency to transmit and one to receive. In digital working, however, we call a channel a dedicated time slot within a data or bit stream. A channel sends particular messages. Things like pages, for when a mobile is called, or origination requests, when a mobile is first turned on and asks for service.

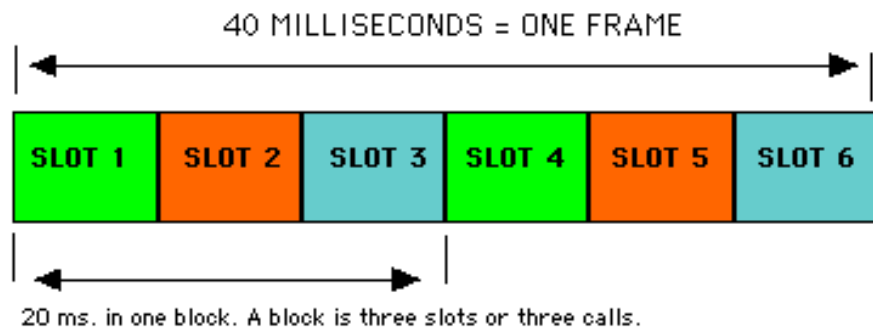
1. Frames

Generic frame with time slots

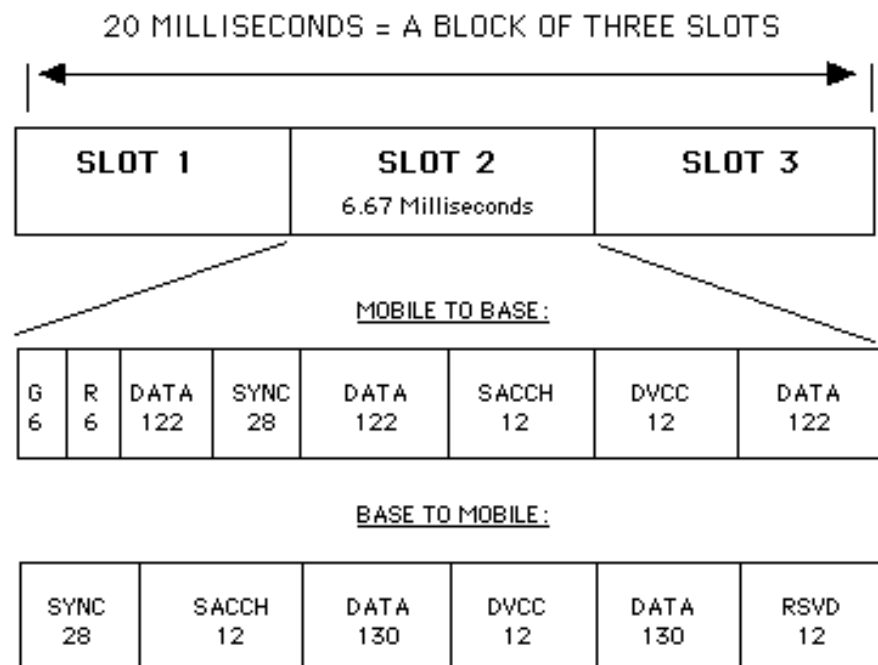


Behold the frame!, a self contained package of data. Remember, a sequence of bits makes up a frame. Frames organize data streams for efficiency, for ease of multiplexing, and to make sure bits don't get lost. In the diagram above we look at basis of time division multiplexing. As we've discussed, TDMA or time division multiple access, places several calls on a single frequency. It does so by separating the conversations in time. Its purpose is to expand a system's carrying capacity while still using the same numbers of frequencies. In the exaggerated example above, imagine that a single part of three digitized and compressed conversations are put into each frame as time goes on.

2. Slots

IS-54B, IS-136 frame with time slots

Welcome to slots. But not the kind you find in Las Vegas. Slots hold individual call information within the frame, remember? In this case we have one frame of information containing six slots. Two slots make up one voice circuit in TDMA. Like slots 1 and 4, 2 and 5, or 3 and 6. The data rate is 48.6 Kbits/s, less than a 56K modem, with each slot transmitting 324 bits in 6.67 ms. How is this rate determined? By the number of samples taken, when speech is first converted to digital. Remember Pulse Amplitude Modulation? If not, [go back](#). Let's look at what's contained in just one slot of half a frame in digital cellular.

IS-54B, now IS-136 time slot structure and the Channels Within

after Macario

Okay, here are the actual bits, arranged in their containers the slots. All numbers above refer to the amount of bits. Note that data fields and channels change depending on the direction or the path that occurs at the time, that is, a link to the mobile from the base station, or a call from the mobile to the base station. Here are the abbreviations:

G: Guard time. Keeps one time slot or data burst separate from the others. R: Ramp time. Lets the transmitter go from a quiet state to full power. DATA: The data bits of the actual conversation. DVCC: Digital verification color code. Data field that keeps the mobile on frequency. RSVD: Reserved. SACCH: Slow associated control channel. Where system control information goes. SYNC: Time synchronization signal. Full explanations on the [next page](#) in the PCS series.

Still confused? Read this page over. And don't think you have to get it all straight right now. It will be less confusing as you read more, of my writing as well as others. Look up all of these terms in a good telecom dictionary and see what those writers state. Taken together, your reading will help make understanding cellular easier. [E-mail](#) me if you still have problems with this text. Perhaps I can re-write parts to make them less confusing.

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(Page 6) Cellular Telephone Basics *continued* . . .

Pages: Getting a Call -- The Process

Okay, your phone's now registered with your local system. Let's say you get a call. It's the F.B.I., asking you to turn yourself in. You laugh and hang up. As you speed to Mexico you marvel at the technology involved. What happened? Your phone recognized its mobile number on the paging channel. Remember, that's always the forward control channel or path except in a CDMA system. The mobile responded by sending its identifying information again to the MTSO, along with a message confirming that it received the page. The system responded by sending a voice channel assignment to the cell you were in. The cell site's transceiver got this information and began setting things up. It first informed the mobile about the new channel, say, channel 10 in cell number 8. It then generated a supervisory audio tone or SAT on the forward voice frequency. What's that?

The SAT, Dial Tone, and Blank and Burst

[Remember that we are discussing the original or default call set up routine in AMPS. IS-136, and IS-95 use a different, all digital method, although they switch back to this basic version we are now describing in non-digital territory. GSM also uses a different, incompatible technique to set up calls.]

An SAT is a high pitched, inaudible tone that helps the system distinguish between callers on the same channel but in different cells. The mobile tunes to its assigned channel and it looks for the right supervisory audio tone. Upon hearing it, the mobile throws the tone back to the cell site on its reverse voice channel. What engineers call transpond, the automatic relaying of a signal. We now have a loop going between the cell site and the phone. No SAT or the wrong SAT means no good.

AMPS generates the supervisory audio tone at three different non-radio frequencies. SAT 0 is at 5970 Hz, SAT 1 is at 6000 Hz, and SAT 2 is at 6030 Hz. Using different frequencies makes sure that the mobile is using the right channel assignment. It's not enough to get a tone on the right forward and reverse path -- the mobile must connect to the right channel and the right SAT.

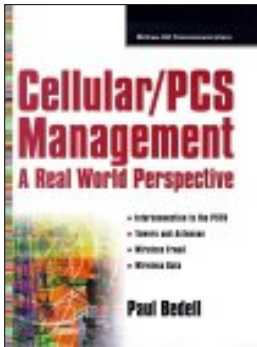
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[Appendix: Early Bell System overview of IMTS and cellular](#)

[Appendix: Call processing diagram](#)

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Two steps. This tone is transmitted continuously during a call. You don't hear it since it's filtered during transmission. The mobile, in fact, drops a call after five seconds if it loses or has the wrong the SAT. [\[Much more on the SAT and co-channel interference\]](#) The all digital GSM and PCS systems, by comparison, drops the call like AMPS but then automatically tries to re-connect on another channel that may not be suffering the same interference.

 [Excellent .pdf file from Paul Bedell on co-channel interference, carrier to interference ratio, adjacent channel interference and so on, along with good background information everyone can use to understand cellular radio. \(280K, 14 pages in .pdf\)](#)

[The file above is from his book Cellular/PCS Management. More information and reviews are here \(external link to Amazon.com\)](#)

The cell site unmutes the forward voice channel if the SAT gets returned, causing the mobile to take the mute off the reverse voice channel. Your phone then produces a ring for you to hear. This is unlike a landline telephone in which ringing gets produced at a central office or switch. To digress briefly, dial tone is not present on AMPS phones, although E.F. Johnson phones produced land line type dial tone within the unit. [\[See dial tone.\]](#)

Can't keep track of these steps? Check out the [call processing diagram](#)

Enough about the SAT. I mentioned another tone that's generated by the mobile phone itself. It's called the signaling tone or ST. Don't confuse it with the SAT. You need the supervisory audio tone first. The ST comes in after that; it's necessary to complete the call. The mobile produces the ST, compared to the SAT which the cell site originates. It's a 10 kHz audio tone. The mobile starts transmitting this signal back to the cell on the forward voice path once it gets an alerting message. Your phone stops transmitting it once you pick up the handset or otherwise go off hook to answer the ring. Cell folks might call this confirmation of alert. The system knows that you've picked up the phone when the ST stops.

Thanks to Dwayne Rosenburgh N3BJM for corrections on the SAT and ST

AMPS uses signaling tones of different lengths to indicate three other things. *Cleardown* or termination means hanging up, going on hook, or terminating a call. The phone sends a signaling tone of 1.8 seconds when that happens. 400 ms. of ST means a hookflash. Hookflash requests additional services during a conversation in some areas. Confirmation of handover request is another arcane cell term. The ST gets sent for 50 ms. before your call is handed from one cell to another. Along with the SAT. That assures a smooth handoff from one cell to another. The MTSO assigns a new channel, checks for the right SAT and listens for a signaling tone when a handover occurs. Complicated but effective and all happening in less than a second. [\[See SIT\]](#)

Okay, we're now on the line with someone. Maybe you! How does the mobile communicate with the base station, now that a conversation is in progress? Yes, there is a control frequency but the mobile can only transmit on one frequency at a time. So what happens? The secret is a straightforward process known as

blank and burst. As Mark van der Hoek puts it,

"Once a call is up on a voice channel, all signaling is done on the voice channel via a scheme known as "Blank and Burst". When the site needs to send an order to the mobile, such as hand off, power up, or power down, it mutes the SAT on the voice channel. This is filtered at the mobile so that the customer never hears it. When the SAT is muted, the phone mutes the audio path, thus the "blank", and the site sends a "burst" of data. The process takes a fraction of a second and is scarcely noticeable to the customer. Again, it's more noticeable on a Motorola system than on Ericsson or Lucent. You can sometimes hear the 'bzzt' of the data burst."

Blank and burst is similar to the way many telco payphones signal. Let's say you're making a long distance call. The operator or the automated coin toll service computer asks you for \$1.35 for the first three minutes. And maybe another dollar during the conversation. The payphone will mute or blank out the voice channel when you deposit the coins. That's so it can burst the tones of the different denominations to the operator or ACTS. These days you won't often hear those tones. And all done through blank and burst. Now let's get back to cellular.

D. Origination -- Making a call

Making a mobile call uses many steps that help receive a call. The same basic process. Punch out the number that you want to call. Press the send button. Your mobile transmits that telephone number, along with a request for service signal, and all the information used to register a call to the cell site. The mobile transmits this information on the strongest reverse control channel. The MTSO checks out this info and assigns a voice channel. It communicates that assignment to the mobile on the forward control channel. The cell site opens a voice channel and transmits a SAT on it. The mobile detects the SAT and locks on, transmitting it back to the cell site. The MTSO detects this confirmation and sends the mobile a message in return. This could be several things. It might be a busy signal, ringback or whatever tone was delivered to the switch. Making a call, however, involves far more problems and resources than an incoming call does.

Making a call and getting a call from your cellular phone should be equally easy. It isn't, but not for technical reasons, that is setting up and carrying a call. Rather, originating a call from a mobile presents fraud issues for the user and the carrier. Especially when you are out of your local area. Incoming calls don't present a risk to the carrier. Someone on the other end is paying for them. The carrier, however, is responsible for the cost of fraudulent calls originating in its system. Most systems shut down roaming or do an operator intercept rather than allow a questionable call. I've had close friends asked for their credit card numbers by operators to place a call. [[See cloning comments](#)]

Can you imagine giving a credit card number or a calling card number over the air? You're now making calls at a payphone, just like the good old days. Cellular One has shut down roaming "privileges" altogether in New York City,

Washington and Miami at different times. But you can go through their operator and pay three times the cost of a normal call if you like. So what's going on? Why the problem with some outgoing calls? We first have to look at some more terms and procedures. We need to see what happens with call processing at the switch and network level. This is the exciting world of precall validation.

[Please see the next page -->](#)

Notes

[Dial tone] During the start of your call a "No Service" lamp or display instead tells you if coverage isn't available. If coverage is available you punch in your numbers and get a response back from the system. Imagine dialing your landline phone without taking the receiver off the hook. If you could dial like that, where would be the for dial tone? ([back to text](#))

[Much more on the SAT and co-channel interference] The supervisory audio tone distinguishes between co-channel interferences, an intimidatingly named but important to know problem in cellular radio. Co-channel interferences are cellular customers using the same channel set in different cells who unknowingly interfere with each other. We know all about frequency reuse and that radio engineers carefully assign channels in each cell to minimize interference. But what happens when they do? Let's see how AMPS uses the SAT in practice and how it handles the interference problem.

Mark van der Hoek describes two people, a businessman using his cell phone in the city, and a hiker on top of a mountain overlooking the city. The businessman's call is going well. But now the hiker decides to use his phone to tell his friends he has climbed the summit. (Or as we American climbers say, "bagged the peak.")

From the climber's position he can see all of the city and consequently the entire area under cellular coverage. Since radio waves travel in nearly a straight line at high frequencies, it's possible his call could be taken by nearly any cell. Like the one the businessman is now using. This is not what radio engineers plan on, since the nearest cell site usually handles a call, in fact, Mark points out they don't want people using cell phones on an airplane! "Knock it off, turkey! Can't you see you're confusing the poor cell sites?"

If the hiker's mobile is told by the cell site first setting up his call to go channel 656, SAT 0, but his radio tunes now to a different cell with channel 656, SAT 1, instead, a fade timer in the mobile shuts down its transmitter after five seconds. In that way an existing call in the cell is not disrupted.

If the mobile gets the right channel and SAT but in a different cell than intended, FM capture occurs, where the stronger call on the frequency will displace, at least temporarily, the weaker call. Both callers now hear each other's conversation. A multiple SAT condition is the same as no SAT, so the fade timer starts on both calls. If the correct SAT does not resume before the fade timer expires, both calls are terminated.

Mark puts it simply, "Remember, the only thing a mobile can do with SAT is

detect it and transpond it. Either it gets what it was told to expect, and transponds it, or it doesn't get what it was told to expect, in which case it starts the fade timer. If the fade timer expires, the mobile's transmitter is shut down and the call is over." ([back to text](#))

[SIT] "A large supplier and a carrier I worked for went round and round on this. If their system did not detect hand-off confirmation, it tore down the call. Even if it got to the next site successfully. Their reasoning was that, if the mobile was in such a poor radio frequency environment that 50 ms of ST could not be detected, the call is in bad shape and should be torn down. We disagreed. We said, "Let the customer decide. If it's a lousy call, they'll hang up. If it's a good call, we want it to stay up!" Just because a mobile on channel 423 is in trouble doesn't mean that it will be when it hands off to channel 742 in another cell! In fact, a hand-off may happen just in time to save a call that is going south. Why?"

"Well, just because there is interference on channel 423 doesn't mean that there is on 742! Or what if the hand-off dragged? That is, for whatever reason the call did not hand off at approximately half way between the cells. (Lot's of reasons that could happen.) So the path to the serving site is stretched thiiiiin, almost to the point of dropping the call. But the hand-off, almost by definition in this case, will be to a site that is very close. That ought to be a good thing, you'd think. Well, the system supplier predicted Gloom, Doom, and Massive Dropped Calls if we changed it. We insisted, and things worked much better. Hand-off failures and dropped calls did not increase, and perceived service was much better. For this and a number of other reasons I have long suspected that their system did not do a good job of detecting ST . . ." ([back to text](#))

[Clone comments] "You could make more clear that this is due to validation and fraud issues, not to the mechanics of setting up the call, since this is pretty much the same for originations and terminations."

"By the way, at AirTouch we took a big bite out of fraudulent calls when we stopped automatically giving every customer international dialing capability. We gave it to any legitimate customer who asked for it, but the default was no international dialing. So the cloners would rarely get a MIN/ESN combo that would allow them to make calls to Colombia to make those 'arrangements'. Yes, the drug traffic was a huge part of the cloning problem. We had some folks who worked a lot with law enforcement, particularly the DEA. Another large part of it was the creeps who would sell calls to South America on the street corners of L.A. Illegal immigrants would line up to make calls home on this cloned phone."

"Actually, even though it's an inconvenience, being cloned can be fun if you are an engineer working for the carrier. You can do all kinds of fun things with the cloner. Like seeing where they are making their calls and informing the police. Like hotlining the phone so that ALL calls go straight to customer service. It would have been fun to hotline them to INS, but INS wouldn't have liked that."<grin> ([back to text](#))

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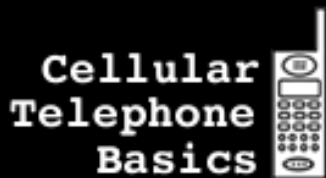
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Precall Validation -- Process and Terms

We know that pressing send or turning on the phone conveys information about the phone to the cell site and then to the MTSO. A call gets checked with all this information. There are many parts to each digital message. A five digit code called the home system identification number (SID or sometimes SIDH) identifies the cellular carrier your phone is registered with. For example, Cellular One's code in Sacramento, California, is 00129. Go to Stockton forty miles south and Cellular One uses 00224. A system can easily identify roamers with this information. The "Roaming" lamp flashes or the LED pulses if you are out of your local area. Or the "No Service" lamp comes on if the mobile can't pick up a decent signal. This number is keypad programmable, of course, since people change carriers and move to different areas. You can find yours by calling up a local cellular dealer. Or by putting your phone in the programming mode. [[See Programming](#)].

This number doesn't go off in a numerical form, of course, but as a binary string of zero's and ones. These digital signals are repeated several times to make sure they get received. The mobile identification number or MIN is your telephone's number. MINs are keypad programmable. You or a dealer can assign it any number desired. That makes it different than its electronic serial number which we'll discuss next. A MIN is ten digits long. A MIN is not your directory number since it is not long enough to include a country code. It's also limited when it comes to future uses since it isn't long enough to carry an extension number. [[See MIN](#)]

The electronic serial number or ESN is a unique number assigned to each phone. One per phone! Every cell phone starts out with just one ESN. This number gets electronically burned into the phone's ROM, or read only memory chip. A phone's MIN may change but the serial number remains the same. The ESN is a long binary number. Its 32 bit size provides billions of possible serial numbers. The ESN gets transmitted whenever the phone is turned on, handed over to another cell or at regular intervals decided by the system. Every ten to fifteen minutes is typical. Capturing an ESN lies at the heart of cloning. You'll often hear about stolen codes. "Someone stole Major Giuliani's and Commissioner Bratton's codes." The ESN is what is actually being intercepted. A code is something that stands for something else. In this case, the ESN. A

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[Appendix: Early Bell System
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hexadecimal number represents the ESN for programming and test purposes. Such a number might look like this: 82 57 2C 01.

The station class mark or SCM tells the cell site and the switch what power level the mobile operates at. The cell site can turn down the power in your phone, lowering it to a level that will do the job while not interfering with the rest of the system. In years past the station class mark also told the switch not to assign older phones to a so called expanded channel, since those phones were not built with the new frequencies the FCC allowed.

The switch process this information along with other data. It first checks for a valid ESN/MIN combination. You don't get access unless your phone number matches up with a correct, valid serial number and MIN. You have to have both unless, perhaps, if you call 911. The local carrier checks its own database first. Each carrier maintains its own records but the database may be almost anywhere. These local databases are updated, supposedly, around the clock by two much larger data bases maintained by Electronic Data Systems and GTE. EDS maintains records for most of the former Bell companies and their new cellular spin offs. GTE maintains records for GTE cellular companies as well as for other companies. Your call will not proceed returned unless everything checks out. These database companies try to supply a current list of bad ESNs as well as information to the network on the tens of thousands cellular users coming on line every day.

A local caller will probably get access if validation is successful. Roamers may not have the same luck if they're in another state or fairly distant from their home system. Even seven miles from San Francisco, depending on the area you are in. (I know this personally.) A roamer's record must be checked from afar. Many carriers still can't agree on the way to exchange their information or how to pay for it. A lot comes down to cost. A distant system may still be dependent on older switches or slower databases that can't provide a quick response. The so called North American Cellular Network attempts to link each participating carrier together with the same intelligent network/system 7 facilities.

Still, that leaves many rural areas out of the loop. A call may be dropped or intercepted rather than allowed access. In addition, the various carriers are always arguing over fees to query each others databases. Fraud is enough of a problem in some areas that many systems will not take a chance in passing a call through. It's really a numbers game. How much is the system actually losing, compared to how much prevention would cost? Preventive measures may cost millions of dollars to put in place at each MTSO. Still, as the years go along, cooperation among carriers is getting better and the number of easily cloned analog phones in use are declining. Roaming is now easier than a few years ago.

[AMPS carries on. As a backup for digital cellular, including some dual mode PCS phones, and as a primary system in some rural areas. See "Continues" below:](#)

VIII. AMPS and Digital Systems compared

The most commonly used digital cellular system in America is IS-136, colloquially known as D-AMPS or digital AMPS. (Concentrate on the industry name, not the marketing terms like D-AMPS.) It was formerly known as IS-54,

and is an evolutionary step up from that technology. This system is all digital, unlike the analog AMPS. IS-136 uses a multiplexing technique called TDMA or time division multiple access. The TDMA based IS-136 uses puts three calls into the same 30kHz channel space that AMPS uses to carry one call. It does this by digitally slicing and dicing parts of each conversation into a single data stream, like filling up one boxcar after another with freight. We'll see how that works in a bit.

TDMA is a transmission technique or access technology, while IS-136 or GSM are operating systems. In the same way AMPS is also an operating system, using a different access technology, FDMA, or frequency division multiple access. See the difference? Let's clear this up.

To access means to use, make available, or take control. In a communication system like the analog based Advanced Mobile Phone Service, we access that system by using frequency division multiple access or FDMA. Frequency division means calls are placed or divided by frequency, that is, one call goes on one frequency, say, 100 MHz, and another call goes on another, say, 200 MHz. Multiple access means the cell site can handle many calls at once. You can also put digital signals on many frequencies, of course, and that would still be FDMA. But AMPS traffic is analog.

(Access technology, although a current wireless phrase, is, to me, an open and formless term. Transmission, the process of transmitting, of conveying intelligence from one point to another, is a long settled, traditional way to express how signals are sent along. I'll use the terms here interchangeably.)

Time division multiple access or TDMA handles multiple and simultaneous calls by dividing them in time, not by frequency. This is purely digital transmission. Voice traffic is digitized and portions of many calls are put into a single bit stream, one sample at a time. We'll see with IS-136 that three calls are placed on a single radio channel, one after another. Note how TDMA is the access technology and IS-136 is the operating system?

Another access method is code division multiple access or CDMA. The cellular system that uses it, IS-95, tags each and every part of multiple conversations with a specific digital code. That code lets the operating system reassemble the jumbled calls at the base station. Again, CDMA is the transmission method and IS-95 is the operating system.

All IS-136 phones handle analog traffic as well as digital, a great feature since you can travel to rural areas that don't have digital service and still make a call. The beauty of phones with an AMPS backup mode is they default to analog. As long as your carrier maintains analog channels you can get through. And this applies as well as the previously mentioned IS-95, a cellular system using CDMA or code division multiple access. Your phone still operates in analog if it can't get a CDMA channel. But I am getting ahead of myself. Back to time division multiple access.

TDMA's chief benefit to carriers or cellular operators comes from increasing call capacity -- a channel can carry three conversations instead of just one. But, you say, so could NAMPS, the now dead analog system we looked at briefly. What's the big deal? NAMPS had the same fading problems as AMPS, lacked

the error correction that digital systems provided and wasn't sophisticated enough to handle encryption or advanced services. Things such as calling number identification, extension phone service and messaging. In addition, you can't monitor a TDMA conversation as easily as an analog call. So, there are other reasons than call capacity to move to a different technology. Many people ascribe benefits to TDMA because it is a digital system. Yes and no.

[Please see the next page -->](#)

NOTES

[Programming] Thorn, ibid, 2 see also "Cellular Lite: A Less Filling Blend of Technology & Industry News" Nuts and Volts Magazine (March 1993) ([back to text](#))

[MIN] Crowe, David "Why MINs Are Phone Numbers and Why They Shouldn't Be" Cellular Networking Perspectives (December, 1994) <http://www.cnp-wireless.com>



[Continues] AMPS isn't dead yet, despite the digital cellular methods this article explores. Besides acting as a backup or default operating system for digital cellular, including some dual mode PCS phones, analog based Advanced Mobile Phone Service continues as a primary operating system, bringing much needed basic wireless communications to many rural parts of the world.

I recently got an e-mail (11/12/2000) from a reader who lives in [Marathon, Ontario, Canada](#), on the tip of the North Shore of Lake Superior. As he refers to the Lake, "The world's greatest inland sea!" He reports, "We just got cell service here in Marathon. It is a simple analogue system. There is absolutely no

competition for wireless service. Two dealers in town sell the phones. In the absence of competition there are no offers of free phones; the cheapest mobiles sell for (and old analogue ones to boot!) \$399.00 Canadian . . ." And you thought you paid too much for cellular.

More recently I got an e-mail from a reader living in Wheatland, Wyoming. He, too, has only analog cellular (AMPS) to use. [\[back to text\]](#)

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Cellular Telephone Basics



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(Page 8) Cellular Telephone Basics continued . . .

Advanced features depend on digital but conserving bandwidth does not. How's that? Three conversations get handled on a single frequency. Call capacity increases. But is that a virtue of digital? No, it is a virtue of multiplexing. A digital signal does not automatically mean less bandwidth, in fact, it means more. [\[See more bandwidth\]](#) Multiplexing means transmitting multiple conversations on the same frequency at once. In this case, small parts of three conversations get sent almost simultaneously. This was not the same with the old analog NAMPS, which split the frequency band into three discrete sub-frequencies of 10khz apiece. TDMA uses the whole frequency to transmit while NAMPS did not.

This is a good place to pause now that we are talking about digital. AMPS is a hybrid system, combining digital signaling on the setup channels and on the voice channel when it uses blank and burst. Voice traffic, though, is analog. As well as tones to keep it on frequency and help it find a vacant channel. That's AMPS. But IS-136 is all digital. That's because it uses digital on its set-up channels, the same radio frequencies that AMPS uses, and all digital signaling on the voice channel. TDMA, GSM, and CDMA cellular (IS-95) are all digital. Let's look at some TDMA basics. But before we do, let me mention one thing.



[Wonderful information on IS-136 here. It's from a chapter in IS-136 TDMA Technology, Economics, and Services, by Harte, Smith, and Jacobs \(1.2mb, 62 pages in .pdf\)](#)

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I wrote in passing about how increasing call capacity was the chief benefit of TDMA to cellular operators. But it is not necessarily of benefit to the caller, since most new digital routines play havoc with voice quality. An uncompressed, non-multiplexed, bandwidth hogging analog signal simply sounds better than its present day compressed, digital counterpart. As the August, 2000 [Consumers Digest](#) put it:

"Digital cellular service does have a couple of drawbacks, the most important of which is audio quality. Analog cellular phones sound worlds better. Many folks have commented on what we call the

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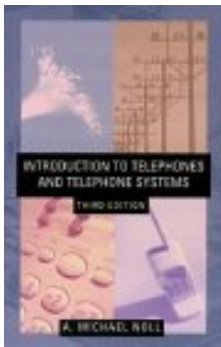
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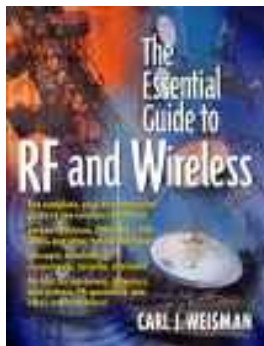
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[Introduction to Telephones and Telephone Systems \(external link to Amazon\)](#) (Artech House)
 Professor A. Michael Noll



 [This is from Noll's book, it is an excellent introduction to cellular and it is free: Chapter 9: Wireless Telephone Systems](#)



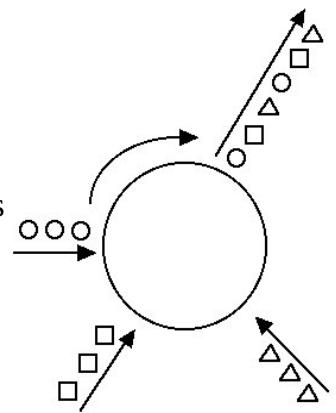
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 Easy to read, affordable book on wireless basics. (12 pages, 72K

'Flipper Effect.'" It refers to the sound of your voice taking on an 'underwater-like' quality with many digital phones. In poor signal areas or when cell sites are struggling with high call volume, digital phones will often lose full-duplex capability (the ability of both parties to talk simultaneously), and your voice may break up and sound garbled."

Getting back to our narrative, and to review, we see that going digital doesn't mean anything special. A *multiplexed* digital signal is what is key. Each frequency gets divided into six repeating time slots or frames. Two slots in each frame get assigned for each call. An empty slot serves as a guard space. This may sound esoteric but it is not. Time division multiplexing is a proven technology. It's the basis for T1, still the backbone of digital transmission in this country. Using this method, a T1 line can carry 24 separate phone lines into your house or business with just an extra twisted pair. Demultiplexing those conversations is no more difficult than adding the right circuit board to a personal computer. TDMA is a little different than TDM but it does have a long history in satellite working.

[More on digital: http://www.TelecomWriting.com/PCS/Multiplexing.htm](http://www.TelecomWriting.com/PCS/Multiplexing.htm)

What is important to understand is that the system synchronizes each mobile with a master clock when a phone initiates or receives a call. It assigns a specific time slot for that call to use during the conversation. Think of a circus carousel and three groups of kids waiting for a ride. The horses represent a time slot. Let's say there are eight horses on the carousel. Each group of kids gets told to jump on a different colored horse when it comes around. One group rides a red horse, one rides a white one and the other one rides a black horse. They ride the carousel until they get off at a designated point. Now, if our kids were orderly, you'd see three lines of children descending on the carousel with one line of kids moving away. In the case of TDMA, one revolution of the ride might represent one frame. This precisely synchronized system keeps everyone's call in order. This synchronization continues throughout the call. Timing information is in every frame. Any digital scheme, though, is no circus. The actual complexity of these systems is daunting. You should you [read further](#) if you are interested.



[Take a look into frames](#)

There are variations of TDMA. The only one that I am aware of in America is E-TDMA. It is or was operated in Mobile, Alabama by Bell South. Hughes Network Systems developed this E-TDMA or Enhanced TDMA. It runs on their equipment. Hughes developed much of their expertise in this area with satellites. E-TDMA seems to be a dynamic system. Slots get assigned a frame position as needed. Let's say that you are listening to your wife or a girlfriend. She's doing all the talking because you've forgotten her birthday. Again. Your transmit path is open but it's not doing much. As I understand it, "digital speech interpolation" or DSI stuffs the frame that your call would normally use with

in .pdf)

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other bits from other calls. In other words, it fills in the quiet spaces in your call with other information. DSI kicks in when your signal level drops to a pre-determined level. Call capacity gets increased over normal TDMA. This trick had been limited before to very high density telephone trunks passing traffic between toll offices. Their system also uses half rate vocoders, advanced speech compression equipment that can double the amount of calls carried.

Before we turn to another multiplexing scheme, CDMA, let's consider how a digital cellular phone determines how to choose a digital channel and not an analog one. Perhaps I should have covered that before this section, but you may know enough terminology to understand what Mark van der Hoek has to say:

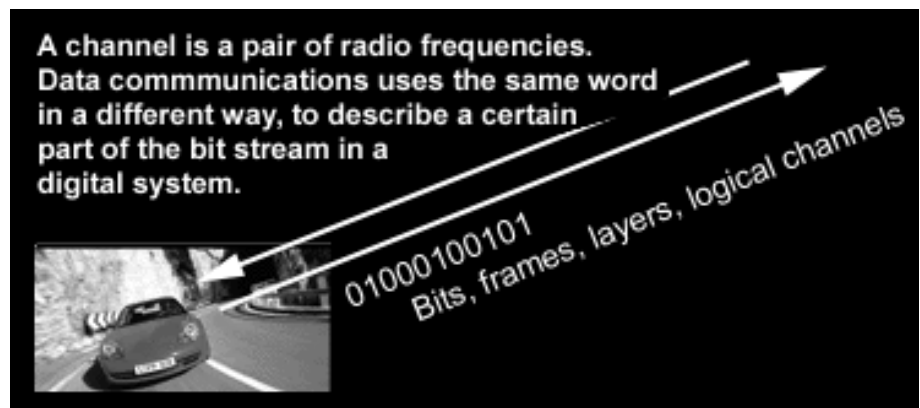
"The AMPS system control channel has a bit in its data stream which is called the 'Extended Protocol Bit.' This was designed in by Bell Labs to facilitate unknown future enhancements. It is used by both CDMA and TDMA 800 MHz systems."

"When a dual mode phone (TDMA or CDMA and AMPS) first powers up, it goes through a self check, then starts scanning the 21 control or setup channels, the same as an AMPS only phone. [Like you've described before](#). When it locks on, it looks for what's called an Extended Protocol Bit within that data stream. If it is low, it stays in AMPS. If that bit is high, the phone goes looking for digital service, according to an established routine. That routine is obviously different for CDMA and TDMA.

"TDMA phones then tune to one of the RF channels that has been set up by the carrier as a TDMA channel. Within that TDMA channel data stream is found blocks of control information interspersed in a carefully defined sequence with voice data. Some of these blocks are designated as the access or control channel for TDMA. This logical or data channel, a term brought in from the computer side, constitutes the access channel."

I know this is hard to follow. Although I don't have a graphic of the digital control channel in IS-54, you can get an idea of a [data stream by going here](#).

"Remember, the term 'channel' may refer to a pair of radio frequencies or to a particular segment of data. When data is involved it constitutes the 'logical channel'." In TDMA, the sequence differentiates a number of logical channels. This different use of the same term channel, at once for radio frequencies and at the same time for blocks of data information, accounts for many reader's confusion. By comparison, in CDMA everything is on the same RF channel. No setting up on one radio frequency channel and then moving off to another. Within the one radio frequency channel we have traffic (voice) channels, access channels, and sync channels, differentiated by Walsh code."



Let's now look at CDMA. [please see next page-->](#)

Notes

[More bandwidth] "The most noticeable disadvantage that is directly associated with digital systems is the additional bandwidth necessary to carry the digital signal as opposed to its analog counterpart. A standard T1 transmission link carrying a DS-1 signal transmits 24 voice channels of about 4kHz each. The digital transmission rate on the link is 1.544 Mbps, and the bandwidth re-quired is about 772 kHz. Since only 96 kHz would be required to carry 24 analog channels (4khz x 24 channels), about eight times as much bandwidth is required to carry the digitally (722kHz / 96 = 8.04). The extra bandwidth is effectively traded for the lower signal to noise ratio." Fike, John L. and George Friend, Understanding Telephone Electronics SAMS, Carmel 1983 ([back to text](#))

[TDMA] There's a wealth of general information on TDMA available. But some of the best is by Harte, et. al:



[Wonderful information on IS-136 and TDMA here. It's from a chapter in IS-136 TDMA Technology, Economics, and Services, by Harte, Smith, and Jacobs \(1.2mb, 62 pages in .pdf\)](#)

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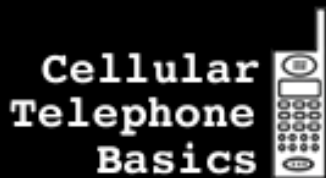
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(Page Nine) Cellular Telephone Basics *continued* . . .

IX Code Division Multiple Access -- IS-95

Code Division Multiple Access has many variants as well. [InterDigital \(external link\)](#), for example, produces a broadband CDMA system called B-CDMA that is different from [Qualcomm's \(external link\)](#) narrowband CDMA system. In the coming years wideband may dominate. But narrowband CDMA right now is dominant in the United States, used with the operating system IS-95. I should repeat here what I wrote at the start of this article. I know some of this is advanced and sounds like gibberish, but bear with me or skip ahead two paragraphs:

Systems built on time division multiplexing will gradually be replaced with other access technologies. CDMA is the future of digital cellular radio. Time division systems are now being regarded as legacy technologies, older methods that must be accommodated in the future, but ones which are not the future itself. (Time division duplexing, as used in cordless telephone schemes: DECT and Personal Handy Phone systems might have a place but this still isn't clear.) Right now all digital cellular radio systems are second generation, prioritizing on voice traffic, [circuit switching](#), and slow data transfer speeds. 3G, while still delivering voice, will emphasize data, packet switching, and high speed access.

Over the years, in stages hard to follow, often with 2G and 3G techniques co-existing, TDMA based [GSM\(external link\)](#) and AT&T's IS-136 cellular service will be replaced with a wideband CDMA system, the much hoped for [Universal Mobile Telephone System \(external link\)](#). Strangely, IS-136 will first be replaced by GSM before going to UMTS. Technologies like [EDGE and GPRS\(Nokia white paper\)](#) will extend the life of these present TDMA systems but eventually new infrastructure and new spectrum will allow CDMA/UMTS development. The present CDMA system, IS-95, which Qualcomm supports and the Sprint PCS network uses, is narrowband CDMA. In the Ericsson/Qualcomm view of the future, IS-95 will also go to wideband CDMA.



[Excellent writing on this transition period from 2G to 3G and beyond is in this](#)

[printable .pdf file](#), a chapter from The Essential Guide to Wireless Communications Applications by Andy Dornan. Many good charts. (454K, 21 pages in .pdf)

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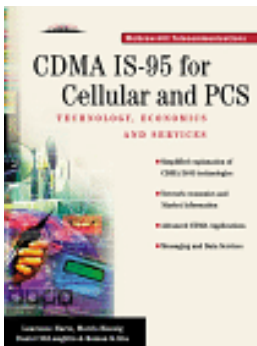
[Appendix: Early Bell System overview of IMTS and cellular](#)

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[CDMA IS-95 for Cellular and PCS: Technology, Applications, and Resource Guide by Harte, et.al](#)

(external link to Amazon)



[Short but good introduction to IS-95 from the above title \(10 pages, 275K, in .pdf\)](#)



[IS-95 handoffs \(3 pages, 240K, in .pdf\)](#)

The Five Major Cellular Radio Systems

AMPS -- Mostly analog

These three default to AMPS operation

- IS-54 -- First digital service -- TDMA based
(IS-54 and IS 136 are now considered one system)
- IS-136 -- Newest digital service -- TDMA based
- IS-95 -- Digital service -- CDMA based

GSM -- Digital service incompatible with above systems. Uses TDMA.

A. Before We Begin -- A Cellular Radio Review

We've discussed, at least in passing, five different cellular radio systems. We looked in particular at AMPS, the mostly analog, original cellular radio scheme. That's because three digital schemes default to AMPS, so it's important to understand this basic operating system. We also looked at IS-54, the first digital service, which followed AMPS and is now folded into IS-136. This AT&T offering, the newest of the TDMA services, still retains an AMPS operating mode. IS-54 and now IS-136 co-exist with AMPS service, that is, a carrier can mix and match these digital and analog services on whatever channel sets they choose. IS-95 is a different kind of service, a CDMA, spread spectrum offering that while not an evolution of the TDMA schemes, still defaults to advanced mobile phone service where a IS-95 signal cannot be detected.

Confused by all these names and abbreviations? Consider how many different operating systems computers use: Unix, Linux, Windows, NT, DOS, the Macintosh OS, and so on. They do the same things in different ways but they are all computers. Cellular radio is like that, different ways to communicate but all having in common a distributed network of cell sites, the principle of frequency-reuse, handoffs, and so on.

If an American carrier uses these words or phrases, then you have one of these technologies:

If your phone has a ["SIM or smart card" or memory chip](#) it is using GSM

If your phone uses CDMA the technology is IS-95

If the carrier doesn't mention either word above, or if it says it uses TDMA, then you are using IS-136

And iDEN is, well, iDEN, a proprietary operating system built by [Motorola \(external link\)](#) that, among others, NEXTEL uses.

PCS1900, although not a real trade name, usually refers to an IS-95 system operating at 1900MHz. Usually. If you see a reference to PCS1900 as a GSM service then it is a TDMA based system, not a CDMA technology. PCS1900 in CDMA is not compatible with other services, but it has a mode which lets the phone choose AMPS service if PCS1900 isn't available. Want more confusion? Many carriers that offer IS-136 and GSM, like Cingular, refer to IS-136 as simply TDMA. This is deceptive since GSM is also TDMA. Whatever. And since we are reviewing, let's make sure we understand what transmission technologies are involved.

Different transmission techniques enable the different cellular radio systems. These technologies are the infrastructure of radio. In frequency division multiple access, we separate radio channels or calls by frequency, like the way broadcast radio stations are separated by frequency. One call per channel. In time division multiple access we separate calls by time, one after another. Since calls are separated by time TDMA can put several calls on one channel. In code division multiple access we separate calls by code, putting all the calls this time on a single channel. Unique codes assigned to every bit of every conversation keeps them separate. Now, back to CDMA, specifically IS-95. (Make sure to download the .pdf files to the left.)

Back to the CDMA Discussion

Qualcomm's CDMA system uses some very advanced speech compression techniques, utilizing a variable rate vocoder, a speech synthesiser and voice processor in one. Vocoder is in every digital handset or phone; they digitize your voice and compress it. Phil Karn, KA9Q, one of the principal engineers behind Qualcomm, wrote about an early vocoder like this:

"It [o]perates at data rates of 1200, 2400, 4800 and 9600 bps. When a user talks, the 9600 bps data rate is generally used. When the user stops talking, the vocoder generally idles at 1200 bps so you still hear background noise; the phone doesn't just 'go dead'. The vocoder works with 20 millisecond frames, so each frame can be 3, 6, 12 or 24 bytes long, including overhead. The rate can be changed arbitrarily from frame to frame under control of the vocoder."

This is really sophisticated technology, eerily called VAD, for voice activity detection. Changing data rates allows more calls per cell, since each conversation occupies bandwidth only when needed, letting others in during the

idle times. Some say VAD is the 'trick' in CDMA that allows greater capacity, and not anything in spread spectrum itself. These data rate changes help with battery life, too, since the mobile can power down in those moments when not transmitting as much information.

Several years ago CDMA was in its infancy. Some wondered if it would work. I was not among the doubters. In May, 1995 I wrote in my magazine private line that I felt the future was with this technology. I still think so and Mark van der Hoek agrees. [Click here if](#) you want to read his comments or continue on this page if you want to learn more about this technology.

A Summary of CDMA

Another transmission technique

Code division multiple access is quite a different way to send information, it's a spread spectrum technique. Instead of concentrating a message in the smallest spectrum possible, say in a radio frequency 10 kHz wide, CDMA spreads that signal out, making it wider. A frequency might be 1.25 or even 5 MHz wide, 10 times or more the width a conventional call might use. Now, why would anyone want to do that?, to go from a seemingly efficient method to a method that seems deliberately inefficient?

The military did much early development on CDMA. They did so because a signal using this transmission technique is diffused or scattered -- difficult to block, listen in on, or even identify. The signal appears more like background noise than a normal, concentrated signal which you can easily target. For the consumer CDMA appeals since a conversation can't be picked up with a scanner like an analog AMPS call. Think of CDMA in another way. Imagine a dinner party with 10 people, 8 of them speaking English and two speaking Spanish. The two Spanish speakers can hear each other talking with out a problem, since their language or 'code' is so specific. All the other conversations, at least to their ears, are disregarded as background noise.

CDMA is a transmission technique, a technology, a way to pass information between the base station and the mobile. Although called 'multiple access', it is really another multiplexing method, a way to put many calls at once on a single channel. As stated before, analog cellular or AMPS uses frequency division multiplexing, in which callers are separated by frequency, TDMA separates callers by time, and CDMA separates calls by code. CDMA traffic includes telephone calls, be they voice or data, as well as signaling and supervisory information. CDMA is a part of an overall operating system that provides cellular radio service. The most widespread CDMA based cellular radio system is called IS-95.



Download this! In these pages from *Bluetooth Demystified* (McGraw Hill), Nathan Muller presents good information on CDMA, spread spectrum, spreading codes, direct sequence, and frequency hopping. [\(6 pages, 509K in .pdf\)](#)

[Bluetooth Demystified ordering information \(external link to Amazon\)](#)

A different way to share a channel

Unlike FDMA and TDMA, all callers share the same channel with all other callers. Doesn't that sound odd? Even stranger, all of them use the same sized signal. Imagine dozens of AM radio stations all broadcasting on the same frequency at the same time with the same 10Khz sized signal. Sounds crazy, doesn't it? But CDMA does something like that, only using very low powered mobiles to reduce interference, and of course, some special coding. "With CDMA, unique digital codes, rather than separate RF frequencies or channels, are used to differentiate subscribers. The codes are shared by both the mobile station (cellular phone) and the base station, and are called "pseudo-Random Code Sequences." [[CDG](#)] Don't panic about that last phrase. Instead, let's get comfortable with CDMA terms by seeing see how this transmission technique works.

As the Cellular Development group puts it, "A CDMA call starts with a standard rate of 9600 bits per second (9.6 kilobits per second). This is then spread to a transmitted rate of about 1.23 Megabits per second. Spreading means that digital codes are applied to the data bits associated with users in a cell. These data bits are transmitted along with the signals of all the other users in that cell. When the signal is received, the codes are removed from the desired signal, separating the users and returning the call to a rate of 9600 bps."

Get it? We start with a single call digitized at 9600 bits per second, a rate like a really old modem. (Let's not talk about modem baud rates here, let's just keep to raw bits.) CDMA then spreads or applies this 9600 bit stream by using a code transmitted at 1.23 Megabits. Every caller in the cell occupies the same 1.23 Megabit bandwidth and each call is the same size. A guard band brings the total bandwidth up to 1.25 Megabits. Once at the receiver the equipment identifies the call, separates its pieces from the spreading code and other calls, and returns the signal back to its original 9600 bit rate. For perspective, a CDMA channel occupies 10% of a carrier's allocated spectrum. [---> next page, please --->](#)

Notes

Probably the best reference is the paper "On the System Design Aspects of Code Division Multiple Access (CDMA) Applied to Digital Cellular and Personal Communications Networks" by Allen Salmasi and Klein S. Gilhausen [WT6G], from the Proceedings of the 41st IEEE Vehicular Technology Conference, St Louis MO May 19-22 1991.

There are also several papers on Qualcomm's CDMA system in the May 1991 IEEE Transactions on Vehicular Technology, including one on the capacity of CDMA.

Musings from a Wireless Wizard

Q. So, [Mark van der Hoek](#), what would it take to have cell phones stop dropping calls?

A. What is required is a network with a cell site on every corner, in every tunnel, in every subterranean parking structure, every office building, perfectly optimized. Oh, and you have to perfectly control all customers so that they

never attempt to use more resources than the system has available. What people don't realize is that this kind of perfection is not even realized on wireline networks. Wireline networks suffer from dropped and blocked calls, and always have. They have it a lot less than a wireless network, but they do have it. And a wireless network has variables that would give a wireline network engineer nightmares. Chaos theory applies here. Weather, traffic, ball games letting out, earthquakes. Hey, in our Seattle network, for the hour after the recent earthquake, the call volume went from an average of 50,000 calls to over 600,000. Oh, that reminds me! You can't guarantee "no drops" until you can guarantee that the land line network will never block a call! So now you have to perfectly control all of that, too! You see, it's not just about the air interface. It's not just about the hardware. . .

Thanks again to Mark van der Hoek of [WFI](#)



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(Page Ten) Cellular Telephone Basics *continued* . . .

Synchronization

To make this transmission method work it is not enough just to have a fancy coding scheme. To keep track of all this information flying back and forth we need to synchronize it with a master clock. As the CDG puts it, "In the final stages of the encoding of the radio link from the base station to the mobile, CDMA adds a special "pseudo-random code" to the signal that repeats itself after a finite amount of time. Base stations in the system distinguish themselves from each other by transmitting different portions of the code at a given time. In other words, the base stations transmit time offset versions of the same pseudo-random code."

Arrgh. Another phrase with the word 'code in it, one more term to keep track of! Don't despair. Even if "pseudo-random code" is fiercesomely titled, it's chore is simple to state: keep base station traffic to its own cell site by issuing a code. Synchronize that code with a master clock to correlate the code. Like putting a time stamp on each piece of information. CDMA uses The Global Positioning System or GPS, a network of navigation satellites that, along with supplying geographical coordinates, continuously transmits an incredibly accurate time signal.

What Every Radio System Must Consider

Radio systems, like life, demand tradeoffs or compromises. The CDG says, "CDMA cell coverage is dependent upon the way the system is designed. In fact, three primary system characteristics-Coverage, Quality, and Capacity-must be balanced off of each other to arrive at the desired level of system performance." Wider coverage, normally a good thing, means using higher powered mobiles which means more radio interference. Increasing capacity means putting more calls into the same amount of spectrum which means calls may be blocked and voice quality will decrease. That's because you must compress those calls to fit the spectrum allowed. So many things must be balanced. As the saying goes, radio systems aren't just sold, they are engineered.

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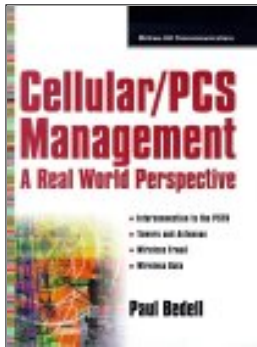
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[Cellular/PCs Management, from McGraw Hill \(external link to Amazon.com\)](#)

 [Excellent writing on the transition period from 2G to 3G and beyond is in this printable .pdf file](#), a chapter from The Essential Guide to Wireless Communications Applications by Andy Dornan. Many good charts. (454K, 21 pages in .pdf)

[Ordering information for the above title is here \(external link to Amazon.com\)](#)

G. CDMA Benefits

The CDG states that CDMA systems have seven advantages over other cellular radio transmission techniques. (GSM and IS-136 operators will contest this list.) CDG says benefits are:

- 1.Capacity increases of 8 to 10 times that of an AMPS analog system and 4 to 5 times that of a GSM system
- 2.Improved call quality, with better and more consistent sound as compared to AMPS systems
- 3.Simplified system planning through the use of the same frequency in every sector of every cell
- 4.Enhanced privacy
- 5.Improved coverage characteristics, allowing for the possibility of fewer cell sites
- 6.Increased talk time for portables
- 7.Bandwidth on demand

Good, readable information on CDMA is here:

<http://www.cellular.co.za/celltech.htm>

A Few More Details

IS-95, as I've mentioned before, is another cellular radio technique. It uses CDMA but is backward compatible with the analog based AMPS. IS-95 handles calls differently than TDMA schemes, although registration is the same. IS-95 queries the same network resources and databases to authenticate a caller. One thing that does differ IS-95, besides the different transmission scheme, are handoffs. It's tough transferring a call between cells in any cellular radio system. Keeping a conversation going while a cellular user travels at seventy miles per hour from one cell to the next finds many calls dropped. CDMA features soft handoffs, where two or more cell sites may be handling the call at the same time. A final handoff gets done only when the system makes sure it's safe to do so. Check out the file just below for a better summary:



Paul Bedell writes an excellent summary of CDMA, including information on soft handoffs, [in this .pdf file](#). It's just six pages, about 273K.

[It's from his book Cellular/PCs Management. More information and reviews are here \(external link to Amazon.com\)](#)

I hope the above comments were helpful and that you visit the [CDG site soon](#). Let's finish this article with some comments by Mark van der Hoek. He says that the most significant feature of CDMA is how it delivers its features without a great deal of extra overhead. He notes how CDMA cell sites can expand or contract, breathing if you will, depending on how many callers come into the cell. This flexibility comes built into a CDMA system. Here are some more comments from him:

"CDMA is already dominant, and 3G will be CDMA, and everyone knows it. The matter was really settled, though some still won't admit it, when Ericsson, the Big Kahuna of GSM, Great Champion of The Sacred Technology,

capitulated to Qualcomm by buying Qualcomm's infrastructure division. The rest is working out the details of the surrender. TDMA just can't deliver the capacity. In fact, I understand that the GSM standard documents spell out TDMA as an interim technology until CDMA could be perfected for commercial use."

"A further note on CDMA bandwidth. IS-95 CDMA (Qualcomm) uses a bandwidth of 1.25 MHz. Anyone know why? I have fun with this one, because few people, even in the industry, know the answer. PhDs often don't know the answer! That's because it is not a technical issue. The key to the matter can be found in the autograph in one of my reference books, "Mobile Communications Design Fundamentals" by William C. Y. Lee. The inscription reads, 'I am very glad to work with you in this stage of designing CDMA system, with my best wishes. Bill Lee, AirTouch Comm Los Angeles, CA March 22, 1995'."

"Dr. Lee is a major figure in the cellular industry, but few know of the contribution he made to CDMA. Dr. Lee was one of the engineers at Bell Labs in the '60s who developed cellular. He later came to work for PacTel Cellular (later AirTouch) as Chief Science Officer. Qualcomm approached him in 1992 or 1993 about using CDMA technology for cellular. TDMA was getting off the ground at that time, and Qualcomm had to move fast to have any hope of prevailing in the marketplace. They proposed to Dr. Lee that PacTel fund them (I think the number was \$100,000) to do a "Proof of Concept", which is basically a theoretical paper showing the practicality of an idea. Dr. Lee considered Qualcomm's proposal, and said, "No." Qualcomm was shocked. Then Dr. Lee told them we'll fund you 10 times that amount and you build us a working prototype."

"It is not too much to say that we have CDMA where it is today in part because of Dr. Lee. Qualcomm built their prototype system piggybacked on PacTel's San Diego network. During the development phase it was realized that deployment of CDMA meant turning off channels in the analog system. (What we call "spectrum clearing".) "How much can we turn off?" was the question. Dr. Lee considered it, and came back with the answer, "10%". Well, that worked out to 1.25 MHz, and that's where it landed. (All of this according to Dr. Lee, who is a brilliant and genuinely nice person.) By comparison, though, 3rd generation systems will have a wider bandwidth, than the 1.25 MHz bandwidth used for CDMA in IS-95 . The biggest discussion about 3G is now what kind of CDMA will be used. Bandwidth is the sticking point. Will it be 3.75 MHz or 5 MHz? You can see [discussions on it at the CDG site](#). " **please see next page-->**

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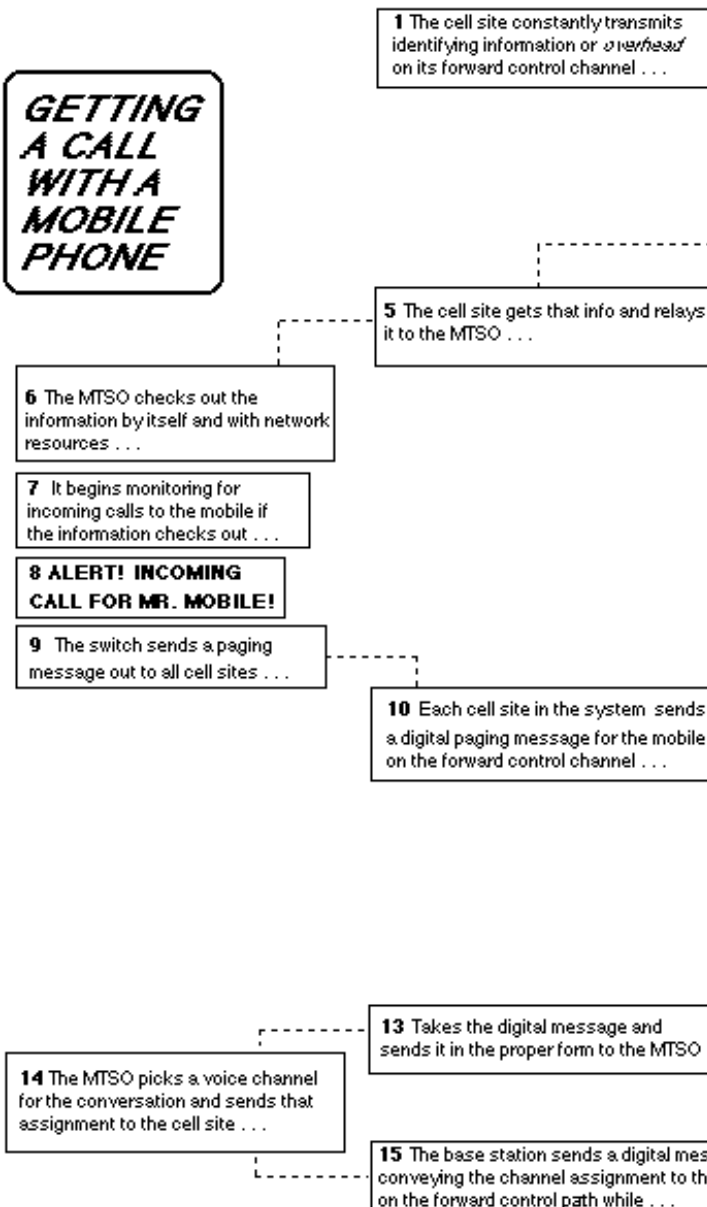
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(Page Eleven) Appendix: Cellular Telephone Basics *continued* . . .

X. AMPS Call Processing

This is AMPS call processing for analog and digital services, CDMA or IS-95 excluded . . .

The MTSO



The Cell Site

The Mobile

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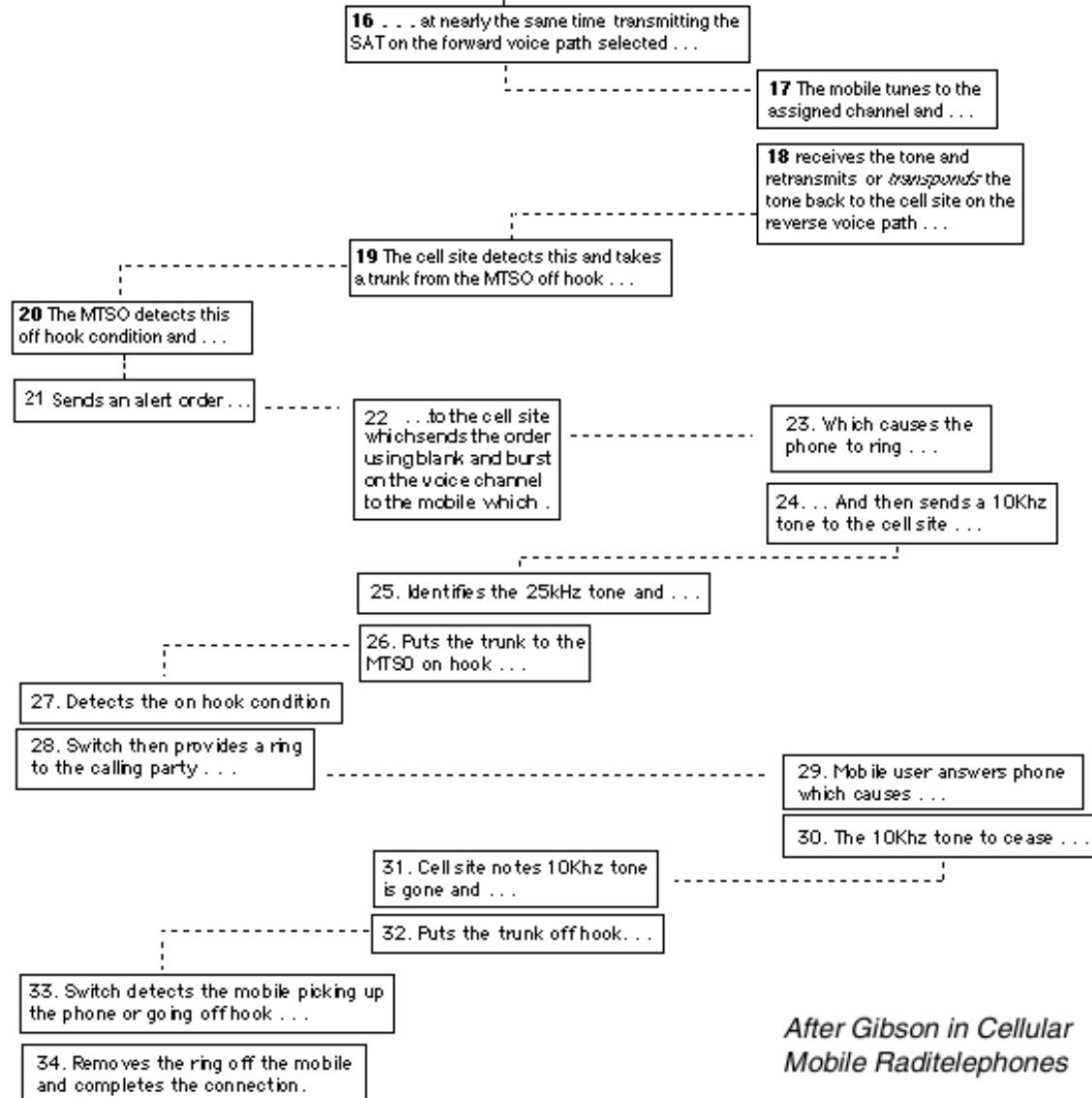
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The MTSO

The Cell Site

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*After Gibson in Cellular
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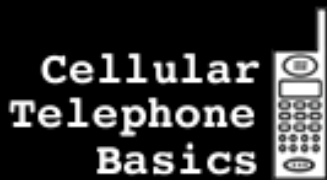
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(Page 12) Cellular Telephone Basics, Appendix: Page 1 of Bell System Overview

Learn the present by looking at the past. Here's some great reading on the transition from mobile telephone service to cellular. It outlines the IMTS system that influenced tone signaling in AMPS, and gives some clear diagrams outlining AMPS' structure. This is from the long out of print A History of Engineering and Science in the Bell System: Communications Sciences (1925 -- 1980), prepared by members of the technical staff, AT&T Bell Laboratories, c. 1984, p.518 et. seq.:

More on IMTS! [\(1\) Service cost and per-minute charges table/](#) [\(2\) Product literature photos/](#) [\(3\) Briefcase Model Phone /](#) [\(4\) More info on the briefcase model/](#) [\(5\) MTS and IMTS history/](#) [\(6\) Bell System](#) [\(7\) Outline of IMTS/](#) [\(8\) Land Mobile Page 1 \(375K\)/](#) [\(9\) Land Mobile Page Two \(375K\)/](#) [\(10\) The Canyon GCS Briefcase Telephone](#)

11.4.1 LAND MOBILE TELEPHONE SYSTEMS from

A History of Engineering and Science in the Bell System: Communications Sciences (1925 -- 1980)

Channel Availability

Mobile telephone service began in the late 1940s. By the seventies, it included a total of thirty-three 2-way channels below 500 megahertz MHz), as shown in Table 11-2. The 35-MHz band, which is not well suited to mobile service (because of propagation anomalies), is not heavily used. The other bands are fully utilized in the larger cities. In spite of this, the combination of few available channels per city and large demand has led to excessive blocking. The FCC's recent allocation of 666 channels at 850 MHz for use by cellular systems (described below) should change this situation. This allocation is split equally between wire-line and radio common carriers (each is allocated 333 channels).

In many areas, the wire-line carrier will be the local operating company.

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Use of conventional systems on the new channels would increase the traffic-handling capacity by a factor of about 10. The cellular approach, however, will increase the capacity by a factor of 100 or more. How this increase is achieved is discussed later in this section. The potential for very efficient use of so valuable and limited a resource as the frequency spectrum was a persuasive factor in the FCC's decision.

Transmission Considerations

Radio propagation over smooth earth can be described by an inverse power law; that is, the received signal varies as an inverse power of the distance. Unlike fixed radio systems (for example, broadcast television or the microwave systems described in Chapter 9), however, transmission to or from a moving user is subject to large, unpredictable, sometimes rapid fluctuations of both amplitude and phase caused by:

Shadowing: This impairment is caused by hills, buildings, dense forests, etc. It is reciprocal, affecting land-to-mobile and mobile-to-land transmission alike, and changes only slowly over tens of feet.

Multipath interference: Because the transmitted signal may travel over multiple paths of differing loss and length, the received signal in mobile communications varies rapidly in both amplitude and phase as the multiple signals reinforce or cancel one another.

Noise: Other vehicles, electric power transmission, industrial processing, etc., create broadband noise that impairs the channel, especially at 150 MHz and below.

Because of these effects, radio channels can be used reliably to communicate at distances of only about 20 miles, and the same channel (frequency) cannot be reused for another talking path less than 75 miles away except by careful planning and design.

In a typical land-based radio system at 15 or 450 MHz, one channel comprises a single frequency-modulation (FM) transmitter with 50- to 20-watt output power, plus one or more receivers with 0.3- to 0.5 microvolt sensitivity. This equipment is coupled by receiver selection and voice-processing circuitry into a control terminal that connects one or more of these channels to the telephone network (see Figure 11-34). The control terminal is housed in a local switching office. The radio equipment is housed near the mast and antenna, which are often on very tall buildings or a nearby hilltop.

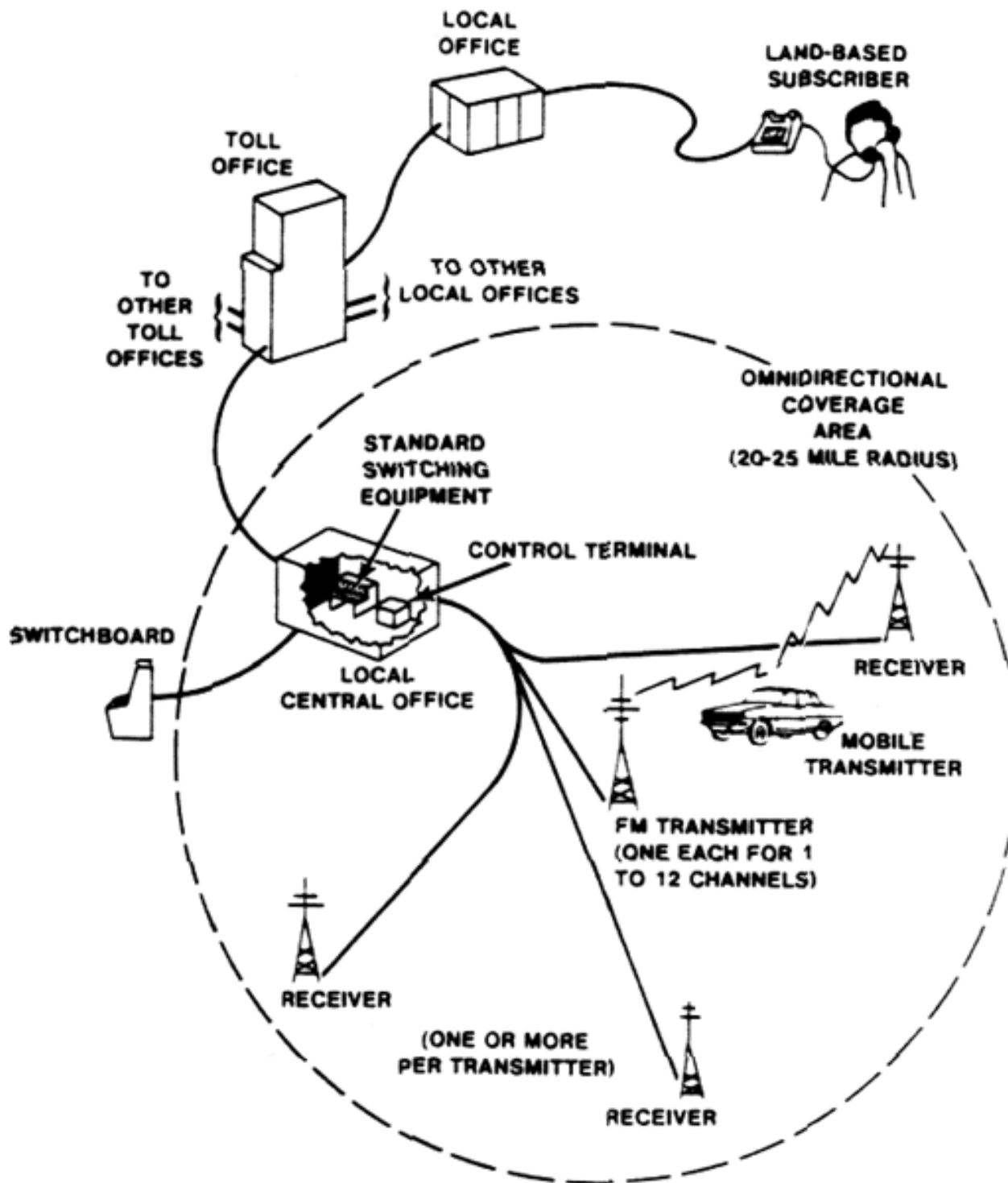


Figure 11-34. A manual, or MJ/MK, mobile telephone system.

Conventional System Operation

Originally, all mobile telephone systems operated manually, much as most private radio systems do today. A few of these early systems are still in use but because they are obsolete, they will not be discussed here.

More recent systems (the MJ system at 150 KHz and the MK system at 450 KHz) [[Improved Mobile Telephone Service or IMTS, ed.](#)] provide automatic dial operation. Control equipment at the central office continually chooses an idle channel (if there is one) among the locally equipped complement of channels and marks it with an "idle" tone. All idle mobiles scan these channels and lock onto the one marked with the idle tone. All incoming and outgoing calls are then routed over this channel. Signaling in both directions uses low-speed audio tone pulses for user identification and for dialing. Compatibility with manual mobile units is maintained in many areas served by the automatic systems by providing mobile-service operators. Conversely, MJ and MK mobile units can operate in manual areas using manual procedures.

One desirable feature of a mobile telephone system is the ability to roam; that is, subscribers must be able to call and be called in cities other than their home areas. The numbering plan must be compatible with the North American numbering plan. Further, for land-originated calls, a routing plan must allow calls to be forwarded to the current location. In the MJ system, operators do this. Because of the availability of the MJ system to subscribers requiring the roam feature, the MK system need not be arranged for roaming . . .

[Editor's note. IMTS authority [Geoff Fors \(external link\)](#) makes these important points: "There are some errors in AT&T's history of mobile telephone data. The UHF MK system mobiles did not have manual capability and could not roam. The MK head, the handheld device you actually made phone calls with, was a stripped-out version of Motorola's "FACTS" control head. What was stripped out was the Roam and the Manual features, and the operator-selected-channel option. MK phones were not popular and are very rare today."]

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Cellular Telephone Basics



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(Page 13) Cellular Telephone Basics *continued* : Bell System Overview

From: A History of Engineering and Science in the Bell System: Communications Sciences (1925 -- 1980)

Advanced Mobile Phone Service (continued)

Cellular Concept. Although the MJ and MK automatic systems offer some major improvements in call handling, the basic problems, few channels and the inefficient use of available channels still limit the traffic capacity of these conventionally designed systems. Advanced Mobile Phone Service overcomes these problems by using a novel cellular approach. It operates on frequencies in the 825- to 845 MHz and 870-to 890-MHz bands recently made available by the FCC. The large number of channels available in the new bands has made the cellular approach practical.

A cellular plan differs from a conventional one in that the planned reuse of channels makes interference, in addition to signal coverage, a primary concern of the designer. Quality calculations must take the statistical properties of interference into account, and the control plan must be robust enough to perform reliably in the face of interference. By placing base stations in a more or less regular grid (spacing them uniformly), the area to be served is partitioned into many roughly hexagonal cells, which are packed together to cover the region completely. Cell size is based on the traffic density expected in the area and can range from 1 to 10 miles in radius.

Up to fifty channels are assigned to each cell to achieve their regular reuse and to control interference between adjacent cells. This is illustrated in Figure 11-35, where cell A' can use the same channels as cell A. Because of the inverse power law of propagation, the spatial separation between cells A and A' can be made large enough to ensure statistically that a signal-to-interference ratio greater than or equal to 17 dB is maintained over 90 percent of the area. Maintenance of this ratio ensures that a majority of users will rate the service quality good or better.

-
- ▶ [Cell phones and plans](#)
 - ▶ [Levine's GSM/PCS .pdf file](#)
 - ▶ [Telephone history series](#)
 - ▶ [Mobile telephone history](#)
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 - ▶ [I-Mode Page](#)
 - ▶ [Land mobile](#)

Cellular systems also differ from conventional systems in two significant ways:

- ▶ [Bluetooth](#)
- ▶ [Cell phones on airplanes](#)
- ▶ [Cellular reception problems](#)

High transmitted power and very tall antennas are not required.

Wide FM deviation is permissible without causing significant levels of interference from adjacent channels.

[Appendix: Early Bell System overview of IMTS and cellular](#)

[Appendix: Call processing diagram](#)

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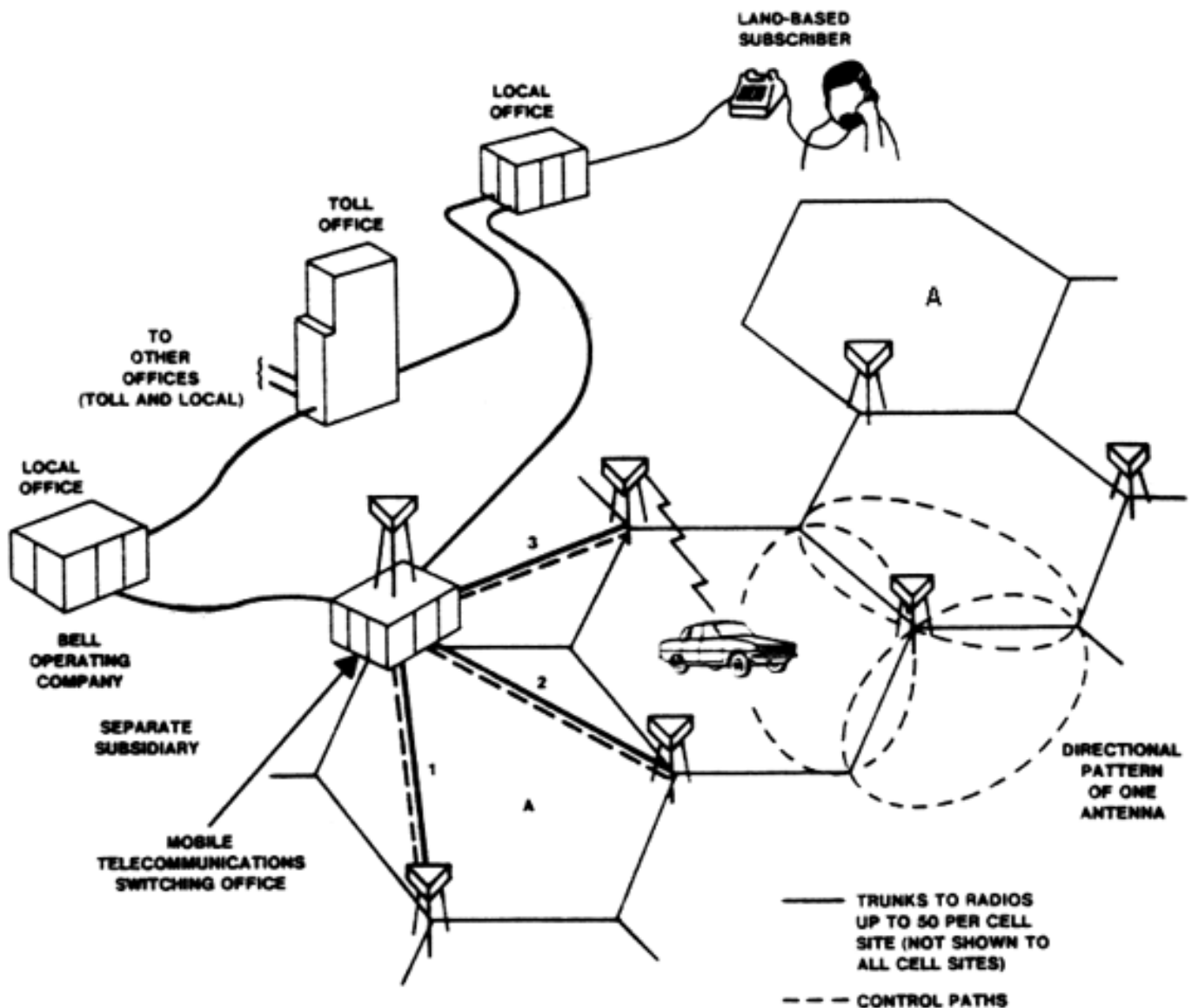


Figure 11-35. Advanced Mobile Phone Service system plan.

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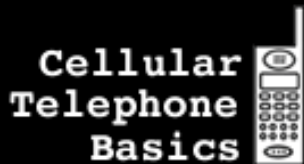
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(Page Fourteen) Appendix: Cellular Telephone Basics *continued*. . .

From A History of Engineering and Science in the Bell System: Communications Sciences (1925 -- 1980)

The latter is responsible for the high voice quality and high signaling reliability of the Advanced Mobile Phone Service.

In any given area, both the size of the cells and the distance between cells using the same group of channels determine the efficiency with which frequencies can be reused. When a system is newly installed in an area (when large cells are serving only a few customers), frequency reuse is unnecessary. Later, as the service grows, a dense system will have many small cells and many customers), a given channel in a large city could be serving customers in twenty or more nonadjacent cells simultaneously. The cellular plan permits staged growth. To progress from the early to the more mature configuration over a period of years, new cell sites can be added halfway between existing cell sites in stages. Such a combination of newer, smaller cells and original, larger cells is shown in Figure 11-36.

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[Appendix: Early Bell System overview of IMTS and cellular](#)

[Appendix: Call processing diagram](#)

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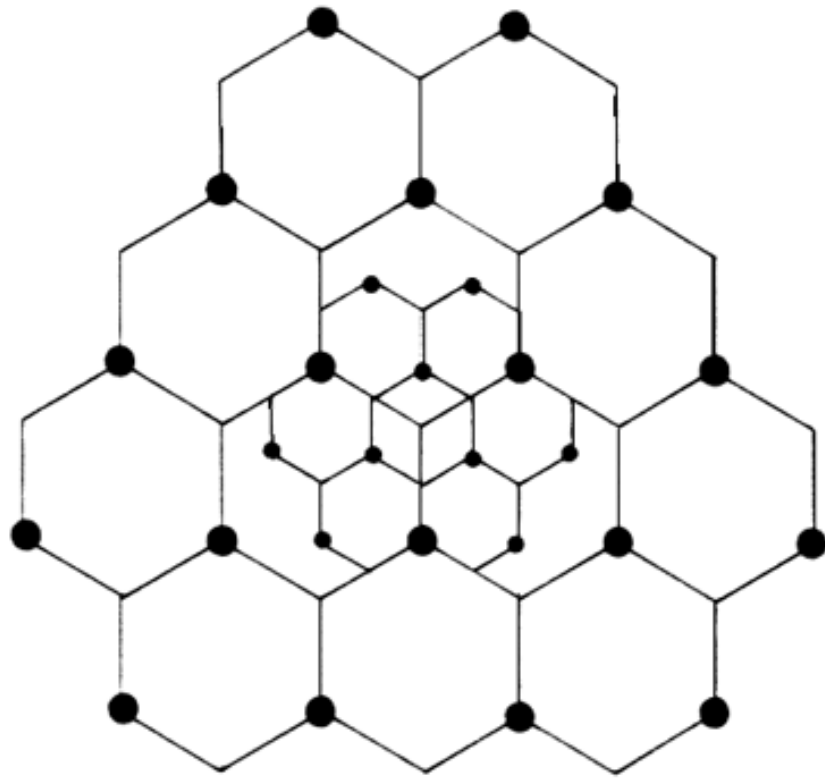


Figure 11-36. Staged growth of a Western Electric *AUTOPLEX* cellular radio system. (*AUTOPLEX* is a trademark of Western Electric.) Cell splitting, by adding new cell sites in areas of high demand, creates more traffic capacity.

One cellular system is the Western Electric AUTOPLEX-100. In this system, a mobile or portable unit in a given cell transmits to and receives from a cell site, or base station, on a channel assigned to that cell. In a mature system, these cell sites are located at alternate corners of each of the hexagonal cells as shown in Figure 11-36. Directional antennas at each cell site point toward the centers of the cells, and each site is connected by standard land transmission facilities to a 1AESS switching system and system controller equipped for Advanced Mobile Phone Service operation (called a mobile telecommunications switching office, or MTSO). Start-up and small-city systems use a somewhat more conventional configuration with a single cell site at the center of each cell.

The efficient use of frequencies that results from the cellular approach permits Advanced Mobile Phone Service customers to enjoy a level of service almost unknown with present mobile telephone service. Grades of service of P(0.02) are anticipated, compared to today's all-too-common P(0.5) or worse. At the same time, the number of customers in a large city can be increased from a maximum of about one thousand for a conventional system to several hundred thousand. Also, because of the stored-program control capability of MTSOs equipped with the 1AESS system, Custom Calling Services and many other features can be offered, some unique to mobile service. Other, smaller, switches provided by Western Electric or other vendors are also available to serve smaller cities and towns.

System Operation: Unlike the MJ and MK systems, Advanced Mobile Phone Service dedicates a special subset of the 333 allocated channels solely to signaling and control. Each mobile or portable unit is equipped with a frequency synthesizer (to generate any one of the 333 channels) and a high speed modem (10 kbps). When idle, a mobile unit chooses the "best control channel to listen to (by measuring signal strength) and reads the high-speed messages coming over this channel. The messages include the identities of called mobiles, local general control information, channel assignments for active mobiles and "filler" words to

maintain synchronism. These data are made highly redundant to combat multi-path interference. A user is alerted to an incoming call when the mobile unit recognizes its identity code in the data message. From the user's standpoint, calls are initiated and received as they would be from any business or residence telephone.

As a mobile unit engaged in a call moves away from a cell site and its signal weakens, the MTSO will automatically instruct it to tune to a different frequency, one assigned to the newly entered cell. This is called handoff. The MTSO determines when handoff should occur by analyzing measurements of radio signal strength made by the present controlling cell site and by its neighbors. The returning instructions for handoff sent during a call must use the voice channel. The data regarding the new channel are sent rapidly (in about 50 milliseconds), and the entire retuning process takes only about 300 milliseconds. In addition to channel assignment, other MTSO functions include maintaining a list of busy (that is, off-hook) mobile units and paging mobile units for which incoming calls are intended.

Regulatory Picture. The FCC intends cellular service to be regulated by competition, with two competing system providers in each large city: a wire-line carrier and a radio common carrier. To prevent any possible cross-subsidization or favoritism, the Bell operating companies must offer their cellular service through separate subsidiaries. These subsidiaries will be chiefly providers of service and, in fact, are currently barred from leasing or selling mobile or portable equipment. Such equipment will be sold by nonaffiliated enterprises or by American Bell Inc.



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Digital Switching

EE6304/TM-708-N

SMU/NTU

Lectures April 21&28, 1998

Cellular & PCS

(print in PowerPoint *notes pages* format to see additional
notes below each slide)

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Print in Power Point *Notes Pages* format. Many pages have notes in this lecture.

Cellular and PCS

General Background of Cellular & PCS

•Different Access Technologies

•System Structure

- Physical Description Radio U_m Interface
- Signal Description

•Call Processing

- Initialization
- Call Origination
 - Mobile origin, mobile destination
- Handover
- Release/Disconnect

•Services

- Voice
- Data & Fax
- Short Message Service (SMS)

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This presentation is a condensed version of lectures used for people actually working in the cellular and PCS industry. It is intended for students having no particular prior exposure to radio or cellular/PCS systems. The author will appreciate notification of any errors, regardless how minor. Please send a marked copy of the relevant page(s) to the address below.

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History and Jargon

- **Analog cellular on the 800 MHz band**
 - Since ~1980 with immense growth rate
 - Nominally over 30 million subscribers today
 - Other analog systems in Europe, Asia, etc.
- **Systems on the 1.9 GHz (1900 MHz) band**
 - Usually called **Personal Communications Systems**
 - even when technologically identical to 800 MHz systems (such as IS-136)
 - 900 MHz and 1.8 GHz bands used in Europe

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There is some confusion in the industry about the similarity or distinction between the terms cellular and PCS. In some cases there is no distinction. In other cases the distinction is not technological, but is based on the frequency band of operation or on who owns the license to operate the system.

Jargon

- **Technically, a cellular system has 2 properties:**
 - Cellular frequency re-use
 - Handover (handoff)
- **So do most PCSs (personal communications systems)**
 - only exception is CT-2 public cordless (current implementations)
- **Today the North American business distinction is mainly..**
 - 800/900 MHz is considered *cellular*
 - including digital cellular such as GSM, IS-54, IS-136
 - 1.9 GHz is considered *PCS*
- **Warning: jargon subject to change without notice! Beware of total confusion...**

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The jargon of the cellular and PCS industry is unfortunately not fully stable. Since not everybody agrees on the distinction between a cellular and PCS system, AT&T was criticized for calling their IS-136 roll out a *digital PCS system* as a marketing name, because it operates on the 800 MHz band. From the purely technological point of view, there is no fundamental distinction between systems which operate on the two bands which justifies using a different name for each band.

This course will follow the description on the slide above just to be unambiguous and agree with what the majority of people in the industry are *currently* saying. A cellular operator is then a company which owns an 800 MHz North American cellular band license. A PCS operator has a 1.9 GHz band license.

Terminology has changed in the last 2 years, and may change again. To avoid pointless arguments, verify definitions before proceeding to shout!

Brief History of Cellular/PCS

- **Manual operator-handled mobile radio (1945...)**
- **Automatic Mobile Radio, e.g. Secode, IMTS (1960...)**
- **Trunked radio (1960...)**
 - cellular-like frequency re-use
 - but no handover!
- **Cellular radio (1978...) required new technology:**
 - control of mobile radio operation via messages from base
 - Mobile transmit (Tx) frequency and power
 - Can be changed *during* a conversation to select best base station or compensate for distance
 - *Handover* continues conversation as mobile station moves from cell to cell

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Cellular radio did not exist until the relatively simple microprocessors of the 1970s were available to provide remote control and sufficient sophistication to act on commands from the base station.

Cellular Frequency Re-use

- **Certain types of radio modulation exhibit “capture effect”**
- **When ratio of desired to undesired signal power is greater than the “capture ratio,” only the stronger signal is apparent**
- **Capture ratio depends on**
 - **Type of modulation: FM, Phase Modulation -- NOT AM**
 - **Bandwidth of signal compared to information**
 - **Analog cellular 30 kHz: capture ratio 63/1 or 18 dB**
 - **Narrow band NAMPS 10 kHz: c.r. is 200/1 or 23 dB**

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Every few years someone re-proposes some type of amplitude modulation (AM) single sideband (SSB) cellular reuse system. These proposals often include elaborate audio compression-expansion (“companding”) and audio noise reduction methods. The objective is to exploit the much narrower bandwidth of AM (only 4 kHz for a 4 kHz audio signal). These proposals ignore the fact that the C/I ratio measured at the antenna is the same audio S/N or S/I ratio that will be heard at the earphone. Therefore, the objective of a 30 dB S/I audio ratio would require something like an $n=28$ frequency plan. In other words, one could not reuse the same carrier frequency in the same city in many systems!

In contrast, FM and phase modulation both exhibit a fairly distinct threshold in $C/(I+n)$. When the desired signal power C is greater than the sum of interference and noise power $(I+n)$ by this ratio, the audio output (or digital bit accuracy) is almost perfect. The audio exhibits a lack of noise corresponding to 30 dB (1000/1 ratio) of S/N, although the FM C/I in an 30 kHz analog cellular system is only 18 dB (63/1). Once the C/I ratio falls below that threshold, clicks and pops are heard, and at even lower C/I, only a random noise hiss is heard. Due to widespread use of FM during World War II (the inventor, Col. Edwin Armstrong, donated his patents free of charge to the armed forces) many people got the idea of cellular reuse about the same time, but only in the 1970s was handover and remotely computer controlled radio carrier frequency selection and transmit power added.

Radio Cells

- **A cellular service area is covered by numerous smaller cells**
 - Each cell has one base station (base antenna location), usually at the cell center
 - The radio coverage in the cell may be optionally:
 - Omnidirectional (azimuthally) with one antenna set
 - Sectored (typically with 3 antenna sets, 120° each)Warning: Some documents use the words cell/sector differently
 - Each sector has *at least* one RF carrier frequency
 - A carrier frequency identification number describes two different (paired) frequencies:
 - downlink (forward): Base Tx, Mobile Rx
 - uplink (reverse): Mobile Tx, Base Rx

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Without cellular frequency reuse, there would not be enough spectrum for a major fraction of the population to use cellular and PCS radio systems. Without handover, calls would need to be limited to the time one dwells in a single cell. (So-called trunked radio systems do not have handover, but do have frequency reuse, and that is their limitation.) Without computer remote control of the mobile station, it would not be practical to continually select the proper frequency for a conversation or a handover, and control the mobile set transmit power accurately as the MS moves close to and away from the base station. All these complicated continual adjustments are done without the need for the user to be a technical whiz and constantly adjust dials and buttons. To quote Captain Queeg in the Herman Wouk novel *The Caine Mutiny*, the system was “designed by geniuses to be used by idiots.” The objective is to make a system which is no more complicated to use than the ordinary landline telephone. The only significant operational difference is that the user dials the desired destination directory number first, before engaging the central switching equipment and hearing a “dial tone.” Some special cellular phones such as the GTE TeleGo handset have even been designed so that the user hears dial tone first so it is perceived exactly like a regular wired telephone!

Cellular Frequency Plan

- **Frequency plan depends on**
 - capture ratio resulting from RF technology
 - Radio signal strength path loss or distance-related attenuation
 - Approximately: received power $\propto 1/\text{distance}^4$ in city
 - Empirical *approximation*, not based on theory
 - Exponent in range 2 (open space) to 4 (cluttered urban environment)
- **A frequency plan is characterized by a cell cluster count in which each frequency is used in one cell**
 - Low capture ratio, high path loss requires small cell cluster (3 or 4)
 - High capture ratio, low path loss requires large cluster (7 or 12)

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The major task of engineers who design and install a cellular system is the placement of the cell base stations, the choice (omni- or sectored directionality) and placement of the antennas, and the assignment of the proper carrier frequencies to each cell or sector. For proper control of handover, the threshold values appropriate to each cell or sector must be set in each cell.

The input information comprises the following factors:

Expected geographic density of call traffic in each area of the city over the planned service life of the system. This includes populations within buildings and underground in tunnels and parking garages, etc.

Topography of the ground surface and the buildings, trees, and other objects on that surface which affect radio propagation.

Relative costs of real estate for towers, building installation of equipment and mounting of antennas.

The traditional objective is to produce a plan for radio coverage of 90% of the service area which works 90% of the time. The objective of 90% of the time recognizes that, among other things, the radio path losses from overhanging foliage reduces the street level radio signal strength during the spring and summer, compared to the fall and winter seasons. The mutual interference between cells having the same reuse radio carrier frequencies (cocarrier interference) should be below the capture ratio value. External sources of radio interference (other radio systems, electrical radiation from signs, electric machinery, etc.) should be identified and properly handled.

Special Frequency Reuse Problems

- Without multi-cell frequency reuse, practical systems would not have enough traffic capacity
- However, the possibility of co-channel (or co-carrier) interference is always of concern
- Cellular/PCS systems have various methods to prevent miscommunication with a co-channel signal from another cell:
 - Analog systems include a different Supervisory Audio Tone - SAT (above 3.5 kHz bandpass telephone audio channel)
 - Unfortunately, the TIA-553 North American standard only provides 3 SAT choices (5970, 6000, 6030 Hz)
 - TDMA digital systems include a repeating digital identifier code in each transmission burst and associated with each control message
 - 8 code choices in GSM/PCS-1900
 - 255 code choices in IS-136
 - CDMA systems use many different uplink CDMA spreading codes in different cells. Many choices (2⁴²), but only 62 downlink code choices in each cell.

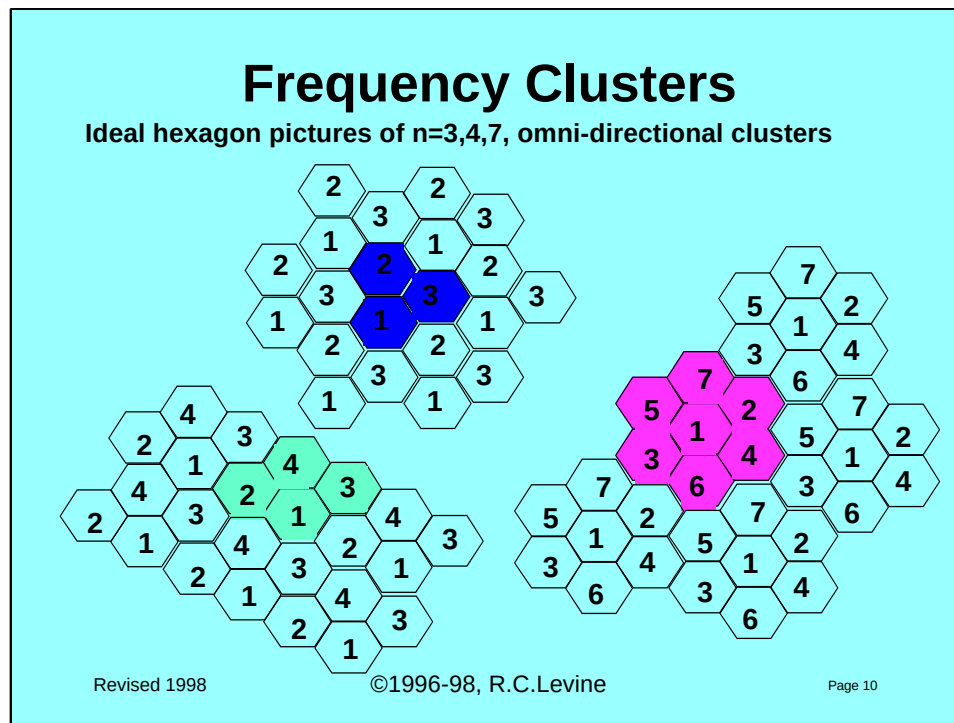
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In most systems, if a problem of reception of the wrong radio signal or a radio signal not containing the correct identification code or signal persists for 5 continuous seconds, the immediate way the system design deals with it is to release the radio link. (In the GSM/PCS-1900 system, there is an automatic reconnection following such a release, normally on another radio channel which hopefully is not experiencing such bad interference.) There is not much else to do in the short term, since the customer is either experiencing garbage audio due to radio interference which is so strong that it interferes with communication, or the customer is in communication with the wrong person.

The long term solution is to identify those areas where such problems exist, and to correct the radio coverage in these areas. The correction of the radio coverage may require altering the base transmitter power, changing the height and/or the mechanical or electrical downtilt of the base radio antenna, or use of a radio repeater. In some cases, a relocation of the base antenna may be needed if other methods are not sufficient, but this is very costly so it is saved as the last measure.

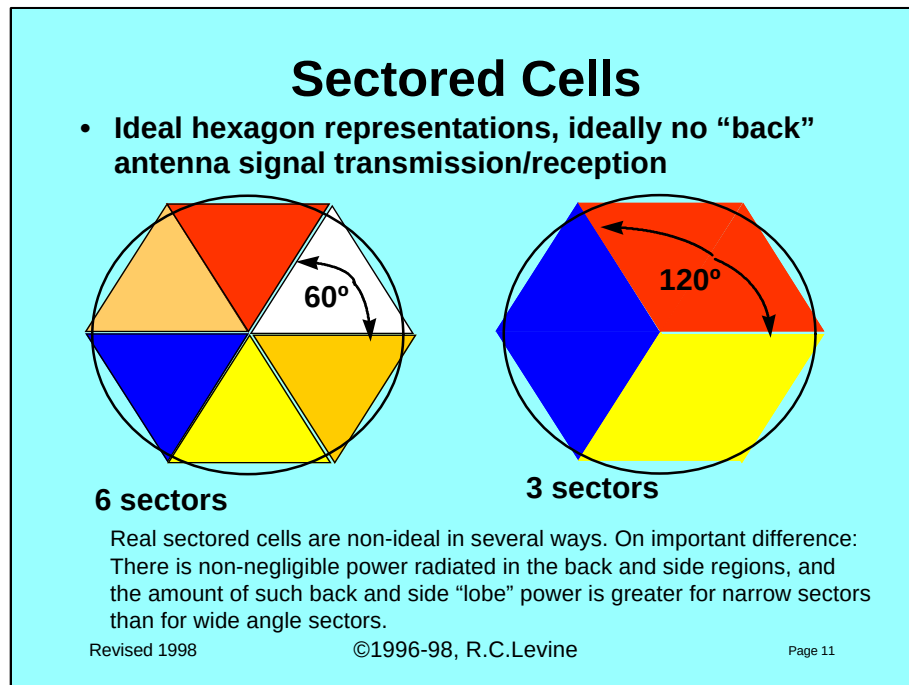


The number in each hexagonal cell represents the first (lowest usually) carrier frequency number assigned to that cell. In the $n=3$ clusters, cell 1 can also be used for carrier frequencies number 4, 7, 10, etc. so there are $1/3$ of all available frequencies used in each cell. However, the cocarrier interference frequencies are very close to that cell. Observe the many near (but not adjacent) cells also labeled with 1. In general there are 6 nearest cocarrier neighbor cells, and their centers are only 1.5 cell diameters away from the central 1 cell. There is also a second and third rank (and even more distant) of cocarrier cells, but they are not shown on the diagram.

In the $n=4$ cluster, the cells labeled 1 can also be used for carrier 5, 9, 13, etc. Thus this system does not have as high a capacity as the $n=3$ frequency engineering plan. Also, there are 4 nearest cocarrier cells (also labeled 1) but 2 of them are 1.5 diameters away and two are 2 diameters away. The next rank of cocarrier cells are about 3 diameters away.

In the $n=7$ cluster, cells labeled 1 may also be used for carriers 8, 15, 22, etc. Around each cell labeled 1 there are 6 nearest cocarrier cells (only 4 are shown in the diagram), at a distance of about 2.5 diameters.

Because of using (horizontally) omnidirectional antennas at all sites, each cell is subject to cocarrier interference from all cocarrier cells in all compass directions. A distinctive base station identity code (BSIC) can be assigned by the operator to each cluster. Three of the 6 bits are arbitrarily chosen by the operator, and the other 3 bits indicate one of 8 permitted values of the training/synchronizing sequence which is used in full TDMA bursts (explained on another page). All the full burst transmissions in this cell also use the specific training bit sequence code specified by the BSIC. The same BSIC should only be used in very distant cocarrier cells, if at all. This BSIC code is broadcast periodically by the base station, so the MS knows it. The BSIC is used in several places in the coding to prevent a receiver from using a cocarrier interfering signal from another base station operating on the same carrier frequency. One example relates to the random access burst, shown on another page.



Sectorized cells are created by installing multiple antenna sets at the base location. Each set of antennas is directional rather than omnidirectional. Sectorized cells have two advantages over omnidirectional cells. First, by limiting the radio reception/transmission to the “front” of the angular sector and not transmitting or receiving any signal from the “back” they reduce the level of interference by a ratio of 3/1 or 6/1 for 3 and 6 sectors, respectively. This improves the signal quality, which is manifested as a lower BER in a digital system. Because the total interference from other cells is reduced, the cluster can be redesigned from a $n=7$ to an $n=4$ plan, in some cases, thus increasing the capacity per cell.

When sectorized cells are used in place of originally omnidirectional cells, but there is no change in the frequency plan, the traffic capacity actually goes down. This is a result of segregating the overall set of carrier frequencies into 3 (or 6) subsets in a sectorized cell. The overall blocking probability of a number of channels is increased (and thus the usable traffic capacity is reduced) when they are subdivided into a number of exclusive subsets, and the MSs in each sector can only choose from those carriers available in that sector. The higher traffic capacity available when the same number of MSs in the cell can use any or all of the various carriers in the omnidirectional case is called “trunking efficiency.”

Sectored Cells

- **Narrow sectors reduce Co-channel interference**
 - Permits geographically closer frequency re-use
 - **Thus more carriers/cell, more capacity**
 - qualification: smaller trunk groups reduce “trunking efficiency”
- **But... back and side lobes are problems**
 - Permit “spot” co-channel interference
 - “sneak path” interference which only occurs intermittently, difficult to identify and debug
 - “smart antennas” (adaptive phased arrays) address this problem better (but at high cost)

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Some systems separate the carrier frequencies into subsets which operate separately in each sector. In some vendor's systems the cells are sectored but individual carriers can be “switched” from sector to sector. This is presently more common in analog cellular systems, but is a coming capability for GSM related systems as well. This capability to move channels to the sector with the most traffic overcomes the trunking limitation imposed by provisioning a fixed number of channels in each sector without regard to the changing traffic load demand in each sector.

In some systems, “smart” antennas have been proposed which permit dynamically forming the radio directionality beam for each TDMA time slot separately so that it can point to the MS it communicates with. This requires a high degree of interaction of information between the base station signaling hardware and software and the antenna beam forming system. A limited approach to this idea using passive “dumb” antennas is to use an omnidirectional pattern for the beacon carrier (which is used to start the setup of calls), and then transfer the MS to a carrier which is used in only one sector to continue the call. The omnidirectional coverage can be achieved by either a separate antenna for that one carrier frequency, or by connecting the beacon carrier to/from all the sector antenna sets. In general, this requires a more sophisticated base transceiver (BTS) than the normal design. The special BTS must have multiple receiver inputs so it can determine which sector the MS is located in.

Uplink-Downlink Balance

- **Need equally good signal quality both directions-**
 - two-way communications is the objective
 - areas covered *only* by downlink are not useful, may cause excessive co-channel interference to other cells
- **Base Tx is more powerful (e.g. 5 to 10W/carrier) than MS (max 2W for PCS-1900)**
- **Compensate for this via:**
 - Base Rx diversity (equivalent gain of 2-5 dB)
 - Base Rx antenna gain (typ 5-7 dB or more)
 - Low-noise amplifier (LNA) in base receive multicoupler

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The downlink limits for different samples of the same mobile station production run will differ very slightly because of minor variations in the internal noise of the MS receiver. Similarly the uplink performance will vary slightly due to minor differences in actual compared to nominal transmit power. There is also, clearly, a greater uplink operating range and consequently a larger useful cell size for a mobile station of a higher power class (a higher rated maximum transmit power level). In general this difference is much less significant in a PCS-1900 system, where all the power classes are slightly different low power levels below 1 watt, than in the case of a GSM or North American cellular system, where the power difference between the largest and smallest power class is very significant.

In general, the system operator makes a decision to support a certain power class, and by default they will also support any *higher* MS power class as well. In some cases, the operator knows that their design will not provide 90% area and time coverage to the very smallest power class MS units. Typically, system operators first design for all but the lowest power class, and then adjust the system coverage as described on another page, to eventually handle all power classes. These adjustments may take 1 or 2 years. The immediate need for many operators is to meet a legally mandated target of overall population area coverage as soon as possible.

System Design and Installation

- **System designer estimates geographical traffic density**
 - **Market, demographic, and specific geographic features such as high-traffic roads, areas of pedestrian congregation, etc.**
 - **Desirable to do this for near, mid and distant future dates**
 - **Conduct design “backward in time,” then:**
 - **Chose some cell sites for longest term usefulness**
 - so no cells need be abandoned at later date
 - **First increase capacity by adding channels at a site**
 - **Then “split” cells into smaller cells**
 - new antenna sites installed

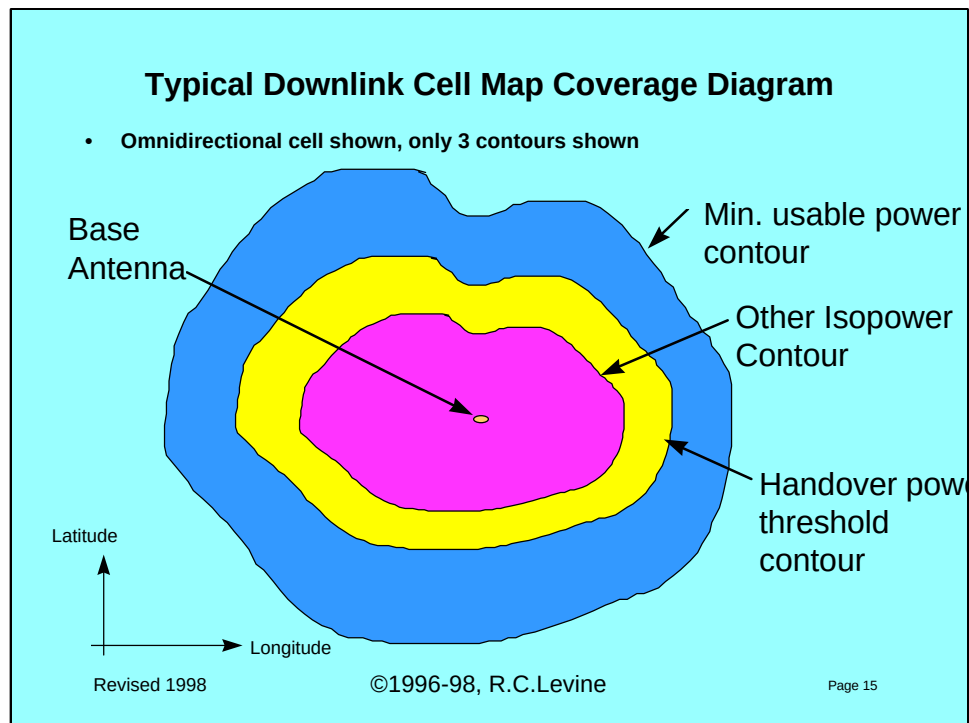
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These steps are common to all cellular system designs, regardless of the specific RF technology.

The relation between number of installed traffic channels and the traffic load which they can carry is a well understood process. Tables, charts or computer programs based on Erlang B or C probability distribution (or other statistical traffic models) are used to estimate the relationship between number of cells and expected total number of hours of simultaneous conversations per clock hour for a given probability of blocking (or grade of service GOS). For cellular and PCS systems the legally accepted GOS is a 2% probability of blocking, often expressed by the symbolic expression P02. Although a number of different statistical models are used in the industry, the ultimate refinement or fine tuning of the overall traffic handling design is always based on actual in-service traffic measurements. As the system traffic load increases, the first stage of upgrade uses additional base transceivers installed at each cell having increased traffic demand, to provide more carriers and thus more traffic channels. When the full allotment of carriers has been installed under the frequency plan that is in place, additional cell (antenna) sites can be constructed, usually by subdividing a cell into 3 or 7 smaller cells covering the original cell area (so-called cell splitting).



The indentation in the north-by-northeast portion of this cell is probably explainable due to a hill, tall building, or other obstacle. The greater range to the west and south compared to the shorter range to the east is probably due to generally greater path loss in the eastern propagation direction. This in turn may be explainable by more convoluted terrain in the eastern part of the cell, or heavier overhead foliage (particularly in and near summer season) in that portion of the cell.

This picture does not illustrate the appearance of small (blue) areas of weak signal strength which will often appear in the magenta (central) area of the diagram, due to locally strong absorption or shadowing of the radio signal. If this weak signal area does not coincide with an area of population (for example, if it is in the middle of a garbage dump, or a lake not used by people) then it is of little concern. If it is in a highly populated area (a shopping center or major business district) then we need to increase the signal strength there. This may be done by any of a number of methods. One of the simplest is to increase the base transmitter power, but this may not be sufficient, and it will increase overall cell size and cause more interference to other cocarrier cells in the system. We can use a radio repeater to increase the radio illumination in the weak signal area, but this also causes some increase in multipath at the edges of the weak area where both the repeater and the direct signal appear. In an extreme case, we may choose another base antenna location during the design phase to get more complete illumination, or use a larger number of small cells. These last methods are the most expensive, in general.

Contour Map Explained

- **Transparent overlay for USCGS map**
 - Positions on paper match Lambert conical projection
- **Not an antenna directionality graph**
 - Isopower curves are a result of antenna directionality *and* local site effects as well
- **Each color boundary is a specified iso-power curve (only a few important contours shown)**
 - Like isotherms on a weather map
 - Iso-BER can also be plotted
- **Theoretical**
 - Output from site-specific software: LCC, MSI Planet, etc.
- **Experimental**
 - Vehicle equipped with calibrated Rx and GPS

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Although an antenna directionality graph (dB on radial scale and angle on the angular scale of a polar graph) shown in a manufacturer's catalog is a good guide to the ground cover from that antenna, the final overlay showing lines of constant power (radio signal strength indication - RSSI) and constant BER value on a map is the true indication of cell coverage. One can make a reasonable estimate of ground radio coverage using any one of a number of software packages which estimate path loss, and utilize the actual directionality data for the antenna used at the base station, as well as data from the US Coast and Geodetic Survey (USCGS) which indicates the height of the ground above sea level at each 15 minutes of latitude and longitude. From this we get a theoretical graph of signal strength and/or BER contours. Measured data from the field indicating RSSI can be plotted as an overlay in the form of contours of constant RSSI and/or BER as well. Experimental data is even more accurate and should be gathered at each cell site before starting service. A major reason for the greater accuracy of experimental data is that most computer programs for computing radio wave propagation treat the effects of buildings, trees and other objects on the radio propagation in a very approximate and somewhat subjective way. Real measured data does not involve assumptions to the same extent that these radio coverage software packages do!

Control of Cell Size

- **Antenna height should be sufficient to cover largest expected cell via line of sight**
 - Inflexible situation to be limited by height
- **Downlink range mainly controlled by**
 - Base Tx power level adjustment
 - Antenna gain, directivity
 - Use of electrical and/or mechanical antenna downtilt
 - Electrical downtilt is preferable for omnidirectional antennas
 - Careful about back lobe effects with mechanical downtilt in sectored cells

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Cell coverage must frequently be adjusted seasonally due to the different amounts of absorption from foliage (leaves, etc.) on trees over the street and sidewalk areas where the mobile users are located. Base transmitter power must be increased slightly in the summer, and then decreased slightly in the winter. Usually no physical change is made in the base receiver usable range, except by mechanically tilting the antenna to point its main lobe at the most distant service area. The uplink is designed with adequate coverage so it is as large as the largest expected downlink coverage area. Changes in the nominal uplink (base receiver) cell size are actually mainly software changes in the handoff thresholds for RSSI or BER, which are discussed later in these notes.

Minimum Signal

- **Minimum usable signal strength must exceed total noise and interference by the appropriate $C/(I+n)$ ratio (typically 17 dB for analog 30 kHz)**
- **Noise level of receiver**
 - Fundamental physical property of thermal motion of discrete electrons
 - Calculate from temperature, bandwidth: $n=kT \cdot \Delta f$, 0.8 fW or -121 dBm for 200 kHz signal bandwidth
 - Noise Figure of receiver (added noise from internal amplifier) adds typ. 3 to 7 dB more (-119 to -116 dBm)
- **Interference: primarily co-carrier signals, level set by design as *low* as possible**
 - Greater Tx level at all stations works, but wastes power

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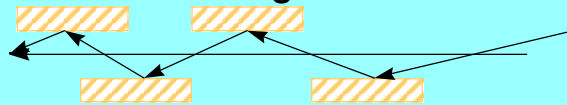
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A *noise limited* system would require a signal strength at the outer periphery of a cell to be at least -101 dBm for a receiver with a -119 intrinsic noise and using 18 dB as the desired S/n ratio for good reception. Only the outermost boundary of the outermost cells of a system are noise limited. In all other parts of the system, the interference (primarily co-channel interference) from other cells in the system is the primary factor. Cellular and PCS systems are designed to be interference limited. Thus, the minimum usable signal strength at the periphery of an *interior* (interference limited) cell is typically about -95 dB. We design the system to use the lowest feasible transmitter power all around (bases and mobiles) so we get maximum talk time from battery powered mobile sets and minimize wasted excessive power.

Incidentally, the maximum power that a radio receiver can use without distortion or intermodulation is typically about 50 to 60 dB greater than the minimum power due to internal noise. We thus say that the receiver has a 50 or 60 dB *dynamic range*. Part of this dynamic range is the result of automatic gain control (AGC), which internally adjusts the receiver RF amplification to suit the incoming signal strength. Weaker signals are amplified to the fullest extent possible. Stronger signals are automatically amplified at a lower amplification setting. The result is that signals appear at the internal detector or discriminator stage of the receiver, where they are demodulated, at about the same voltage level regardless of their radio signal strength at the Rx antenna.

Multipath, Fading and ISI

- RF transmission is degraded by “multipath”
- Multipath propagation occurs when there are radio reflective surfaces in the environment
- At the Rx antenna the total signal is the sum of
 - direct rays
 - rays delayed due to several reflections and a zig-zag path
- Multipath can cause both *fast fading* and *inter-symbol interference (ISI)*

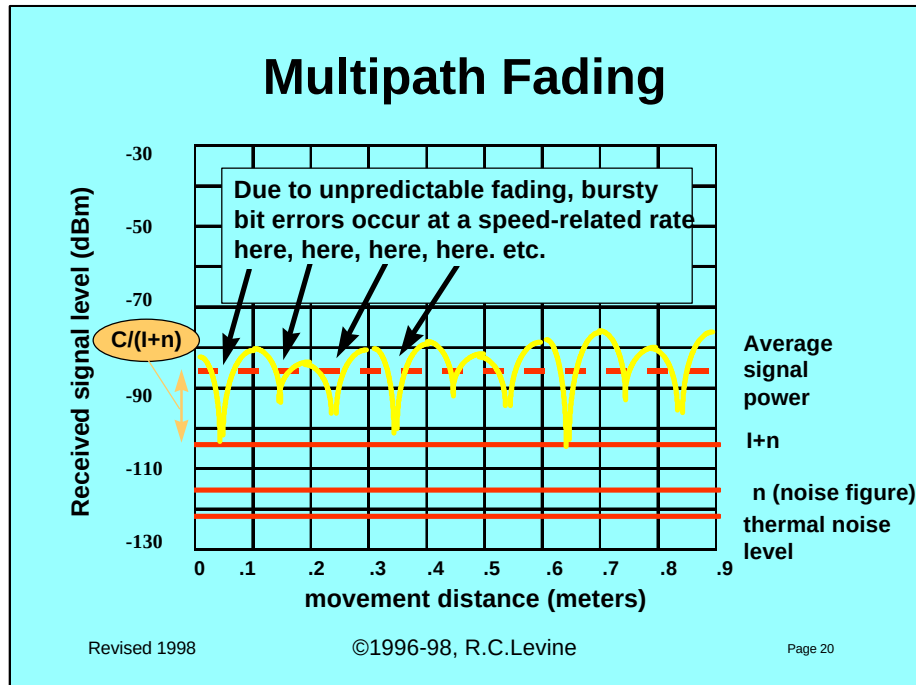


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Radio multipath occurs in all frequency bands, but the way in which it affects UHF radio for PCS systems is primarily due to the fact that the wavelength is smaller than human size, so we can move (on foot or in a vehicle) at a speed of several wavelengths per second.



Irregular but approximately periodic fades are a characteristic of multipath radio propagation. The major fades occur approximately a half wavelength apart when the various delayed radio rays are almost parallel.

When the signal strength fades, the interference and noise in the receiver dominates for a short time and the output depends on chance rather than the transmitted signal. The objective of a good design is to keep the intrinsic bit error rate (BER) below about 1%, by designing the system so the average signal strength is stronger than the combination of interference (I) and noise (n) by the capture ratio (typically in the range of 17 dB) even at the outer edges of the cell. This goal is not always achieved fully, and as we approach the outer edge of the cell, the BER increases to 3, 5 or even (briefly) 8%. This can be detected due to the use of error detection codes in the digital signal transmissions, and used to initiate a handover.

The radio receiver internally produces a noise level which is the result of thermal agitation of the electrons which make up the small electric current. The power level of thermal variation in current is proportional to the absolute (Kelvin) temperature and the bandwidth of the receiver. Due to imperfections in the transistors and diodes used in the radio, there is a further increase in noise level described by a so-called noise figure, producing a total equivalent noise n. The interference, primarily from other cocarrier sources in other cells, adds to this to produce the “floor” for interference limited operation.

Fading Happens Because...

- **Direct and delayed rays are out of phase**
 - During part of an oscillation cycle, one electromagnetic wave is pushing the electrons in the antenna in the *opposite* direction from the other electromagnetic wave.
- **In the special case of two waves of equal amplitude, exact cancellation occurs at some locations**
- **Due to short wavelength, a very tiny delay time spread can produce significant fading**
 - ~300 mm (12 in) wavelength for 800 MHz
 - ~150 mm (6 in) wavelength for 1.9 GHz

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We almost never get two equally strong rays producing total cancellation. In most situations there are a large number of delayed rays having a variety of signal strengths. The result is a random fading pattern rather than a strictly periodic fading, although the major fades are approximately periodic. The depth of the fades in most cases is limited. The deepest fades are about 20 dB below average power level, and that does not occur very often. The strongest peak signal levels are about 6 dB above average level, but most peaks are lower than that.

To Combat Fading...

- **Fading allowance (margin) in RF coverage design**
- **Diversity: place, time, frequency**
 - **Receive antenna diversity (at the base station)**
 - Fading seldom occurs simultaneously at two places, particularly when they are an odd number of quarter wavelengths apart
 - **Time and/or frequency diversity of the signal**
 - Fading seldom occurs simultaneously at two different frequencies in the same place, so signal could be transmitted again later in time, or RF frequency can be changed intermittently, or a wideband signal is used made up of many different frequency components
- **Interleaving, a form of time diversity**
 - Bits from a digital signal are separated and some are sent at a later time than others, then reassembled
- **Error Protection Coding (using additional digital bits):**
 - **Error detection codes together with retransmitting algorithms replace badly received data**
 - **Error correction codes allow identification and reversal of wrong bits**

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We never get perfect error-free digital radio transmission on a moving UHF transceiver, but we can achieve almost perfect final processed data rate if we design the system with adequate compensation for raw bit errors by means of error protection coding, proper use of antennas and equalizers, and always operate in regions of adequate signal strength.

InterSymbol Interference (ISI)

- **When the multipath delay spread is greater than about 20% of the symbol duration, ISI can be a problem. To combat ISI...**
- **First, the receivers are equipped with an adaptive equalizer**
 - This equalizer examines the effect of multipath delay on the known training sequence, and then uses this information to undo that effect on the other bits in the cell using internally delayed replicas of the signal
- **Second, the error protection codes help detect/correct errors regardless of whether they are due to fading or ISI**
- **ISI cannot be combatted by using a stronger signal.**

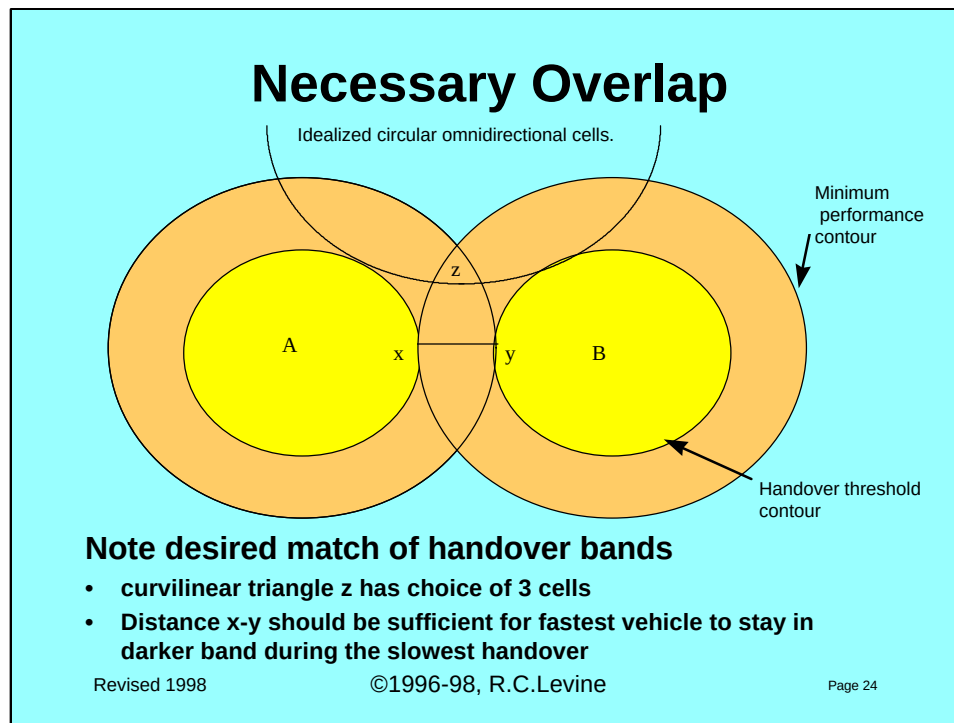
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Before the actual field tests, there was a great deal of concern that large delay spreads would make a high bit rate system like GSM impractical. Measured delay spreads in the foothills of mountains are as large as 16 μ seconds. Typical delay spreads in crowded city areas are 4 to 8 μ s. This is a larger time interval than the bit duration of the GSM/PCS-1900 bit (only 3.6 μ sec). However, the adaptive equalizer used in GSM and PCS-1900 does a more than adequate job correcting this ISI. Nevertheless, it is desirable to design the placement of base antennas so that strong delayed reflected radio signals (such as from the side of a cliff) are minimized by placing the base antennas so that illumination of such reflective vertical wall-like surfaces is avoided.

Similar concerns were expressed before the testing phases of the North American TDMA system, although the lower bit rate there makes the symbol duration more than twice the worst measured delay spread. Again, these concerns appear to be unwarranted based on actual system performance.



Cells are often represented by simplified abstract shapes such as a hexagon or a circle. In this diagram, a circle is used to illustrate two important contours of equal power (or more aptly, equal BER in a digital system). The MS can operate adequately all the way out to the outer circle, in both the yellow and darker areas. It is desirable that the handover threshold (usually based on BER, but also involving RSSI - radio signal strength indication in many systems) should be aligned with the outer boundary of the adjacent cell or sector.

If the handover boundary is too close in, then the handover process may start before the MS enters the valid service region of the adjacent cell. If the handover boundary is set too far out, then the system may not have time to perform a handover for a very fast vehicle moving from one cell to another. The system does have a recovery algorithm to reconnect a call which is dropped because of such a problem, but the recurrence of such problems is a clue that the handover threshold should be fixed. Note when this happens on a high-speed expressway which crosses the mutual cell boundary lines.

Some areas, like region **z**, can receive adequate service from any one of 3 cells. When a MS enters that area from one cell, there are two possible handover target cells. If the relative signal quality or the available number of traffic channels in the two cells does not immediately settle the issue, data based on historical patterns of handover and geography of roads in area **z** will help to choose the best target most of the time.

Handoff Control Parameters

- For analog systems, radio signal strength indication (RSSI) is the major measurable parameter
 - Sometimes RSSI is misleading, particularly when significant interference is present
- For digital systems, BER *theoretically* tells all...
 - Incorporates effects of weak RSSI and/or bad interference
 - BER reported for traffic channel in mobile-assisted handoff (MAHO)
- Some operators like to trigger handoff based on inclusive-OR of
 - RSSI below sector-optimal threshold
 - BER above sector-optimal threshold
- Handoff process cancellation levels (of BER, RSSI) are also important
 - usually set at better signal levels than the start threshold, for *intentional* hysteresis

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One of the few things which the system operator can do to “tweak” or “fine tune” the system after all the antennas are fixed in place, is the adjustment of handover threshold values. Everyone treats this as a “magic number” and there is as much superstition as fact surrounding the methods used by various operators to set optimal threshold levels.

The objective is to hand over all calls without dropping any, and also to not start a handover (or cancel it) when it is not needed (since it consumes internal processing and data communication resources within the infrastructure). The prerequisite to meet these objectives is proper RF coverage in all adjacent cells. Then the thresholds must be set as described in the previous page so the cell boundaries line up with adjacent cell thresholds. The preferred parameter to control handovers is the bit error rate (BER). However, if you find that BER and RSSI contours which should match geographically are very separate, it is likely that there is an unsuspected source of RF interference which is increasing the RSSI but corrupting the data, and you should search for and remove it.

The “cancel” threshold is normally set at a better signal quality than the start handover threshold to avoid “ping-pong” starting and stopping of the handover process for a MS which is moving along the threshold boundary. If an MS enters the darker handover zone on the previous page, and then turns around and moves back toward the center of the cell, it is desirable that the MS can actually come in a little closer than the starting radius before canceling the handover process. More on handover later in the course.

To Add Capacity...

- **Install more carriers in cell (up to limit of TotalCarriers/n)**
- **Sectorize (if originally omni) and reduce n from 7 to 4, then install more carriers**
- **Overlay with low power carrier(s)**
 - Only adds capacity in central cell portion
- **Split cell, and install TC/n carriers in new small cells**
- **Use half-rate speech coder when ready**
- **Use smart antennas when ready**

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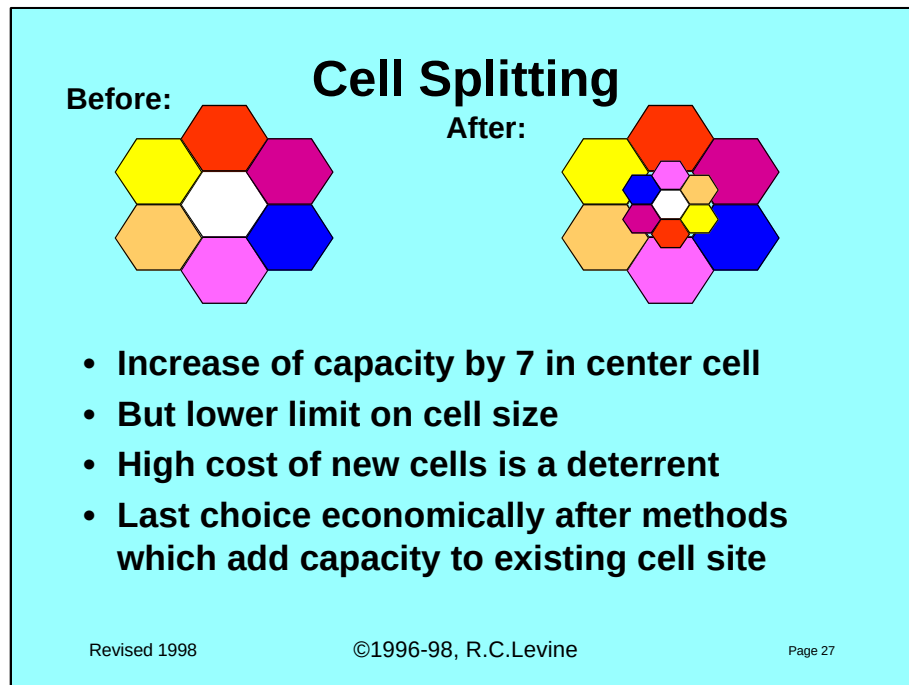
An operator will begin by installing at least one carrier supported by one base transceiver (BTS) in each cell (or each sector). In a TDMA system like GSM or IS-136, that first *beacon* carrier can support the shared channel used for call setup and related operations. The remaining 7 or 2 physical channels (time slots) can support conversations. Any additional carriers each support up to 8 (or 3) conversations. To add more capacity, just add more carriers. But there is a limit due to the number of carriers in your licensed band. If your license only permits 75 PCS-1900 carrier frequencies (A,B, or C band PCS license), and your frequency plan is $n=7$, you can only install $75/7$ or 10 or 11 carriers per cell. (Since the exact ratio is 10.714... you can install 11 carriers in about 70% of the cells, and 10 carriers in the remaining 30%.)

If your initial design was not sectorized, you can change out the antennas and go to 3 sectors per cell, immediately following up with a new frequency engineering plan with $n=4$. You can then increase the number of carriers in each cell from 10 to 18 ($75/4$). Of course, most PCS systems are initially designed with sectorized cells to begin with.

Overlay of some additional carriers which do not fit into the normal frequency plan is helpful only if you have a heavy concentration of traffic near the center of the cell.

Cell splitting is workable but very expensive. You need to justify the capital cost by an almost immediate increase in traffic density.

The half-rate codec and improved smart antennas have great promise for the future.



Academic sources inaccurately describe cell splitting as an essential feature of cellular frequency reuse systems, which allows the capacity to be increased without limit. This is incorrect for two reasons.

First, the lower transmit power which can be controlled in a mobile set cannot go below about 5 milliwatts. This is due to leakage of RF from the internal electronic circuits, even without an external antenna. This limits the cell size to not less than about 50 to 100 meters. Attempting to use a lower design cell size will produce unacceptable cocarrier interference to other small cells.

Second, the cost of additional cell sites is very high, and must be compensated by an almost immediate increase in traffic density and revenue. If the growth is too slow, the cellular operator may lose money for months or years until the traffic and revenue increase by a factor of 7 in the split cell area.

There are several methods for adding more antenna sites without the full cost of a complete base installation. One method is to put only the base transceiver (BTS) at the antenna site, and then use one base controller (BSC) to serve several BTS locations. Another method is to feed the antenna remotely using either CO-axial cables or fiber optics to carry the RF signals to/from a central base equipment installation. A set of small RF amplifiers is needed at the antenna location for both outgoing and incoming RF signals.

Early Cellular Systems

- **First cellular experimental analog systems (1979):**
 - AT&T AMPS system (Chicago, IL)
 - Motorola TACS system (Baltimore, MD, Washington, DC)
- **First commercially operating systems were NMT-450 (Scandinavia) and NTT-MCS (Japan)**
- **In early 1980s, 9 incompatible cellular radio systems were in service in Europe**
 - 7 different incompatible analog technologies
 - 2 nations technology compatible to 2 others,
 - but no roaming service agreements!
- **Clearly incompatible with the technology unification plan for the European Economic Union.**
 - CEPT (later ETSI) convened Groupe Spécial Mobile (GSM) meetings (1982) to develop Pan-European second generation cellular technology. Design documents issued 1989-91.

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The trade names of the first two systems later came to have slightly different meanings. Advanced Mobile Phone Service (AMPS) was originally an AT&T trade name, but later became a generic name for the North American analog 800 MHz technology, particularly when used by non-North American speakers or writers. Total Access Communication System (TACS) was originally a Motorola trade name, but became a generic name for the British 800-900 MHz analog cellular system (which is also known as E-TACS, for European-TACS), particularly when used by non-British speakers and writers. The TAC acronym survives in other Motorola products, such as the MicroTAC™ handset.

CEPT is the acronym of the Conférence Européenne (des Administrations) des Postes et des Télécommunications, an international standards body which still exists but today is more devoted to legal and tariff issues. Most of the technological standards activities of CEPT (particularly for cellular and PCS systems) have now been taken over by the European Telecommunications Standards Institute (ETSI) with headquarters in Sophia Antipolis, France (a suburb of Nice, France).

More North American History

- **Concern about traffic saturation led to experiments in digital cellular:**
 - AT&T Chicago FDM demo (1988)
- **TIA TR45 Sub-committees formed to design digital cellular**
 - TR45.3 decision on TDMA in 1989-90 led to IS-54 “dual mode” digital cellular in 1990
 - Interest in Qualcomm CDMA proposal in '89 led to TR45.5 committee and IS-95 in '92
 - TR45.3 also designed IS-136 “all digital” TDMA in '94

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The FCC and the industry in general has followed a policy of free competition. This will eventually lead to an expected “shake-out” in a few years, since nobody really wants to continue indefinitely with so many different incompatible radio technologies. More comments on this at the very end of the lecture.

Design Objective Contrasts

- **Original first objective of GSM design was Pan-European technological standardization**
 - Secondary objective was high-technology to stimulate European production capabilities
 - Traffic capacity target nominally equivalent to pre-existing 25 kHz European analog cellular bandwidth (200kHz/8)
- **Backward compatibility was *not* an objective**
 - No “dual mode” handsets
- **Contrast this with North American TDMA (IS-54),**
 - First objective: higher capacity
 - Second objective: backward compatibility
 - These North American objectives somewhat complicated the design of an otherwise simpler system

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People frequently ask, “Why are the designs of North American TDMA and GSM/PCS-1900 different in this or that aspect?” Some of the reasons relate to the intended connection to the North American vs. the European public switched telephone network (PSTN), with the attendant technological and regulatory differences. Much of the fundamental difference, however, is based on the difference in design objectives. In North America, a significant amount of time (almost 2 years) was wasted arguing about the access technology, particularly FDMA (frequency division multiple access or use of narrower bandwidth radio channels for each conversation), TDMA (time division multiple access -- actually used in GSM/PCS-1900 and IS-54), and later CDMA (code division multiple access), with each side claiming that their proposed technology had inherently higher capacity than the others. In fact, all three of these access technologies have about the same inherent capacity. The most important system differences relate to secondary factors like the speech coder, DSI, or the economics of sharing common base equipment in TDMA.

The following two references both conclude that the theoretical capacity (conversations/kHz/km²) of CDMA, TDMA and FDMA are all equal, provided that all systems compared either all do (or all do not) use dynamic channel assignment (DSI) via voice activity control to fully utilize available channels during pauses in speech. Of course, there are also numerous publications which conclude that CDMA is inherently capable of greater capacity than other technologies, as well as a few papers which conclude just the opposite.

1. Paul Newson, Mark R. Heath, "The Capacity of a Spread Spectrum CDMA System for Cellular Mobile Radio with Consideration of System Imperfections," *IEEE Journal on Selected Areas in Communications*, V. 12, No.4, May 1994, pp.673-684.

2. P. Jung, P.W. Baier, A. Steil, "Advantages of CDMA and Spread Spectrum Techniques over FDMA and TDMA in Cellular Mobile Radio Applications," *IEEE Transactions on Vehicular Technology*, V. 42, No. 3, August 1993, pp. 357-364.

Access Technology Arguments

- **Many arguments ostensibly raised about access system technology comparisons actually relate to other, alterable aspects:**
 - **Speech coder can be changed, upgraded**
 - **Note recent enhanced full-rate (EFR) coders**
 - **Digital Speech Interpolation (DSI) can be added, upgraded**
 - **Modulation can be changed in design stage**
 - **Features and services can be added**
 - **Are all other factors held constant?**
 - **Is inter-cell reuse interference accurately taken into account?**
 - **Elevated CDMA capacity estimates arise partly from mischaracterization of adjacent cell interference as RF white noise**

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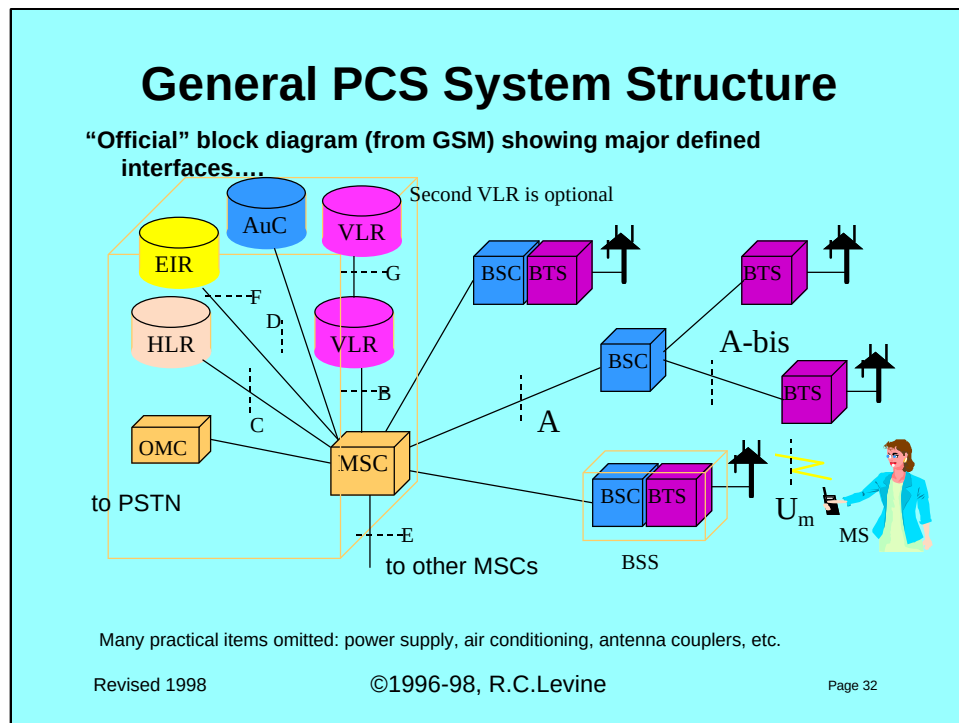
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Unfortunately the objective of some participants in the public debate about PCS and cellular technology is not always to present all the facts and evaluate them dispassionately. There is more fluff and puffery already thrown out on this subject, and the problem is aggravated by the fact that many of the people who need to make executive decisions about which technology to buy do not have a technological education or background, or when they do it is not heavily flavored with the specific technology topics which are most significant for PCS system evaluation.

I feel that the underlying technology is not mysterious, and anyone with an interest and a reasonable background can learn enough to make valid decisions based on their own understanding of the issues. Even though I make much of my income advising executives about technology, it is easier for me to work with a person who understands the technology than with someone who resists learning the technology and just wants a “go/no go” technical opinion from an expert.

You can learn what is required. You can learn the jargon and read the documents and ask questions. And don’t take “expert opinion” as the only answer. The late physicist, Richard P. Feynman, said, “I finally recognized that the reason I could not explain the Pauli exclusion principle [a rule in atomic physics that certain different elementary particles never have the same energy] to my students in simple terms was because I do not really understand it!” Keep that in mind when people tell you, “It’s too complicated to explain.”



This diagram and the names used with it are due to the GSM standards. A very similar terminology has been adopted for North American standards by the TIA.

AuC Authentication Center (data base). Associated with HLR.

BSC Base Station Controller

BSS Base Station Sub-system (collective name for BSC + BTS)

BTS Base Transceiver Station

EIR Equipment Identity Register (data base). Associated with HLR.

HLR Home Location Register (data base). Can be located with the MSC, or may be distant. In some implementations, multiple MSCs share the same HLR.

MS Mobile Station (or Set)- includes portable handsets

MSC Mobile-service Switching Center. In some cases an MSC can also serve as a gateway MSC (GMSC) to the public network. In other cases, it is only connected to other MSCs. The almost synonymous term Mobile Telephone Switching Office (MTSO) is frequently used for this switch in older cellular systems.

OMC Operations and Maintenance Center. In some implementations, one OMC serves multiple MSCs and other equipment.

PSTN Public Switched Telephone Network

VLR Visited Location Register (data base) - includes both visiting and active home subscriber data. Usually built into the MSC. In some implementations, HLR and VLR are the same physical data base, with records active in the VLR specially/temporarily marked as required.

Interface names (A, Abis, B, C, etc.) were arbitrarily assigned in alphabetical order. The U_m label is taken from the customer-network U interface label used in ISDN. Although mnemonics have been proposed for these letters, they are after-the-fact.

VLR Data Base

- **Misleading name- “Visited” Location Register**
- **Data needed to communicate with MS**
 - Equipment identity and authentication-related data
 - Last known Location Area (LA)
 - Power Class, other physical attributes of MS
 - List of special services available to this subscriber
- **More data entered while engaged in a Call**
 - Current cell
 - Encryption keys
 - etc.

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Data from the VLR is used to set up a call and maintain data about the call, including the generation of the detail billing record for billing purposes. All the physical, radio and electronic information needed for setting up a call is available in the VLR.

HLR Data Base

- **Home Location Register**
- **Need not be part of the MSC**
 - One HLR can be shared by several MSCs
 - Some operators plan a single regional HLR for shared use by several MSCs
- **Contains “everything” about the customer**
 - IMEI, Directory Number, classes of service, etc.
 - Current city and LA
 - particularly when not in home system
 - Authentication related information
- **In some implementations HLR and VLR are the same physical data base**
 - VLR records distinguished logically via “active in VLR” bits

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The HLR contains all the “background” information about each subscriber needed to “reload” the VLR when that particular subscriber appears in the service area of the appropriate VLR.

In the GSM or the IS-136 systems, when the customer is roaming to another city or system, the HLR contains the system identification number and the most recent LA in which the MS was located. This occurs automatically when the MS enters a new LA or new system area. A series of transactions take place in the cell and on the carrier frequency which the MS identifies as new (different from the System ID and LA of the previous carrier frequency just used before that). The visited MSC notifies the HLR by means of messages through the signaling network which connects all the MSCs and their associated VLRs and HLRs. In the European GSM network, the signaling messages used for this purpose form a part of a vocabulary or set of messages described as MAP (mobile application part), which is a special subset of Common Channel No. 7 signaling. The MAP was developed just for GSM. In North America, a similar (but not identical) set of messages, also called MAP, are described in TIA standard IS-41. These messages can be transmitted via Common Channel 7 signaling associated with a telephone network, or they can also be transmitted via other types of data communication networks such as TCP/IP or X.25 packet data networks. Each operator and his vendors make a choice about the specifics among these implementation choices.

Base Station Assembly

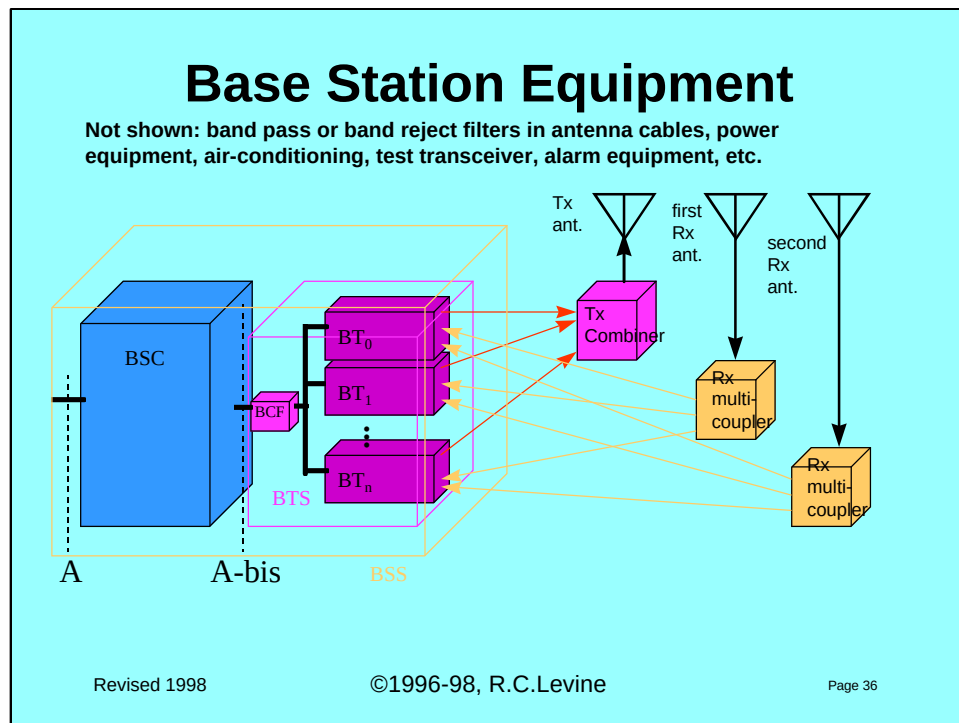
- **Antennas**
 - **Transmit Combiner Processing**
 - **Receive Multicoupler/Low Noise Distribution Amplifier**
- **Base Transceiver**
 - **Transmitter Section**
 - **Receiver Section**
 - **Antenna Diversity Processing in Receiver**
- **Base Station Controller**
- **Many support devices: power, air conditioning,**

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Many aspects of the base station design are specifically intended to make the cost lower than analog systems. For example, the use of only one base transceiver is feasible in a low traffic cell (compared to at least two transceivers in an analog system). Eight channels on one carrier in one transceiver implies that less transmit combiners (or none for a one carrier base installation) are used, reducing the cost and space for equipment, and the power wasted. The ability to operate several BTS units off of a common BSC, even when they are geographically separated, is a major cost saving compared to the need to fully equip each base station with its own control equipment installation in analog technology. The multiplexing and the low RF power level used in PCS systems also makes the equipment smaller and less costly to install. The cost of smaller building space is lower, whether you rent or buy.



Readers who are familiar with analog cellular equipment will note that there is no locating receiver here.

Carrier number zero is associated with Base Transceiver zero, and the common shared channels such as broadcast, dedicated, reverse access, etc., are on this carrier and transceiver. In a GSM system, at least 6 of the time slots on this carrier zero are used for customer traffic. The other transceivers devote all 8 (3 for IS-54 and IS-136) of their time slots to customer traffic.

Standard industry jargon replaces part of many words with the letter x. Some examples:

Tx = transmitter

Rx = receiver

Xtal or Cx = crystal (used in some oscillators, etc.) (not on this slide)

Other abbreviations:

BCF Base Control Function

BT Base Transceiver (one carrier, 8 time slots)

Inside the Boxes

- **Transmit Combiner contains**
 - Tunable resonant cavity filters
 - Directional couplers
- **Its purpose: feed *most* Tx power to Tx antenna, *not* to other transmitters**
- **Receive multi-coupler is RF low-noise pre-amplifier**
 - similar to TV community antenna distribution system
 - distributes Rx signal to all receivers at same level they would get from an *unshared* Rx antenna

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The receive multicoupler can compensate for splitting the receiver antenna signal between several receivers, and it can add a little bit of gain to the signal, but like all amplifiers it also introduces more noise of its own.

Transmit combiners normally discard half the power from the transmitter in the form of heat, because they use a directional coupler which splits the power so half of it goes on to the antenna and half to a suitable resistor with cooling fins. The important part of its operation is that no part of the power gets into the output of other RF transmitters which share the same antenna, to there cause overheating and damage! A transmit combiner typically has 4 (or for some units, 8) inputs and one output. If more than 4 transmitters must be combined onto a single antenna, then two stages of combiners are used, and 75% of the power is turned into heat. This situation is better than for an analog system, but it is still a significant consideration in the overall power budget. Most combiners contain frequency filters which must be manually retuned when the carrier frequency of the associated input is changed. Many vendors make combiner filters which can be remotely tuned by means of a precision remotely-controlled stepper motor which rotates the tuning axle, thus facilitating changes in the carrier frequencies at a cell site without dispatching a technician to the site.

Why 2 Base Rx Antennas?

- **Dual antennas diversity improves base reception sensitivity by as much as 2 to 5 dB vis-à-vis a single antenna**
- **Spacing of antennas should be *odd* multiple of $\lambda/4$, preferably $>8\cdot\lambda$ apart**
- **Several methods for diversity combining:**
 - **Switching/selection**
 - **Equal gain**
 - **Maximal ratio****vendor design choice, not standardized**

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Early (ca. 1978) analog cellular mobile stations used two antennas for *mobile* diversity reception as well. Most customers were unwilling to pay the extra installation costs for a two-antenna system, and single antenna mobile sets have since dominated the market. System designers must design with a single antenna mobile set as their objective, which implies *at least* 3 dB more signal strength must be delivered on the street compared to the “old” mobile diversity sets.

From time to time, various manufacturers have shown special mobile antenna units with two individual antennas mounted one above the other in a slender tube which is no more difficult to install than a single antenna. However, vertical separation diversity is not as effective as horizontal separation diversity, which is universally used at base stations.

Receiver diversity improves signal/noise ratio by 2 to 5 dB using two antennas. The amount of improvement depends on the placement and separation of the antennas and the technology used to combine the two diverse signals. Diversity usually gives at least 2 dB improvement or more in $C/(I+n)$ even for selection diversity. Use of a more sophisticated system such as equal gain or maximal ratio combining can improve that by as much as 2 dB more. Use of more than 2 antennas, or a properly constructed adaptive phased array, can improve the signal/noise even more, but is rarely done in cellular and PCS systems due to increased cost.

Diversity Combining

- **Switching/selection**
 - Stronger of two signals instantaneously selected
 - ~1 dB hysteresis in selection
 - Causes random phase shifts
 - Simplest, about 1.5 to 4 dB $C/(I+n)$ increase
- **Equal gain**
 - Adaptive phase shift hardware used to phase shift one channel to match carrier phase of other, then added coherently
 - about 1.5 dB better than switching diversity
- **Maximal ratio**
 - Like equal gain, but weaker signal is amplified to same average level as stronger signal
 - Most complex, but typically 2dB better than switching diversity

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The random phase shifts which occur as a result of switching/selection diversity restrict its use with phase modulated (as opposed to frequency modulated) signals. The switching instants must be restricted to the beginning or end of a TDMA time slot, and thus the effectiveness of this form of diversity is further reduced if the fading rate corresponds to time intervals generally shorter than a time slot.

Test Transceiver

- **Not required in standards, but available from most vendors**
- **A remotely controllable transceiver which mimics a mobile set**
 - Controlled from operation-maintenance position (OMP)
 - Uses a voice channel in the A interface
- **Permits many useful tests without sending a technician to the site:**
 - Place or receive a call
 - Talk over the radio link
 - Check RSSI independent of BSS equipment
 - etc.

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A test transceiver at each cell is an invaluable piece of equipment. Don't omit it if you are designing or provisioning an installation!

Why UHF Bands?

- “Because they are available” is a legal reason only, although very significant...
 - VHF and below, absolutely no available bands!
 - Former point-point microwave and military bands were made available around 2 GHz band
 - Still some incumbent microwave systems
 - Government auctioned bands to highest bidder
 - Strong financial motive to move quickly
- Technological reasons:
 - UHF follows “line of sight” propagation
 - Little/no over-horizon or “skip” radio propagation
 - MF, HF short-wave bands would be impractical for cellular
 - SHF bands require much more costly components, and some bands are used for extensive installed microwave or have strong attenuation

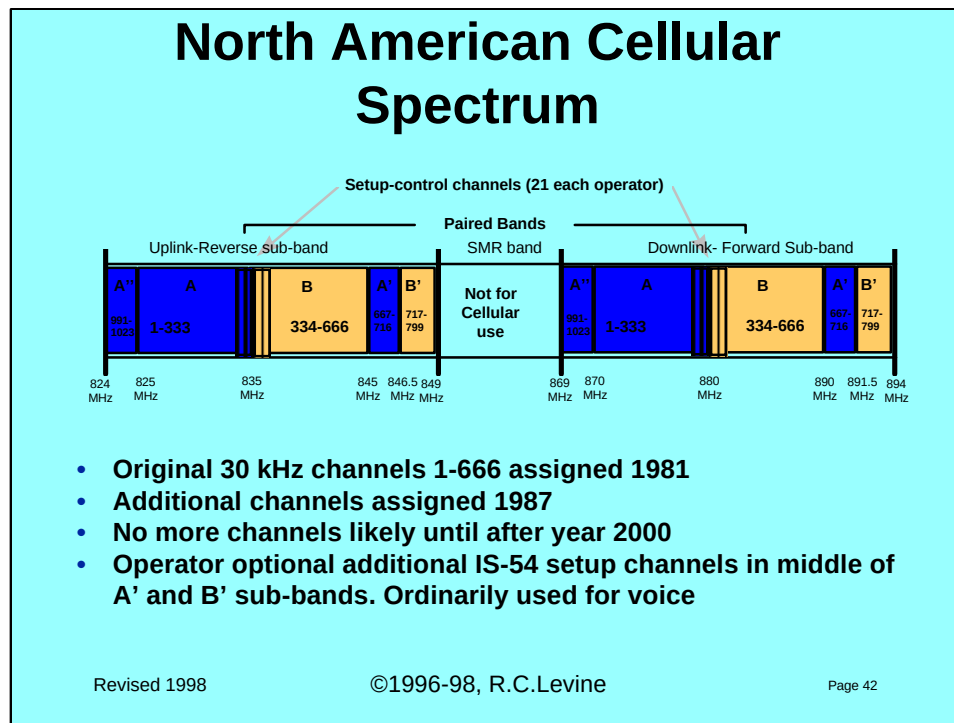
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In radio frequency band jargon, terms like medium, high, ultra high, etc. have very specific meanings. This chart shows the terms and shows a typical use of each band:

MF- Medium Frequency (AM Broadcast band)	100-1000 meters (0.1-1 km) wavelength	30-300 kHz (0.3- 3 MHz)
HF- High Frequency (Short Wave Bands)	10-100 meters wavelength	3- 30 MHz
VHF - Very High Frequency (TV Ch. 2-13 North America)	1-10 meters wavelength	30-300 MHz
UHF- Ultra High Frequency (800 MHz cellular, 900 MHz GSM, 1.9 GHz PCS-1900)	0.1-1 meters wavelength	300-3000 MHz (0.3- 3 GHz)
SHF- Super High Frequency	0.01-0.1 meters wavelength	3-30 GHz

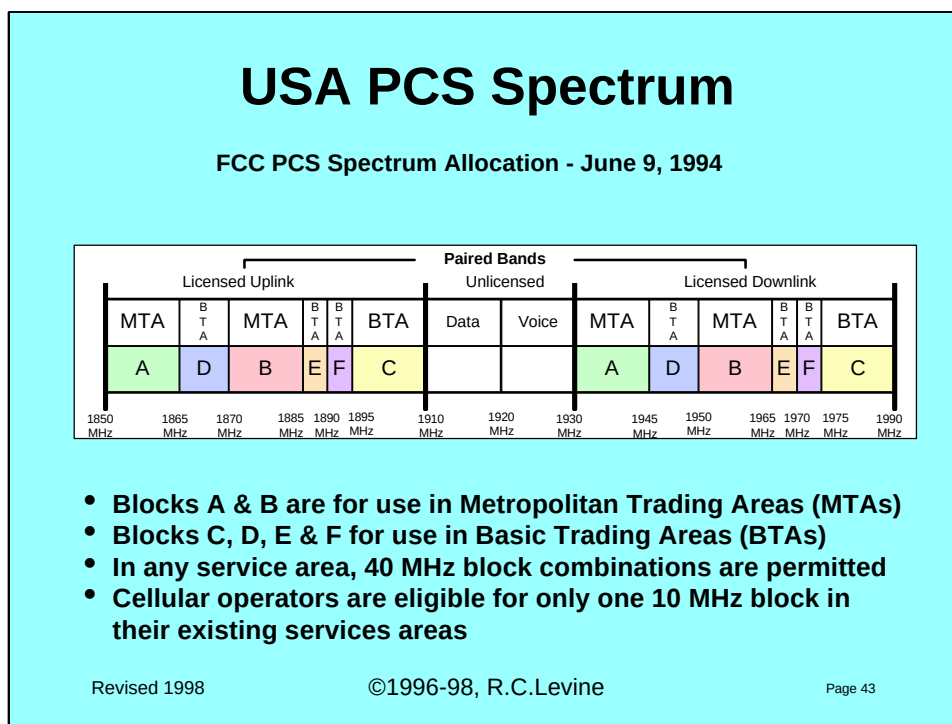


The North American 800 MHz cellular spectrum consists (at present) of 832 RF carrier frequency pairs. Each pair is called a channel, although this term is also used in different ways when a carrier can carry multiple TDMA channels. The 832 carriers are divided legally into two subgroups of 416, each subgroup allocated to one of two competitive operating companies (also called "common carriers" in the legal sense arising historically from railroad terminology). Within the 416 carriers, 21 are legally designated as primary control channels, and are prohibited from use for voice. There are also 21 secondary control channels (used only by IS-54 TDMA dual-mode radios) which may be used for voice instead, at the option of the system operator.

The "A" operating company is legally restricted to not have a financial interest in the local telephone operating company. The "B" operator in general also operates the local "landline" telephone service in the same city. As a memory aid, many "A" licenses are owned by AT&T wireless (formerly McCaw), although many are held by others, and most "B" licenses are owned by former Bell System operating companies, although a few are not. A landline telephone operating company can own a financial interest in an "A" license, so long as it is not in a city where they also own part or all of the landline operation. For example, Southwestern Bell owns a portion of the "A" license in New York, but is prohibited from owning even part of an "A" license in Dallas, where they already own the "B" license.

Analog cellular systems can perform adequately with a 63/1 (18dB) carrier to interference ratio. In a typical analog cellular system frequency allocation plan, the total number of carriers in use are divided into 7 subgroups, with each subgroup (of about 60 carriers) are operating in a cell. The 7 subgroups are arranged in a cluster consisting of 7 cells, and the geometric pattern of this cluster is repeated throughout the service area (typically a city and its suburbs). In some systems, the cells (particularly in the high-traffic areas of downtown) are further subdivided into three sectors, each covering about a 120 degree wedge of the circular cell, by means of three sets of directional base station antennas. Each sector then uses about 20 carriers, of which only one is a control carrier (channel) in analog cellular systems.

In systems using such a modulation and coding technology that the radios can perform adequately with a lower C/I ratio, four cell or three cell clusters, with proportionately higher numbers of carriers per cell, may be used. This produces greater capacity in conversations per square km, using the same cell size as comparable systems.



This shows only a portion of the 1.8-2.2 GHz spectrum which is currently being auctioned for voice and data PCS. Other sections of the spectrum are reserved for later auction. Certain bands are reserved for women and minority owned businesses, to be politically correct in allocation of the spectrum resources.

MTA- Metropolitan Trading Area

BTA- Basic (rural, suburban) Trading Area

(these names come from Rand-McNally commercial atlas maps of business districts in the USA).

Access Technologies

Name	Technology	Bandwidth	conversations/ carrier	speech coding	Modulation
Analog (AMPS) TIA-553, IS- 91, 94	Analog FM	30 kHz	1	analog FM (telephone 3.5 kHz audio)	analog FM (FSK for control signals)
N-AMPS IS-88 (Motorola)	Narrow Band Analog FM	10 kHz	1	analog FM	analog FM (subcarrier AM for control signals)
TDMA IS-54, IS-136	Time Division Multiple Access	30 kHz	3 [6]*	VSELP 8 kb/s + 5 kb/s FEC	Differential $\pi/4$ offset DQPSK
CDMA IS-95 (Qualcomm)	Code Division Multiple Access	1280 kHz	62	QCELP 9.6 or 13 kb/s	Binary and Quad. Phase Shift Keying
GSM and PCS-1900	TDMA	200 kHz	8[16]	REL P 13 kb/s +9.4 kb/s FEC	Digital FM GMSK

* 3[6] refers to 3 conversations at present, planned 6 in the future with half rate speech coder.

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AM	Amplitude Modulation
AMPS	Advanced Mobile 'Phone System, originally an AT&T trade name.
DQPSK	Differential Quadrature Phase Shift Keying.
FEC	Forward Error Correction code.
FM	Frequency Modulation
GMSK	Gaussian Minimum Shift Keying, a special type of digital FM with controlled gradual transitions between the two frequency extremes for the purpose of producing an optimal combination of narrow bandwidth and low susceptibility to interference.
GSM	Global System for Mobile communication, originally Groupe Spécial Mobile
NAMPS	Narrow-band AMPS
QCELP	Qualcomm Code Excited Linear Predictive speech coder.
PCS-1900	North American version of GSM on 1.9 GHz band.
REL P	Regular Pulse Excited Linear Predictive speech coder.
VSELP	Vector Sum Excited Linear Predictive speech coder.

Radio Design Objectives

- **We want a signal which has narrow bandwidth in ratio to the information transmitted**
 - Relatively high “spectral efficiency,” the ratio of data rate, in bits/sec, to bandwidth, in Hz (cycles/s)
- **At the same time, we want high resistance to interference**
 - Usable at a low $C/(I+n)$ ratio
 - Initial C/I used for GSM was 17 to 18 dB (63/1)
 - Now operating at about 14 dB (25/1)
 - permits $n=4$ clusters with 60° sectors
 - Theoretically we can approach 9 dB (8/1)
 - theoretically permits $n=3$ clusters with 60° sectors
 - requires optimum performance from antennas, frequency hopping, and other adjustable parameters

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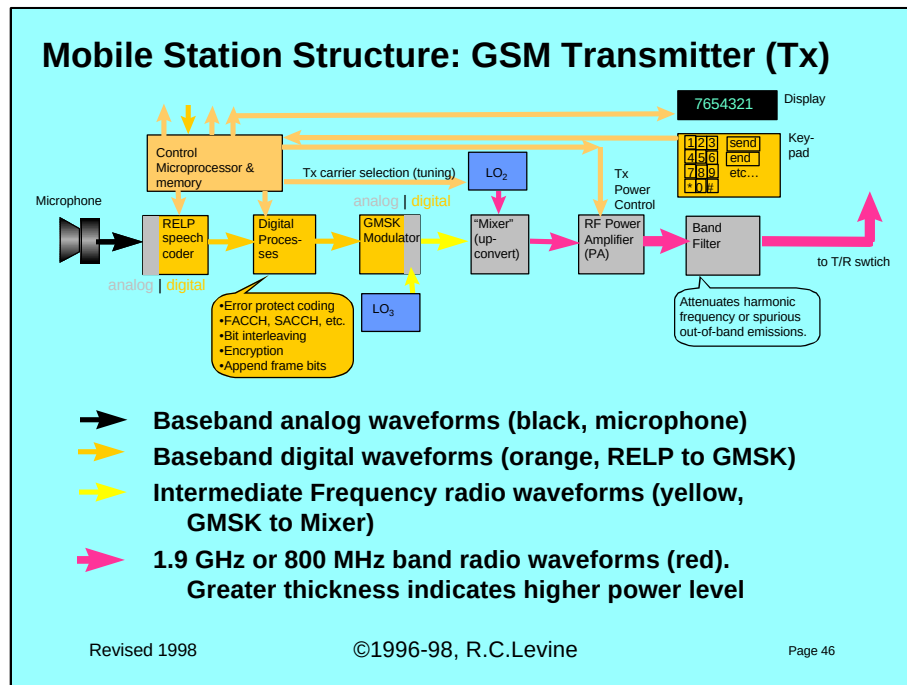
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The term “spectral efficiency” is only part of the story. The term is sometimes loosely used to describe overall capacity of a PCS system when comparing two technologies, and in that case what is actually needed to make a fair comparison is the *geographic* spectral efficiency, conversations/kHz /km² (or other appropriate measure of area). In a system used in an office or multilevel building, the space aspect of this comparison should rightly be based on *cubic* meters rather than land surface area.

Many types of modulation have high spectral efficiency, but rather poor ability to operate error-free in the presence of interference. One can demonstrate this by merely increasing the number of discrete levels used in many existing types of modulation. For example, increase from a 2-level FM signal to a 4 or 8 level FM signal. The bit rate increases (4 bits per symbol can be encoded using a 4-level FM signal), but (with the same signal level) the effect of interference is much worse (that is, a higher C/I ratio is required). Our objective is an optimum combination of the two properties.

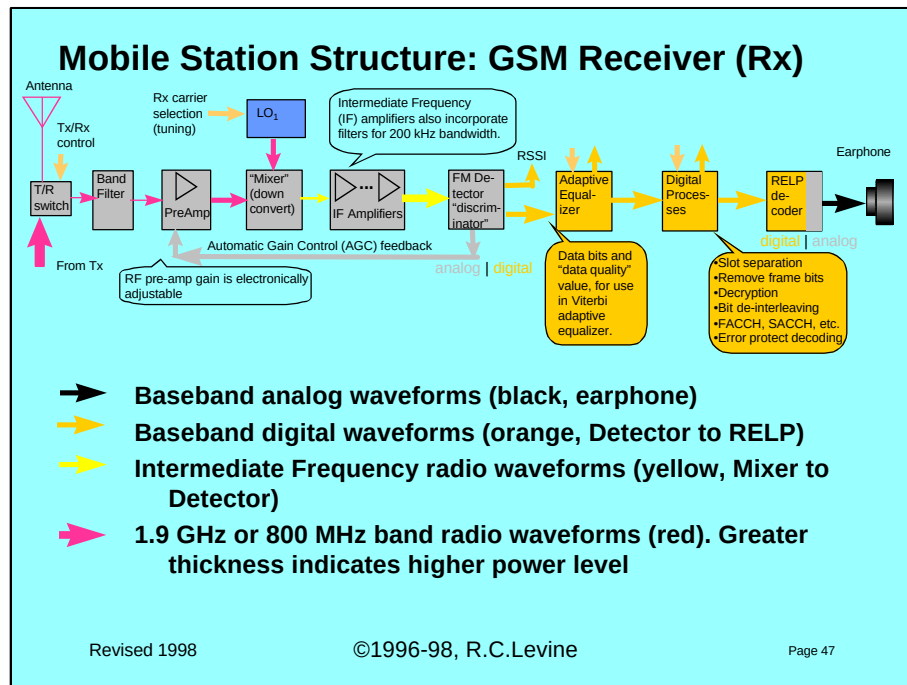
Improvements in the fading performance due to frequency hopping, use of improved antennas, and adaptive equalizers, ultimately permit the operation of the system at a truly lower $C/(I+n)$ ratio, and thus allow more carrier frequencies and more capacity in each cell.



This is a “generic” block diagram of a PCS-1900 Tx section in a handset transceiver. The base Tx is similar, but produces higher RF output power levels, and multiplexes 8 different channels onto one carrier. A particular manufacturer’s design may differ in many details, such as performing more or less of the operations in digital form by means of a digital signal processor (DSP) computer chip.

Both the Tx and the Rx use the “super-heterodyne” technique devised by Col. E.H. Armstrong, a pioneer radio inventor. Complicated signal processing such as modulation in the Tx and amplification and Rx filtering are performed at a relatively low frequency using less precise and less expensive components, which are optimized for use at only one frequency. A replica of the desired signal can be produced at a lower (for the Rx) or a higher (for the Tx) frequency by effectively multiplying it with a local oscillator signal. This multiplication of the two waveforms produces two new frequency components at a frequency equal to the sum and to the difference of the two signals frequencies, respectively. In the Tx, the modulator is design optimized to work at a so-called intermediate frequency (IF) from LO_3 which is typically 70 MHz (although some designers use 10.7 or 26 MHz). The desired transmit frequency signal can be produced by multiplying the modulated signal with the adjustable LO_2 which is set to 70 MHz below the desired Tx frequency (for example, to transmit at 1850.2 MHz, LO_2 is set at 1780.2 MHz). The “image” signal also produced at 1710.2 MHz is removed by filters and/or a dual mixer which subtracts the image signal. In the Rx (next page) LO_1 is adjusted to 70 MHz below the desired carrier frequency.

The RF power amplifier (PA) has adjustable power output level, aside from ramping the power up and down at the beginning and end of each Tx burst. All the major functions of the handset are controlled by the microprocessor, including the initial scanning of the RF spectrum to find and camp onto a broadcast channel so the handset can be initialized to work with the local base system.



This is a “generic” block diagram of a PCS-1900 Rx section in a handset transceiver. The base Rx is similar, but has duplicated modules from the band filter up to the FM demodulator for implementing Rx diversity. Also, the base transceiver uses separate Tx and Rx antennas since it transmits and receives continuously on all 8 time slots; no T/R switch.

The T/R switch uses a positive-intrinsic-negative (PIN) semiconductor diode to prevent high transmit power from getting into the Rx. A PIN diode switches from the ON to the OFF condition very quickly. The band filter attenuates radio signals from out of the 1.9 GHz band so that the Rx will not have “image” signal reception (from antenna signals which are *below* the LO₁ frequency by the IF value).

Most GSM and PCS-1900 Rxs use a Viterbi adaptive equalizer, named for Andrew Viterbi, who incidentally is one of the developers of CDMA, a competitive technology. Other digital technologies such as IS-54 and IS-136 or the RAKE equalizer in CDMA IS-95 mostly use a multiple delay line adaptive equalizer, a different method altogether. The Viterbi equalizer corrects for ISI by encoding an XOR of two time-adjacent bits in the GMSK modulator (see other page), and then evaluating the overall quality of a *sequence* of three or more received data bits, with regard to a numerical measure of the signal accuracy. If the frequency of the received signal is not exactly on the expected value for one bit symbol interval, a measurement of the amount of frequency error is passed to the equalizer along with the binary bit value (0 or 1). The Viterbi algorithm saves bit and accuracy data and checks all combinations of previous bits to find the sequence which has the smallest total error. Typically, it uses the last 3 or 4 bits, and thus has a corresponding 3 or 4 bit delay.

The amplification of the RF pre-amplifier is adjusted continually by means of the AGC feedback signal to provide extra amplification for very weak signals, up to the noise limited minimum receivable signal level. The received signal strength indication (RSSI) is used in the MAHO reports sent to the BS.

Mobile Station Power Classes & Control

- **Mobile sets are manufactured in various power classes**
 - **Large high-power RF output for vehicle mounting typically 3 W (up to 40 W in GSM)**
 - **Medium “bag phones” typically 1.8 W max**
 - **Handsets typically 0.6 W max**
 - Handsets are by far most popular for “use anywhere” convenience
 - Some “low tier” PCS systems use 0.1 or 0.2 W tiny handsets with limited range to base station

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High power class MSs, like the 20 watt vehicle mounted mobile unit in GSM, must have a final PA which can be adjusted for the full range of 16 power steps. They use the lowest power step when they are very close to a base station, or when they are in a small cell.

The high power MS can operate much further from the base, and is valuable for large rural cells.

In the PCS-1900 system, only hand held Mobile Sets of relatively low power are contemplated. Since GSM operates on a different radio band entirely, there is no possibility of someone bringing in a MS with power capabilities in excess of the PCS-1900 design limits and causing technical problems in the system. The PCS-1900 system is designed overall to work with lower power at both the base and mobile transmitter, and to use smaller cells than GSM, most likely in urban areas rather than in the open country.

The system operator has the option in PCS-1900 to adjust the base transmit power on a moment by moment basis, to use only the amount of power needed to communicate with the particular MS now connected. When it is close in to the base, turn down the base transmitter power, reduce cocarrier interference in other cells, and save some electric power cost.

Logical Channel Taxonomy

- **Some communication is via *shared* common physical channel (time slot)**
 - While idle, to get general system information
 - broadcast, paging, etc.
 - first access on uplink
- **Some communication via *dedicated* channel/time slot**
 - continuation of call setup
 - conversation, data communication
- **Logical inconsistency regarding logical channels:**
 - some documents categorize various types of messages which can appear on the same physical time slot as different *logical* channels
 - in other cases, different types of messages are just categorized as different *message types* in the *same* logical channel
 - part of the “computer science mystique”

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Today the concept of layered and structured description is generally applied to packet type digital communications systems. There is great merit in defining the software structure so that it can be divided into relatively independent programming tasks to allow parallel simultaneous development and testing of the software by different programmers. It is also valuable to define different parts of the data message (headers, etc.) so that changes in one portion do not affect other portions. However, the general concept of layered description of data communication systems sometimes reaches such a level of complexity that one can spend more time learning the terminology and jargon than in actually understanding how the system works. Some observers have accused the GSM standards of approaching this extreme level of self-imposed documentation complexity. In this course, we use the logical channel names because they are necessary to refer to the existing documentation effectively, but we do not dwell on them. From your point of view, it is actually sufficient to know only that certain types of messages are only allowed to be transmitted during certain scheduled time intervals on certain permitted time slots. The rest is jargon!

Every profession seems tempted to exalt jargon above meaning. If you try to read most textbooks on group theory applied to such topics as error protection coding or atomic physics, you will note that the first 60% of the book is learning jargon, then 10% is the actual concepts of group theory, and the remaining 30% is application of the theory to the topic at hand!

Analog Cellular Channels

- **Specified frequencies (one per cell or sector) used for setup or control**
 - All MS in cell (except those in conversation) share this frequency
 - Digital Signaling via binary FSK modulation
 - Repetitive 5x transmissions (majority logic) with BCH error detection code
- **Individual frequency used for each conversation in the cell**
 - RSSI measured by locating receivers in adjacent cell
 - Handoff when RSSI falls below acceptable level
 - Handoff is a co-ordinated change in MS frequency and a switchover of the base channel to another base station and matching frequency

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BCH Bose, Chadhouri, Hocquenghem code, a type of block code with extra error detection bits appended to the end of the message block.

RSSI Radio Signal Strength Indication

TDMA Cellular Channels

- **Several (3, 8, etc.) multiplexed conversation channels (time slots) on each frequency**
- **Specified time slot on one frequency used for setup or control**
 - All MS in cell (except those in conversation) share this channel
 - Digital Signaling via same modulation used for coded voice
 - Mostly convolutional FEC error coding used
- **Individual time slot used for each conversation in the cell**
 - RSSI and BER of adjacent cell transmitter measured by MS receivers during otherwise idle time slot (MAHO)
 - Handoff when RSSI falls below (or BER rises above) acceptable levels
 - Handoff is a co-ordinated change in MS frequency and time slot with synchronized base switchover

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BER Bit Error Rate, ratio of erroneously received bits to total received bits.

MAHO Mobile Assisted Hand Off. Mobile set measurements on adjacent cell RSSI and BER provides data for MSC and BSS to decide which is optimum target handoff cell.

Use of BER in addition to RSSI prevents false indication from unduly strong cochannel interference, which can fool RSSI measurement but which produces more detectable bit errors.

MAHO simplifies the system structure and reduces the cost and the data communications traffic load at base stations.

TDMA *Logical* Channels

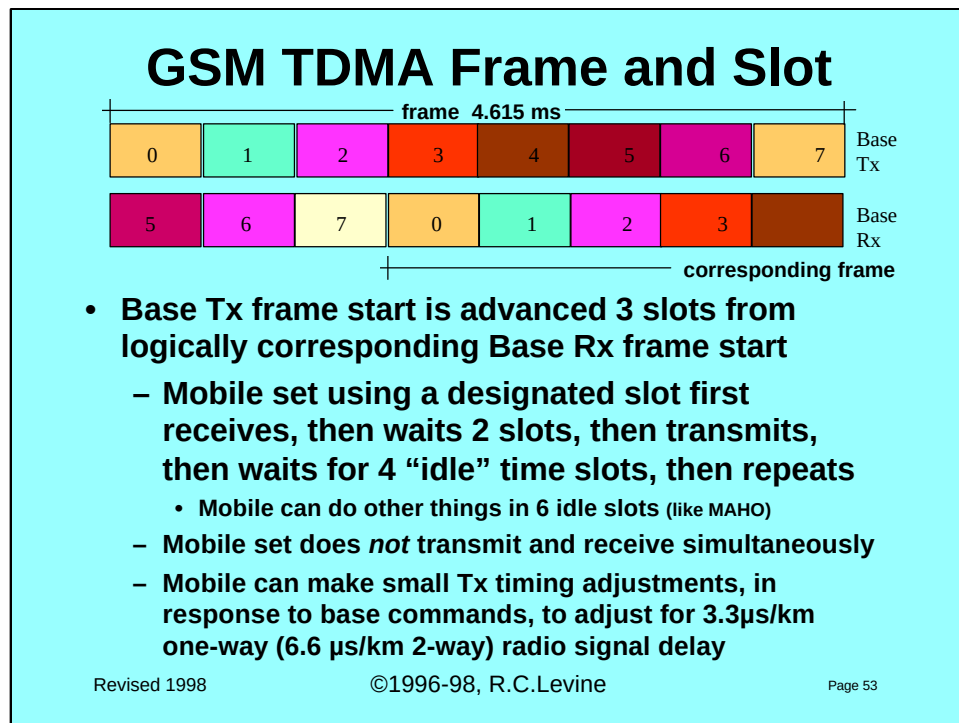
- **Some logical channels are pre-scheduled uses of the same physical time slot**
 - GSM examples: BCCH, PCH, SACCH, etc.
- **Others are un-scheduled, although a time is reserved where they may or may not appear**
 - examples: FACCH, Access burst,
 - When they do not appear, physical reserved time is either unused or devoted to a continual background task

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One of the objectives of this course is to learn the jargon so you can read and understand the documentation on a cellular or PCS system. The names and abbreviations originated for GSM are frequently used in the industry. In some cases the authors of the standards may be accused of slight logical inconsistencies, but in general the name for a logical channel is a useful thing to have, because it indicates unequivocally the physical, scheduled timing, interleaving, and other properties of the information transmitted via that logical channel.



Now we get into the time sequence details of the time division multiple access (TDMA) system. The basic GSM TDMA frame has 8 slots; the IS-54 and IS-136 frame has 6 slots. You will note that all GSM/PCS-1900 documents number sequences in time by starting with 0 (zero) rather than 1, which is the practice in North American standards documents. Remember that the “first” number in a sequence thus is most often 0 rather than 1.

When the future half-rate coder comes into use, an alternative numbering identification counting a double frame as one, and thus labeling the slots from 0 to 15 decimal is also used for some documents.

TDMA Time Slot Structures

- **Two types of burst duration:**
 - **Full duration (normal)**
 - Used for Communication of Data
 - **Shortened burst:**
 - Used for a first access RF burst when the distance (and thus the signal delay) between MS and BS is not yet known
- **Many different types of information contents for Normal Burst**
 - Most 2-way exchanges of information
 - Some 1-way (paging, broadcast, etc.)

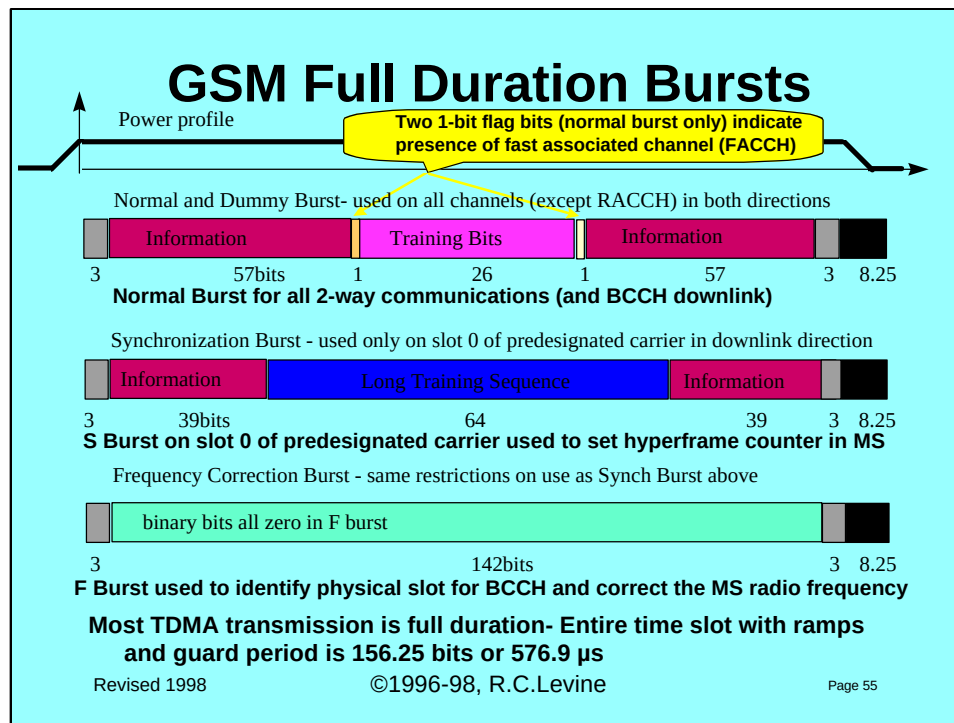
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The shortened burst is only transmitted by the mobile set, *never* by the base station.

The special full duration bursts (frequency correction and synchronization) are only transmitted by the base station, *never* by the mobile set.

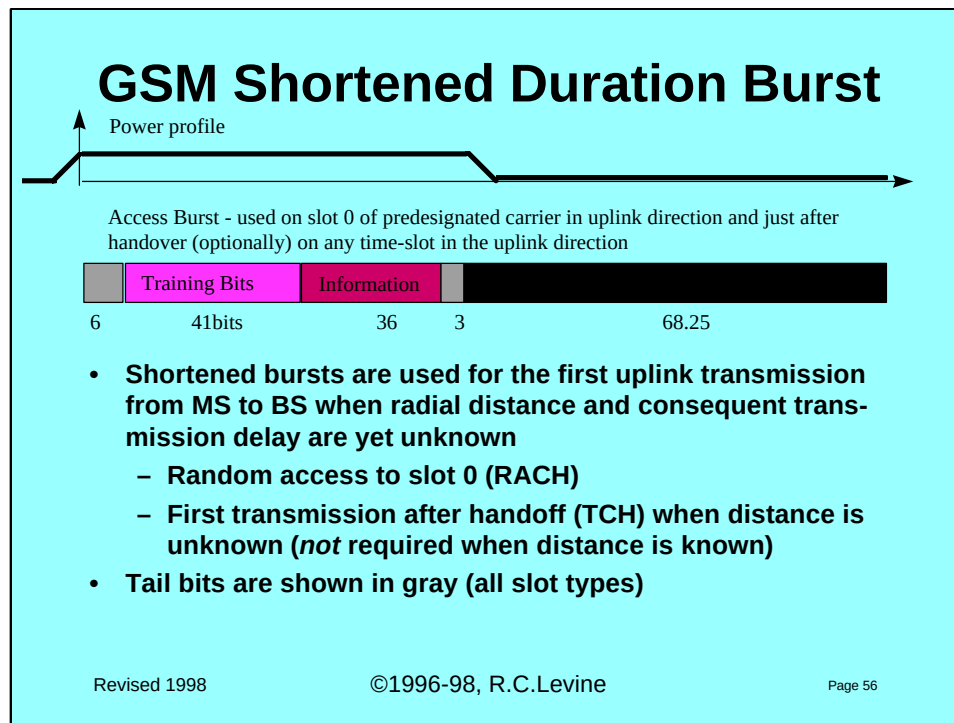


Mobile stations must have transmit power off except for the particular time slot which they use, and therefore they must follow these transmit power profiles.

Base stations on the so-called beacon carrier (the one containing FCCH and SCH bursts) must transmit on all 8 time slots at the same power level, even if some of them are reserved for traffic and there is no traffic at that particular time. They use a so-called dummy burst to fill in on the unassigned traffic time slots in such a case.

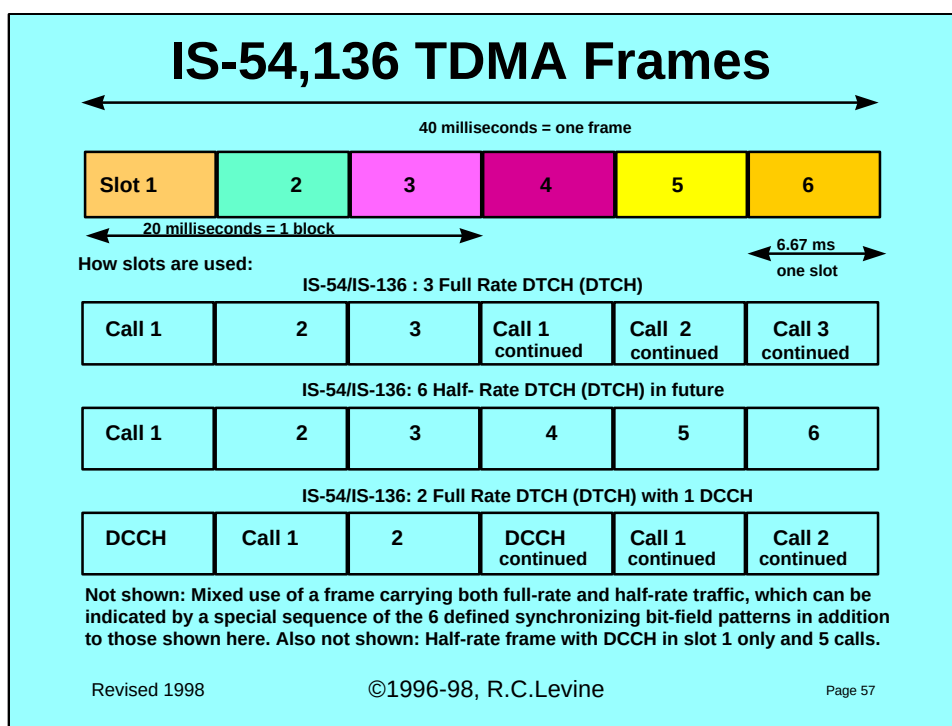
The standard does not require the BS to ramp its transmit power down between immediately consecutive time slots, leaving this choice to the various makers of base equipment. The use of a constant envelope transmit signal, even during the guard times (black intervals on the slide) at a base transmitter makes the RF adjacent carrier frequency emission from the transmitter a little better than required by the standards, and thus lowers the overall interference level to other frequencies in the system a bit.

The base transmitter may adjust the transmit power level separately in each time slot, except on the beacon frequency. Thus, a higher power may be used in a time slot which is transmitting to a MS in the outer part of the cell, while a lower power may be used in a slot transmitting to a MS which is close in. This is optional, but again improves the overall interference level with other cells in the system.



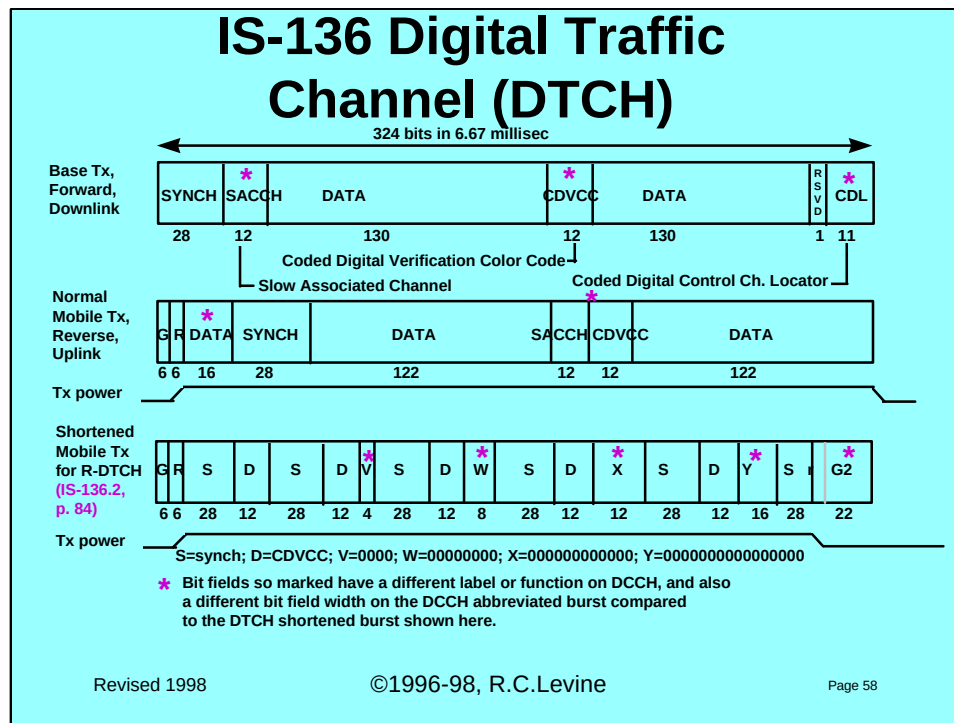
When the MS makes its first transmission to a “new” BS the range and consequent time delay for radio propagation is not yet known. Therefore the MS transmits a shortened burst. The BS measures the time of arrival of the burst and then immediately sends a command message to the MS to adjust its timing so that it can subsequently send full duration bursts.

A “new” BS situation occurs when a MS begins a call or location update, or when it makes a first transmission after a handover while in a connection. In some cases of handover, the geography of the cells is known to the MSC/BSC and the use of a shortened burst can be omitted when the size of two adjacent cells is the same within about a km, or when an MS makes a handover between two angular sectors originating from the same BS so that the distance is unchanged. Thus we can achieve a so-called “seamless” handover with no interruption in the TDMA bit stream. In the case where the two base stations are frame synchronized and, just for discussion, the same time slot number is used on the new carrier, the last time slot burst from the old BS is followed by 7 time slots of receiving and other operations, including re-tuning to the new carrier, and then the next time slot used originates at the new target BS. When the corresponding time slots are not synchronized at the two base stations (but the timing offset is known) or the handover also involves a change in choice of time slot, a similar process occurs and in general there is no “lost” digital data or at worst one time slot of data lost, during the handover. The speech coder can bridge over one missing time slot reasonably well.



At this time, voice traffic is always “full-rate” digitally coded speech at a gross bit rate of 13 kbit/s, which requires 2 out of 6 time slots. Present low bit-rate data traffic (<6.5 kbit/s gross rate) and planned future support of a half-rate speech coder, can be supported by using only one time slot out of 6.

There are 6 defined synch patterns, each one is 14 symbols in duration (IS-136.2, Table 1.2.4-2). In most cases, the six symbols will be used in the six time slots of a frame in “normal” consecutive order, Synch pattern 1 through 6. This normally designates the use of 3 traffic channels in IS-54, and is permitted for use with 3 traffic channels in IS-136. However, IS-136 prefers the use of all 6 consecutive synch patterns for a 6-channel all-half-rate frame/carrier, and the use of only 3 of the synch patterns, repeated in the sequence 123123etc., when only 3 full-rate traffic channels are supported on one frame/carrier. Various other special sequences of the 6 synch symbols are designated in IS-136.2 Table 1.2.4-1, for a frame/carrier which handles a mixture of full-rate and half-rate traffic. In addition, there are future plans for multiple rate traffic channels which carry more bit rate than the full rate channel by using more than 2 of each 6 time slots, and which also can have special synchronizing sequences. This would allow fax or data service at higher bit rates, or superior quality digitally coded speech. As examined at the MS, a specific time slot such as mobile transmit slot number 1 immediately precedes mobile receive (and thus base transmit) time slot number 1. Stated another way, mobile transmit time slot number 2 coincides with mobile receive time slot number 1. This permits time division duplex operation (in addition to use of different Tx/Rx frequencies) in fully digital mode.



The DTCH was historically introduced initially into IS-54, which retained the ACH for call setup purposes. The IS-136 DTCH is backward compatible with the DTCH of IS-54 with the following two modifications:

The IS-54 forward channel has a 12 bit reserved field, all zeros, where the 1 bit reserved field (always set to 1) and the 11-bit CDL field are at the right.

The Abbreviated Burst used on the RACCH (reverse DCCH) is shorter than the Shortened Burst shown here (used only on the reverse DTCH). Also, the bit fields in the Shortened Burst convey no data or information other than synchronization. The Shortened Burst was designed to be used optionally immediately after a handoff for one (or more) frames to control the proper burst timing delay via messages from the BMI (BS) to the MS.

The digital verification color code (DVCC) is an 8-bit code value assigned by the system operator with a unique value in each cell. The coded DVCC (CDVCC) is the 8-bit code augmented with a 4-bit Hamming code for error protection. The purpose of CDVCC is to detect false reception of co-channel interference from another cell in the system and thus prevent using the wrong signal. It has no connection with “color” and is called that for historical reasons.

The SACCH is used for slow messages between the BS and MS. The fast associated control channel (FACCH) is not shown because it uses the same 260 bits in the slot labeled for DATA. The FACCH is created by preempting the DATA bit fields when there is a FACCH message to transmit. FACCH messages are distinguished from coded speech data because of using different error protection code methods.

CDMA: Qualcomm IS-95

- **How CDMA works**
 - **Speech is digitally coded by a LPC-type coder**
 - The coder (QCELP) has excellent quality, but rivaled or exceeded by latest enhanced full rate GSM codec
 - VAD is used to control transmit power and lower the data bit rate when no voice at microphone
 - **Coder bits (at ~10kb/s) are multiplied with PN code (at ~1000 kb/s) to get spread spectrum**
 - **Correlation of received signal with duplicate synchronized PN code to extract original data**
- **Multiple users can share the same RF spectrum by using orthogonal PN codes**
 - **Up to 100 in this example**

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CDMA was first developed for military point-to-point communications. It converts a low bit rate (narrow bandwidth) digital signal into a high bit rate digital signal, thus spreading the spectrum of the resulting RF signal.

To support multiple users each user must have a distinct and separate PN (pseudo-noise) code sequence. All of the PN codes used must be orthogonal to each other. This means that, when one code waveform is multiplied by another (in a NRZ bipolar waveform embodiment) the product is positive and negative in value for equal numbers of PN bit intervals during one data bit interval, and thus the average value of the product is zero. Although use of a PN bit rate at 100 times the data bit rate provides 100 mathematically orthogonal PN codes, some are unsuitable because they are too periodic (like 10101010...) or contain long sequences of 1s or zeros.

When multiple transmitters send signals with different PN codes to a common receiver, the RSSI of all the signals must be very close to equal, or the strongest one will dominate all the others and only it can be decoded without errors. This was a major problem which caused malfunctions of a trial CDMA system used in tests by the Groupe Spécial Mobile in 1986 in Paris. Qualcomm revived the idea of CDMA for cellular in 1989 with an improved closed-loop feedback power control to keep all the received signals from deviating in individual power levels. They are the main proponents of CDMA and the IS-95 standard is based on their design.

CDMA Cellular Channels

- **Multiple code-multiplexed conversation channels on one frequency**
 - Theoretically up to 62 (usually 10 to 20 in use simultaneously)
 - Also pilot codes in each cell for setup channel use
- **Each conversation supported by combining 9.6 kb/s coded speech with 1.28 Mb/s chip code**
 - Each chip code chosen for separability (orthogonality)
 - Desired received signal separated from others by multiplying with replica chip code sequence
 - Requires similar RSSI at base receiver from all MS transmitters
- **Soft handoff supports one MS with multiple BSs**
 - Except when near the center of the cell, the MS is in communication with 2 (or 3) Base Stations all using the same chip code
 - Better (lower BER) base receiver signal is chosen for each speech block
 - Internal adaptive equalizer (RAKE receiver) combines all base transmit signals at MS receiver, giving stronger signal and better performance
 - However, this design approach greatly increases the number of BS-MS links and system complexity
 - Cannot correct for bad RF signal to *all* base stations

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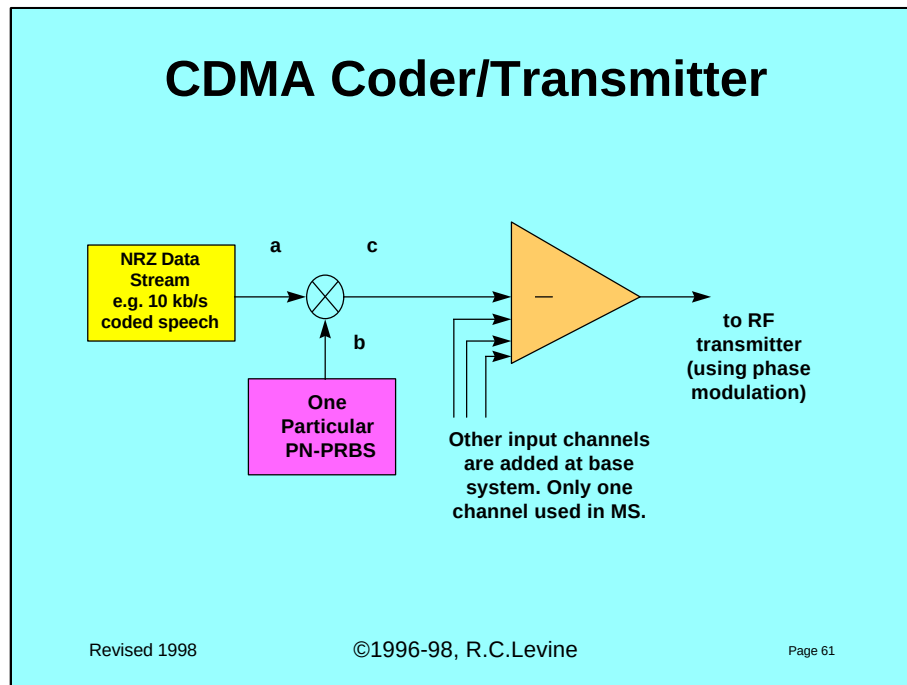
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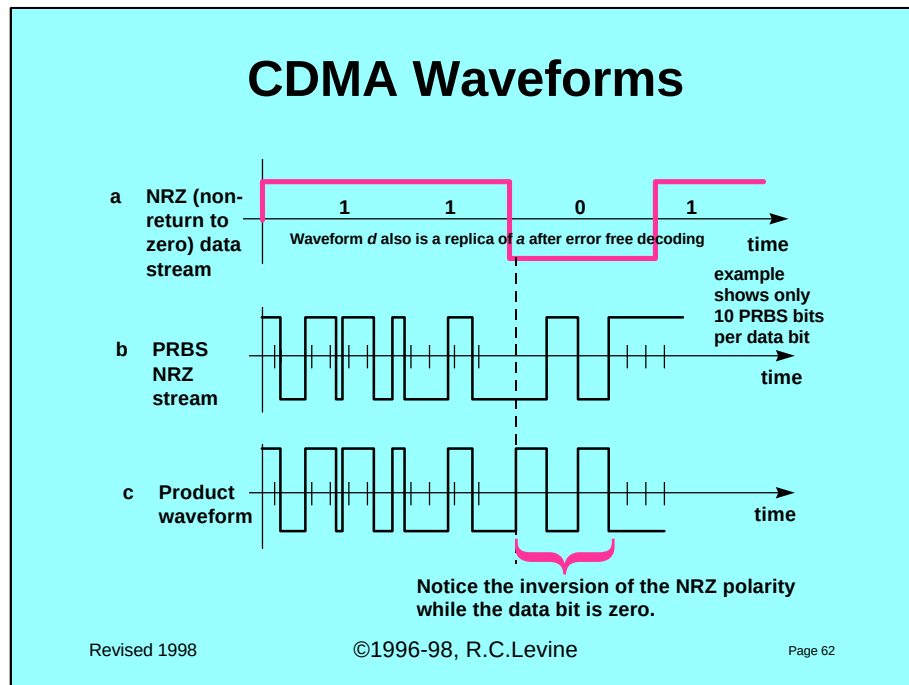
chip A high bit rate pseudo-random (random appearing but actually deterministic) binary bit sequence used to “chop” or “chip” each signal bit into many intermediate bits. Each MS in a cell has a unique chip sequence code which is generated by combining a unique repeated 64 bit code sequence (called a Walsh code) with a very long code unique to the particular MS. The objective of this design is to give each MS a chip code which can be separated from the combination of all other signals with almost complete randomization of the other signals. The chip code is also called a pseudo-random or pseudo-noise binary code or sequence (PN-PRBS or PRBS)

RAKE receiver. This is a type of adaptive radio equalizer which compensates for multipath propagation or for use of multiple base transmitters active at different distances by internally delaying and then combining the multiple versions of the signal which arrive at the receiver antenna.

A major concern with CDMA is that all the received signals arrive at the base receiver with about the same instantaneous RSSI (typically a tolerance of only ± 2 dB is permitted). Tight control of MS transmitter power is achieved by a combination of self adjustments (based on MS receiver signal from the BS transmitter) and periodic feedback control signals coming from the BS.



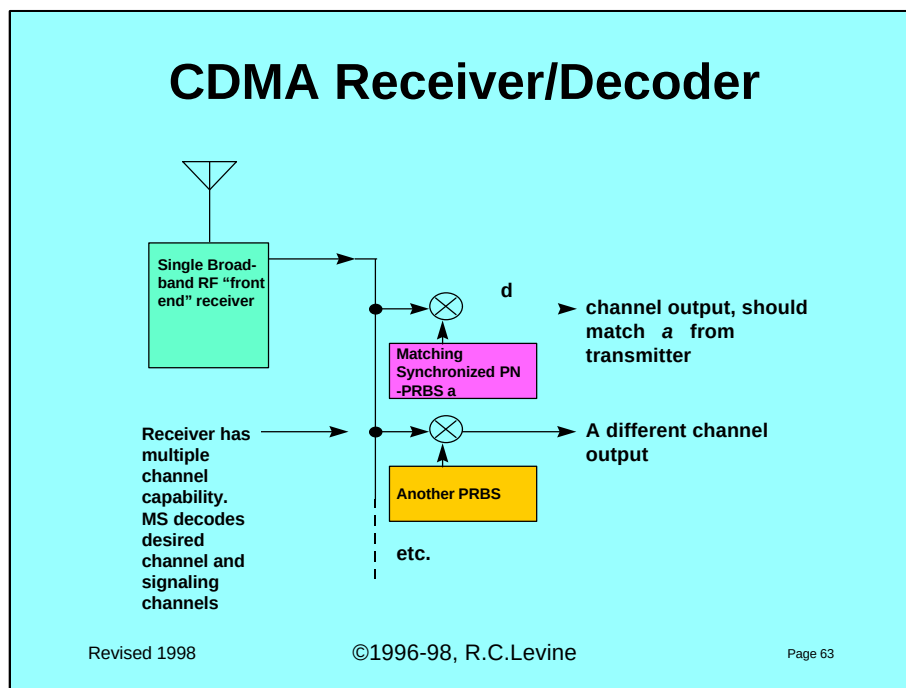
This block diagram shows the essential parts of the CDMA process. The low bit-rate data signal is multiplied by a much higher bit rate signal. Both signals are in NRZ (non-return to zero) form, meaning that the two binary levels are implemented as 1 and -1 volts, for example. At the base transmitter, several different orthogonal PN-PRBS (Pseudo Noise - Pseudo Random Bit Stream) patterns are used, one for each separate data (digitally coded speech) signal. At the mobile transmitter there is only one signal and one PRBS pattern. The actual data bit rate of the Qualcomm IS-95 system is 9.6 kb/s and the actual PRBS bit rate is 1.28 Mb/s.



In this illustration, the PN bit rate is drawn at only 10 times the data bit rate, rather than the 100 described before. To decode a CDMA signal, one must have available at the receiver a replica of the encoding PN-PRBS bit stream, properly synchronized with the received waveform. This local matching PRBS is again multiplied with the received NRZ waveform, and the result is to restore the original low bit-rate signal. It is very similar to encryption, which is the basis of its original military application.

If other orthogonal PRBS coded data streams are also present, they will produce zero average disturbance to the decoded waveform. However, if there are so many of them that they produce a very large random fluctuation of the total signal, or if some of the PRBS codes are not orthogonal to the desired PRBS code, then the result will not average out to zero over a full data bit interval. Also, if one signal is much much stronger (greater amplitude) than all the others, it will be the dominant output signal. This last problem is the one Qualcomm has addressed with their closed loop feedback power control.

In the actual IS-95 system, there are 64 allocated PRBS codes per cell. The proponents claim that another full 64 codes can be used in all adjacent cells, on the same carrier frequency as the central cell. This has proven to be a problem, because the other codes are at least partially correlated (non-zero time average product waveform) with the codes in other cells, thus causing unexpected high levels of BER. There are other IM problems as well.



The process in the baseband part of the receiver is similar to that at the transmitter. The presence of additional signals causes the decoded waveform to fluctuate about its intended mean/average value, but in a properly designed and not overloaded system, it should be clear whether the data bit value is +1 or -1 volt in each bit interval.

Major advantages of CDMA

- **Voice activity control without need for Coordinating messages between mobile and base**
 - This is the only distinct source of high spectral efficiency compared to other access methods
 - DSI methods for TDMA (such as Hughes' E-TDMA) could close this gap in future
- **Relatively easy to configure different data rates for different users**
- **MS transmitter is constant envelope phase modulation Class C (high power efficiency)**

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Using VAD (voice activity detection) to turn off the transmit signal during voice silence intervals is the “gimmick” which actually gives CDMA a greater capacity. The use of CDMA alone is *not* more efficient in its use of radio spectrum or in terms of the recommended figure of merit: number of conversations/unit-area/kHz of spectrum. The use of VAD improves capacity by about 2 to 1 because a speaker is normally silent for about 40 to 60% of the time. By lowering other transmitters' radio power during this interval, we can load the system with more speakers without producing the same level of instantaneous signal voltage variation that would occur if they all transmitted continuously. (This would not be useful for continuous data transmission, of course, but the vast majority of cellular/PCS users use voice.) Furthermore, in a CDMA system it is not necessary to send additional signals between the base and mobile to coordinate channel assignment when a particular user falls silent for a short while. This is the most significant feature of CDMA. Other systems have demonstrated VAD and dynamic channel assignment (satellite, undersea cable and fiber, and Hughes Network Systems' E-TDMA digital cellular system) but they all require added coordinating signals.

CDMA Aspects

- **RAKE receiver, similar in complexity to adaptive equalizer, corrects multipath**
- **Extra cost of soft handoff when only usable with under-capacity installation**
 - Soft handoff requires $n=1$ frequency configuration, which requires that each cell be under-populated to avoid adjacent cell interference
 - Soft handoff design incorporates much extra processing capacity, trunking capacity, etc.
- **Frequency diversity benefits of CDMA are similar to FH in GSM/PCS-1900**
 - Very dependent on specifics of each site multipath statistics

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In early claims, CDMA was said to be immune to the effects of multipath propagation because the delayed signals arrived later than one bit interval, and merely looked like another uncorrelated PRBS signal, which would supposedly not affect the decoding. In fact, it raised the equivalent noise level and had to be controlled by means of a RAKE receiver which is, in effect, another type of adaptive equalizer. A RAKE receiver adds about as much complexity, in terms of integrated circuit hardware inside the receiver, as does an adaptive equalizer in a PCS-1900 or GSM receiver.

IS-95 prescribes a process called soft handoff, during which the MS is in simultaneous contact with two different base stations in two adjacent cells. This requires both BS to be on the same carrier frequency, and both must transmit the same voice signal with the same PRBS coding, and both receive and decode signals from the MS. The better voice signal is chosen for each 20 ms speech coder time window. Although this improves the quality of audio if there are many bad radio coverage spots in the handover region, it greatly adds to the complexity and cost of the CDMA system (both capital cost and monthly recurring operating cost for renting more T-1 links between cells and the MSC). Even using Qualcomm's most optimistic capacity estimates, the cost per customer projected for CDMA is about 30% higher than PCS-1900, and most of the difference can be attributed to soft handoff hardware. In addition, when different carrier frequencies are used in adjacent cells, soft handoff cannot be used.

A great deal has been made by proponents of CDMA regarding the benefits of a wideband signal, since it has less fading, etc. Not to be outdone, PCS-1900 proponents (particularly Ericsson) have claimed that fast frequency hopping in GSM/PCS-1900 works over 15 MHz or more, rather than the "measly" 1MHz of IS-95. Well, the benefit of a wide band signal is significant for both systems, and is indeed somewhat better for FH PCS-1900, but it is a second order problem, mostly very dependent on particulars of site geography, and should not get one embroiled in controversy!

CDMA's Main Difficulties

- Development calendar for completely new system has progressed far too slowly, particularly on 800 MHz band
- Early promises of 40x or 20x or even 15x analog cellular capacity are not demonstrable today. Actual dependable capacity is likely to be ~8x analog
- Sensitivity to narrow band IM from strong signals
 - Every receiver has a dynamic range bounded by two power limits
 - Low power limited by noise effects
 - High power limited by non-linearity
 - CDMA receiver has small dynamic range to receive low level CDMA signal
- Availability of contiguous spectrum is sometimes a problem. Strong narrowband carriers often exist in band:
 - On PCS bands: pre-existing point-to-point microwave systems
 - In 800 MHz cellular: IM products from other cellular carrier frequencies

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InterDigital, a firm which was primarily in the military electronics fields, has also proposed a Wideband CDMA system based on the inventions of Prof. Donald Schilling. Although they have presented their technical proposals at various standards meetings, they appear to be stalled by lack of capital and there is no announced delivery date for a product. Their system uses approximately a 4 MHz PRBS spreading code, and is consequently much wider bandwidth than IS-95. They also have the problem noted regarding pre-existing microwave signals in the middle of their proposed band.

PCS-Primeco started commercial 1.9GHz CDMA PCS service in 14 cities during November, 1996. Limited commercial use of CDMA on the 800 MHz band started in several cities in early 1997.

Types of Handoff

- **Break-before-make handoff**
 - “Hard” analog handoff interrupts audio for about 200 millisec while MS retunes to new carrier frequency
 - “Seamless” TDMA handoff has no interruption in audio. MS retunes between two normal TDMA bursts.
 - Only in a case of two adjacent cells with extremely large difference in radius is a retiming adjustment needed. When this occurs a 20 millisec loss of digitally coded speech occurs, which is normally “bridged” over by the digital coder and is usually imperceptible.
- **Make-before-break handoff**
 - “Soft” and “softer” handoff in CDMA. MS is in temporarily in communication with more than one base station for some time interval during handoff.
 - Soft handoff cannot compensate for bad RF coverage. Dropped calls can still occur.

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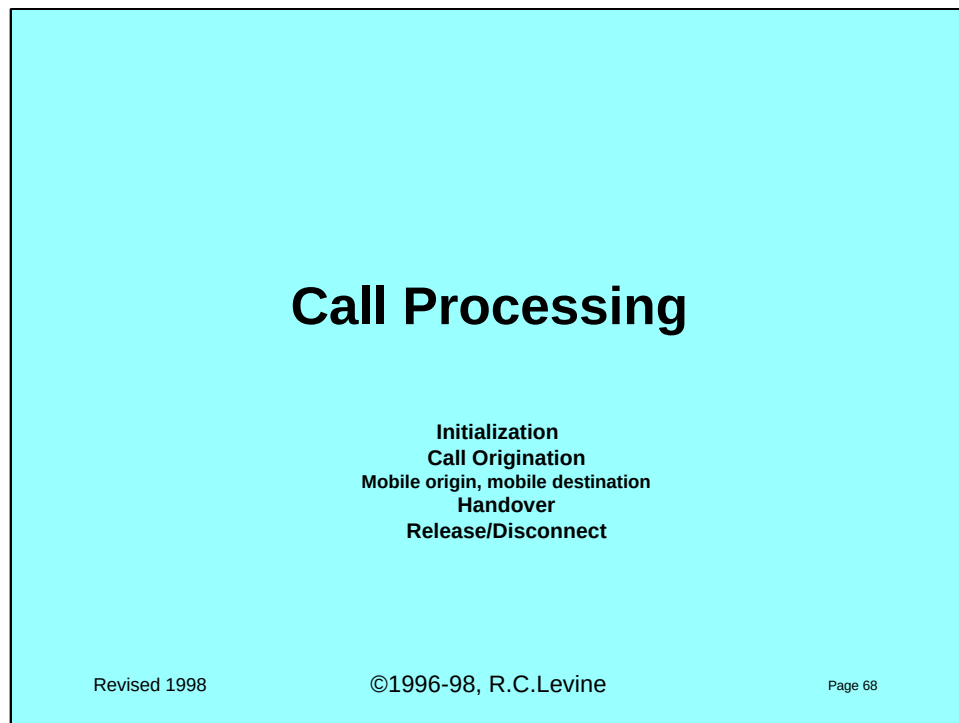
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Both CDMA and TDMA systems produce a much better perception of continuity during handoff than analog. There are pros and cons for the way each digital technology does handoff. Both analog and TDMA require a brief interruption of the speech prior to handoff to give the command to the MS regarding the new frequency (and time slot in TDMA). However, this command requires only 20 ms in TDMA, and this loss of one speech coder frame of speech bits is normally interpolated over smoothly by the TDMA speech codec, giving no perception of audio loss. In a CDMA soft handoff system, there is no similar command, since the MS never changes frequency.

Large scale TDMA systems provide for a command to allow the MS to temporarily transmit shortened radio transmission bursts when handing off to a new cell which is very different in size than the old cell, to allow for adjustment related to the time delay for the radio signals to travel between the BS and MS. However, in most real systems the difference in radius between two adjacent cells is either very small (less than 3 km, corresponding to ~9 microsecond of time) or it is known in advance and can be adjusted without sending shortened bursts. Thus, in real systems there are seldom any loss of bit stream at handoff. Even when one or two short bursts must be sent for re-adjusting the time advance of the MS, only 20 or 40 ms of bits are lost, which is again covered by the normal interpolation capability of the digital speech coder.

At one time, soft handoff proponents implied that soft handoff somehow compensated for flaws in the radio coverage, and thus there was an implied promise that the system design and installation could be accomplished more rapidly or with less detailed coverage measurements than for other technologies. This has proven not to be true in practice. Good RF coverage is necessary for any type of RF technology to prevent dropped calls, bad signal areas, etc. If you need a team of 32 RF engineers and technicians to install, test and monitor an analog or TDMA system, you need the same size team for CDMA as well.



The signaling over the radio link (Um interface) to accomplish these operations will be described at a general level. Then later we will show the form of the messages used, with one specific example.

MS Initializes

- A non-conversation-state MS “looks” for a control or setup frequency (and time slot for TDMA or pilot code for CDMA) when:
 - Power is turned on
 - Signal on the present control channel is weak or has bad bit errors
 - A periodic timer in MS initiates a re-scan
- Then the MS scans *all* the carrier frequencies looking for a control channel, however...
 - A “brand new” MS scans *all* the frequencies
 - Only 21 to scan in 800 MHz analog cellular
 - Scans all when turned on in a “new” area and can’t find the “old” control channels
 - A previously used MS saves the last known control frequencies found in the city in its memory
 - Usually provides faster initialization (seconds vs. minutes to be ready to operate)

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Unlike analog cellular systems, the “beacon” carrier (containing the control channel time slot in a TDMA system) may be any frequency that the operator wants to use for that purpose, so long as there is only one (for GSM designs) carrier per cell/sector which is used in that way. (IS-136 permits multiple control channels in the same cell/sector.) This gives the operator great flexibility. For example, if there is a particularly low traffic cell/sector, it may be provisioned with only one carrier frequency (compatible with the overall frequency plan, of course) and that frequency may be used as a beacon frequency without restriction. There are no frequencies which are legally reserved for voice traffic only nor any reserved for beacon use.

Remember that a GSM beacon carrier can be configured to use one time slot for the broadcast and other generally used channels, and then several other slots may be optionally configured for the stand-alone channels used for the intermediate messages during call setup. Then at least 4 of the remaining 7 time slots as traffic channels, and as many as all 7 if there is minimal call setup, location update, and SMS activity.

An IS-136 control channel always uses slots 1 and 4 (for full rate configuration) or slot 1 only (for half rate configuration). The other slots on that carrier *must* be used as traffic channels.

Idle MS in a cell

- When a power-on but idle MS is in a cell, it normally locks onto the control channel of that cell
 - automatically finds new best RSSI, best BER control channel as it moves from cell to cell
- MS could start a call if user dials a number and presses START button
- MS could “ring” if it is “paged” by means of a message broadcast on the control channels of all cells in the vicinity
 - User can then answer
 - Analog systems normally page all cells in city
 - Digital systems have multi-cell “location areas” (LAs) which broadcast distinct identification numbers periodically
 - MS identifies when it crosses a LA boundary
- MS eventually tunes to a “talk” channel (commanded by the BS) after the preliminaries above

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The MS must find the nearest (or more accurately, the best signal) beacon carrier rapidly, so it can stay in contact with the base system in case of a page, or so that the end user can originate a call.

Preliminary Registration

- In current cellular and PCS networks, the MS must register (identify itself via a radio transmission on the uplink control channel)
 - When first power up for the day
 - When entering a new base system
 - When entering a new LA
 - Just before power down
- This leads to infra-structure network messages which eventually update the home HLR and the current VLR
 - Authentication of the MS
 - MS can originate calls
 - HLR and active VLR know where the MS is currently
 - HLR can cause call forwarding to other cities if pre-arranged

In original analog cellular network designs, much of this did not happen. Fraud was rampant. Call delivery was not done.

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No notes on this page.

Registration Process

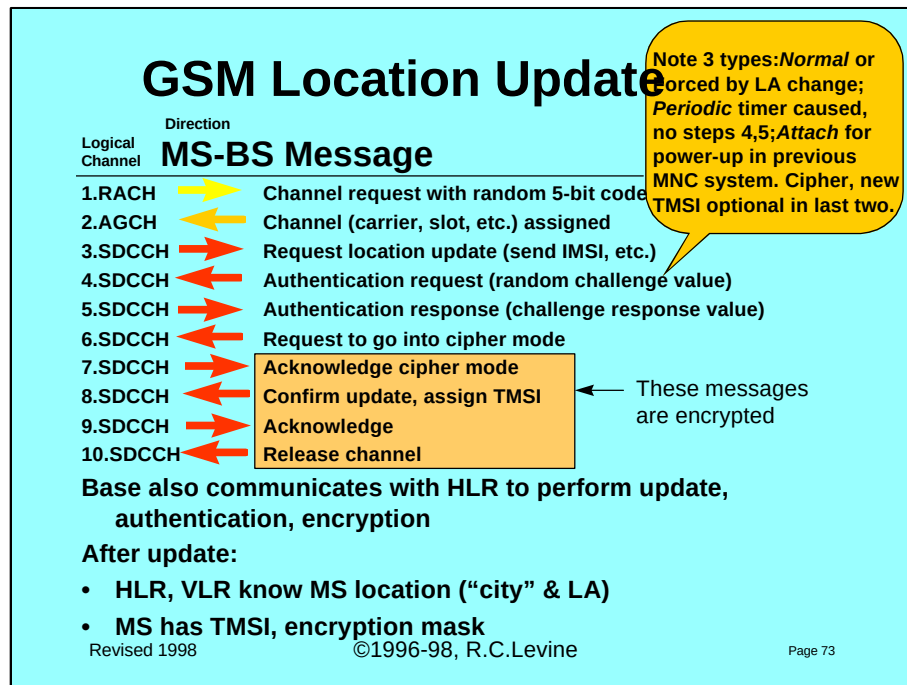
- **A number of transactions occur in a modern digital cellular or PCS system**
Registration
- **Next example is from GSM which performs each operation with a separate message**
- **North American IS-54 and IS-136 combine several data elements into a smaller number of longer messages**
 - **Also encryption is not done on everything at registration time, but rather at calling time**

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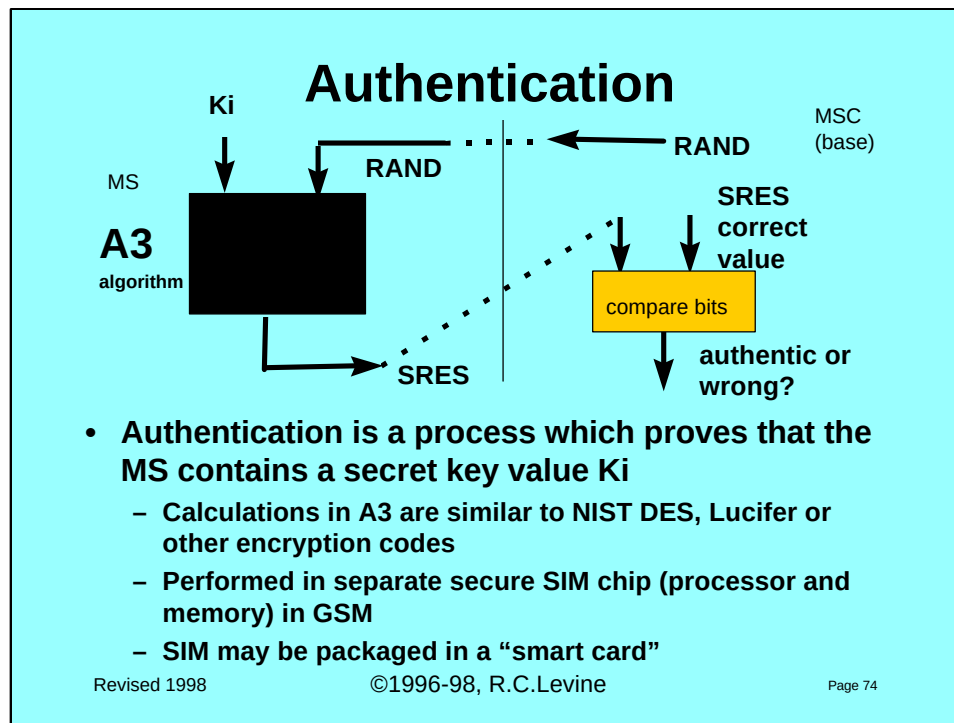
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In the North American cellular system, there was originally no firm plan regarding networks of MSC equipment. Specific features were designed and added as required, in the various releases of the IS-41 standard. In contrast, the GSM system was designed from the beginning with all its network features pre-specified.



Details of cipher mode are explained on another page. In a GSM system, when cipher mode is established, a ciphering key sequence number (CKSN) is set in the base and mobile. On subsequent contacts by the MS with the BS (for further location updates or to begin a call), the MS sends a message with the CKSN value as a data element. If the MS CKSN value agrees with the corresponding value in the base system, the messages and data elements required for establishing ciphering need not be repeated. In that way a new cipher key need not be established just because the MS is doing a location update. However, the practice of most operators is to establish a new cipher key for each telephone connection. In summary, all the steps to establish new cipher keys in other operations following this should be viewed as optional operator choices without explicitly labeling each one thus.

Please note also that there is a GSM SACCH channel associated with the SDCCH channel used for location updating and other pre-connection type exchanges of information, such as short message service (SMS). This SACCH permits the MS to receive a list of nearby beacon frequencies to scan, and then report back the signal quality on each such beacon frequency about one report per second. The purpose and result of this is that a handover can be done, if required, during a location update, call setup or short message transmission. This is not possible in older analog cellular systems.



PCS-1900 authentication involves a two-way transaction. The base station transmits a random “challenge” number RAND (different value on each occasion when a call is to be connected or an authentication is to be performed for another reason) to the mobile set. The mobile set performs a calculation using that number and an internal secret number and returns over the radio link the result of the computation SRES. The base system also knows what the correct result will be, and can reject the connection if the mobile cannot respond with the correct number. The algorithm used for the calculation is not published, but even if it is known to a criminal, the criminal cannot get the right answer without also knowing the internal secret number Ki as well. Even if the entire radio link transaction is copied by a criminal, it will not permit imitation of the valid set, because the base system begins the next authentication with a different challenge value.

This transaction also generates some other secret numbers which are used in subsequent transmissions for encryption of the data. Therefore, nobody can determine which TMSI was assigned to the MS, aside from not being able to “read” the coded speech or call processing data.

This process has proved to be technologically unbreachable in Europe, and there is no technological fraud similar to the major problem with analog cellular. There is still non-technological fraud, such as customers presenting false identity to get service but never paying their bill (subscription fraud).

The mathematical processes involved in DES and Lucifer encryption consist of two repeated operations. One is the permutation or rearrangement of the data bits. The other operation involves XOR (ring sum or modulo 2 sum) of the data bits with an encryption mask or key value. These operations are repeated a number of times (rounds) to thoroughly scramble the data, but they can be reversed by a person who knows both the algorithm and the secret key value.

Recent (April 1998) “cracking” of A3 by U.Cal Berkeley group indicates no flaw in the algorithm, but rather intentional internal use of small constants as key values when longer constants are feasible. The question “why was this done?” remains to be answered.

Call Setups

- **A mobile destination call is the most lengthy to set up because the MS must first be paged and then respond**
- **A mobile origination call is simpler, since the MS begins at a point corresponding to the middle of the previous case**
- **Following example is from GSM**
 - Again, IS-54 or IS-136 perform similar functions, but using a smaller number of longer messages
 - GSM uses an intermediate” standalone channel for these processes
 - IS-54, IS-136 use only the control channel for these processes

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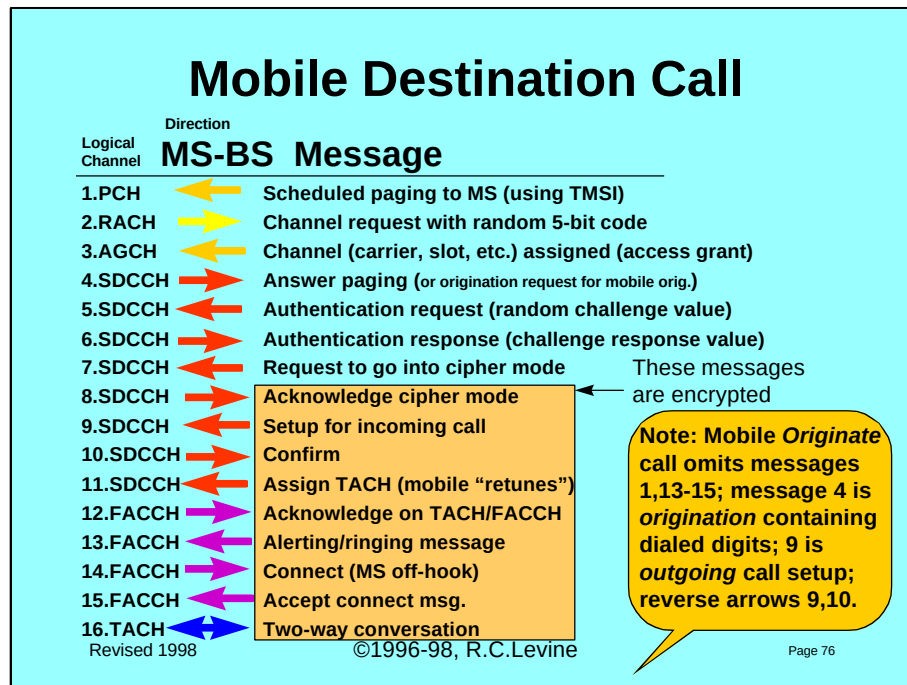
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With regard to authentication, in the North American systems (IS-54, 91, 94, and 136) there is an authentication transaction very similar to that shown on the previous page for GSM. A random challenge number is transmitted from the BS to the MS, and the MS performs a calculation using it and an internal secret number called SSD-A, and returns the result in a reserved data field which is part of the paging response or call setup (for mobile destination or mobile origination respectively).

The secret number SSD-A is derived from a second internal number called the A-key. If the operator suspects that the SSD-A has been compromised, it can be set to a new value by means of over the air transactions. Only a base system which knows the proper value of the A-key can perform these operations. The A-key can be set at the factory or entered by the end user via the keyboard of the mobile set.

Authentication and encryption setup in North American systems are more often performed at call setup time rather than at registration time, as shown for the GSM type system on these pages.



The steps involved in setting up a connection are similar in all cellular and PCS systems. For a mobile destination (also called mobile terminated or answered) call, the base stations in the last known LA must page the MS. In GSM/PCS-1900 the paging for certain IMSI numbers occurs during pre-scheduled time windows only. Therefore, the MS can "sleep" (operate with several internal modules turned off) in a low power-consumption state until a paging window time, thus prolonging the battery recharge interval of the MS.

Following the receipt of a paging message (which contains the TMSI for identification of the proper MS), the MS must make access to the base system and then an exchange of messages leads to directing the MS to the correct TACH. On the way, most of the messages are exchanged using a SDCCH channel, which is used for short intervals by each MS in turn which is involved in a call setup, location update or short message transmission.

A mobile originated call involves primarily the same operations as a mobile destination call. Only messages 1,3,4 and 9 differ in any details. After the connection on the TACH is established, the call is processed for all subsequent steps (handover, release, etc.) in the same way regardless of whether it is mobile originated or mobile destination. Other sequences of call setup are possible in a system with SS7 signaling to the PSTN, so the voice channel does not need to be connected until the called person answers, but are not feasible with present MSC to PSTN signaling.

Handover Control

- **Operator has generally 4 parameters to control handover**
 - **Threshold handover start RSSI**
 - **Threshold handover start BER**
 - Note that either of above could start handover independently
 - **“Delta” of above parameters to cancel handover**
 - In general these delta parameters are used to minimize “ping-pong” effects via intentional hysteresis
- **Values may be set to independent and distinct values in each sector of the system**

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Setting these handover thresholds is one of the few parameters which the operator (as opposed to the manufacturer of the base system) has under control. A lot of experimentation is used to “fine tune” the value of each threshold in each cell or sector.

Why Too Slow Handover?

- **Handover may be unintentionally delayed due to:**
 - **Locating receiver measurement delay in analog systems**
 - **Queuing of MSC-BS data link control messages**
 - **Fix: More total bit rate on these channels**
 - **No available traffic channels in destination cell(s)**
 - **Temporary Fix: traffic leveling handovers where feasible***
 - Delay waiting for a cascade of traffic leveling handovers may drop the call!
 - **Permanent Fix: increase cell capacity (e.g. more carriers)**
 - **Data processing delays (unusual!)**
 - **Install more (parallel) processing capacity**

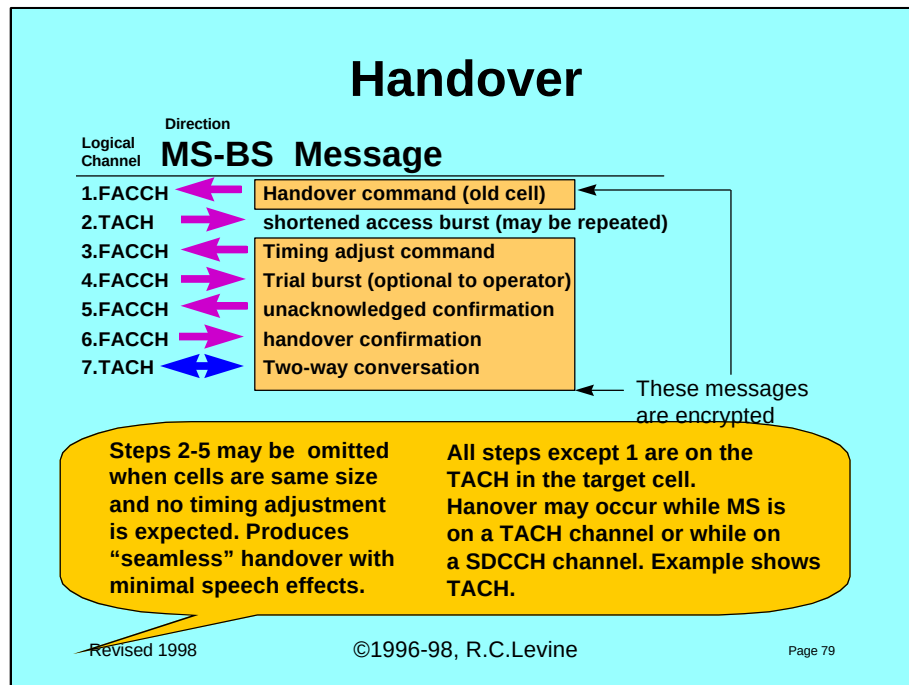
***Dependence on traffic leveling implies need for extra cell overlap**

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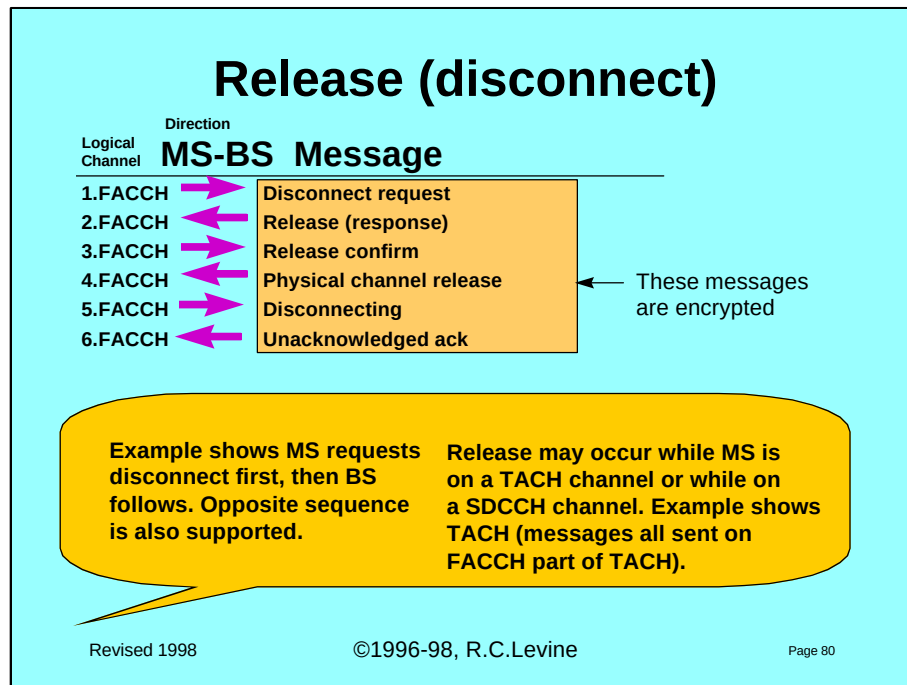
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In most cases, although analog cellular systems suffer from problems arising from handoff delay, a properly provisioned digital cellular system should not have any unexpected delays in performing a handoff.



This shows the commands which are sent AFTER the system has determined that a handoff is necessary and which cell (and carrier frequency and time slot) should be the target of the handoff.

In a TDMA system with adjacent cells of approximately the same size, it is not necessary to make timing adjustments for the transmission delay, so a "seamless" handoff can usually be accomplished with no lost coded speech. CDMA systems also have continuity of speech during a "soft" handoff. Of course, both of these systems may have a brief interruption of the digitally coded speech data in order to send the handoff command (which requires about 0.2 seconds, but the missing data is interpolated over because of the design of the speech coding process. Analog systems always lose about 0.2 seconds of speech during a handoff since they have no designed-in way to save and repeat prior speech during that time.



The number of confirming acknowledgments used in this exchange leading up to a disconnect is testimony to how important it is to never, *never* disconnect a call already in progress. If you have to drop *something* due to an uncontrolled situation, it is better to drop a call attempt which is still at the dialing stage, since the customer will not be so irritated (and often needs to only press the SEND button again). In addition, and not shown explicitly in the diagrams, there is a whole procedure designed for GSM/PCS-1900 to *re-establish* a call which was accidentally or unintentionally disconnected due to bad radio channel errors or other problems. This does not exist in the design of other systems -- you must manually redial if you are accidentally disconnected.

Customer Data or FAX

- In addition to voice, digital cellular systems provide for data and FAX
- Special connectors (Terminal Adapters) are provided on some MSs for a FAX or data terminal
 - The FAX adapter contains a FAX MODEM which extracts the binary FAX information
 - Other devices (laptop PC, etc.) use a simple serial data (RS-232) connector
- The MSC contains a modem pool for PSTN connection
- GSM data is presently limited to 9.6 kbit/s since significant amount of error protection code must be added and available total bit rate is 22.4 kb/s in GSM or 13 kb/s in IS-54, IS-136.
 - IS-136 standards (IS-130) provide for 14.4 kb/s by linking two channels.

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The actual PCS-1900 system data throughput for the low bit rate data streams allows some extra bits for data overhead used or originated by the terminal. Although 9.6 kb/s is the present maximum customer data bit rate, a standard for using 2 or more time slots for the same connection is under development, which will permit 19.2 kb/s or more in the future. This linking of two channels for higher bit rate has already been written out in the IS-130 standard in the North American system, used with the IS-136 standard.

Error Protection Codes

- **Convolutional codes**
 - Similar to multiplication*
- **Cyclic Redundancy Check (CRC)**
 - Similar to transmitting long division*
remainder, recalculating it and comparing at Rx end
- **Block codes**
 - Similar to matrix multiplication*
 - Fire code used for call processing messages in GSM/PCS-1900

* Binary arithmetic is performed without usual carry or borrow for these codes (so called modulo-2 or ring-sum arithmetic)

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Now we have an idea how a message is put together. When the message or some speech coding bits are ready for transmission, they need to have error protection applied to them. Several different types of error protection codes are used in GSM. The major types are listed above with examples on following pages. There are also some specific types not explicitly listed which are used only in one context such as the shortened burst. IS-54 and IS-136 systems use convolutional and CRC codes as the GSM system does, but not block codes like the Fire code. In addition, interleaving of the bits over a number of consecutive time slots is used in both GSM and IS-54 and IS-136. After the bits are re-assembled in the order they had before interleaving, the number of consecutive bit errors due to a radio channel fade is thus reduced. This allows various error correction codes to work more effectively since they have a limitation on the number of consecutive errors which they can correct.

Convolution Code

- **Analogous to multiplying* by a pre-determined constant before transmission**
- **10110•10101=100101110, transmit product**
- **Divide* received bit string by the pre-determined constant at receiver**
 - **Non-zero remainder indicates errors**
 - **Some patterns correspond to limited numbers of bit errors at identifiable bit positions**
 - **correct error(s) by reversing those bits (0 <->1)**
 - **Other patterns correspond to more than one error condition**
 - **errors are detected but not correctable**

* Ring sum or
modulo 2

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The two binary numbers shown in the example correspond to decimal 22 and 21, respectively. If we did ordinary arithmetic multiplication with carry, the product would be decimal 462. Examination of the result above shows that it corresponds to decimal 302, because we did not carry in cases where there were two or more binary 1 values in a bit column at intermediate stages of the multiplication process. The convolutional code is used on most (but not all) of the bits from the speech coder, and on *all* of the bits from data sources, but (in GSM and PCS-1900 only) in conjunction with a Fire block code as well for call processing messages.

Cyclic Redundancy Check Code

- Analogous to dividing* by a pre-determined constant and appending the remainder to the data before transmitting
- The division* is repeated at the receiver, and the computed and received CRC compared
 - Non-zero difference indicates errors
 - Some patterns correspond to limited numbers of bit errors at identifiable bit positions
 - correct error(s) by reversing those bits (0 <->1)
 - Other patterns correspond to more than one error condition
 - errors are detected but not correctable

* Ring sum or modulo 2

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CRC is a good error detecting code, and can fix a very limited number of errors as well. The exact properties depend on the length and type of divisor used to calculate the CRC. Of course, a longer divisor will produce a longer CRC remainder as well. The CRC is used on only some of the most important bits in the speech coding, in combination with a convolutional code.

Block Code (only in GSM)

- Data is matrix multiplied* by a pre-defined matrix to generate parity check bits, which are appended to data and then transmitted
- Matrix process is repeated at receiver, computed parity bits are compared to received parity bits
 - Non-zero difference indicates errors
 - Some patterns correspond to limited numbers of bit errors at identifiable bit positions
 - correct error(s) by reversing those bits (0 $\leftrightarrow$ 1)
 - Other patterns correspond to more than one error condition
 - errors are detected but not correctable

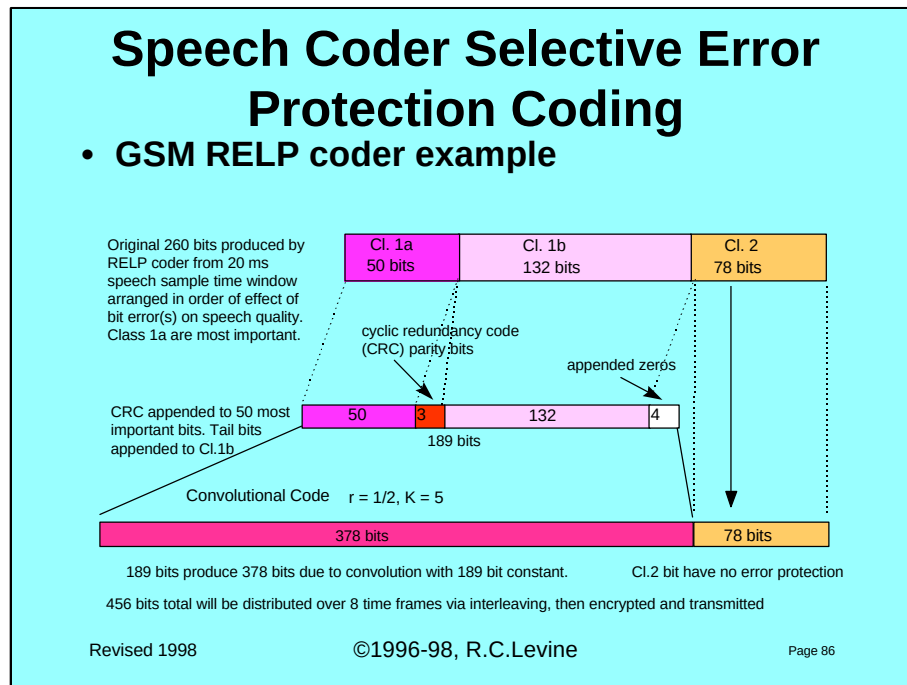
* Ring sum or
modulo 2

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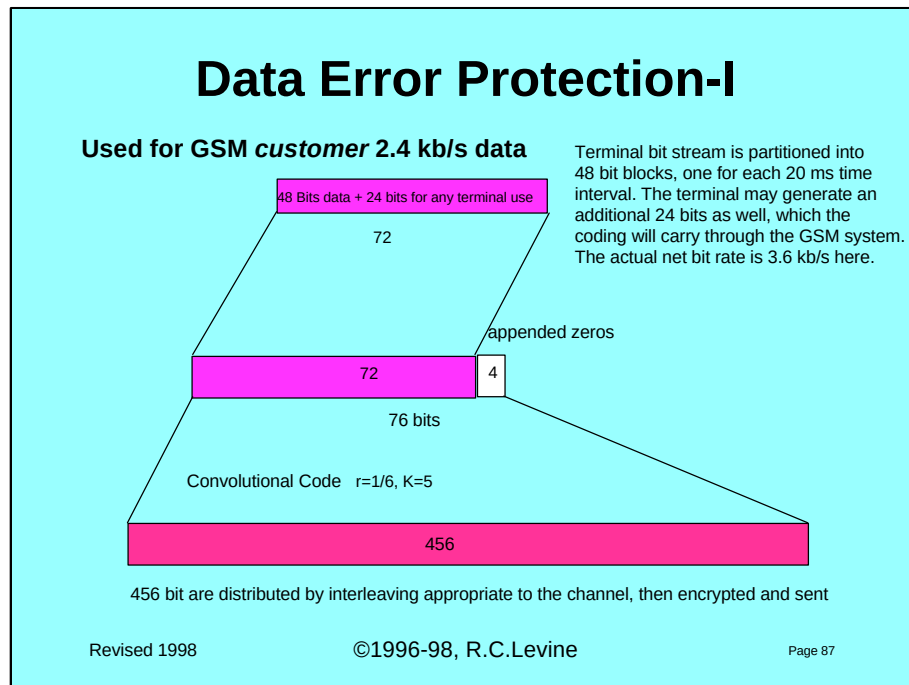
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The particular block code, used only in GSM and PCS-1900, is the Fire code, named after its inventor Emanuel Fire. It is a very good error *detecting* code, and is used only for data which can be retransmitted with some delay, by means of an ARQ protocol, without affecting the system too adversely. It is not a forward error correcting code and is not used for speech coding or customer data.



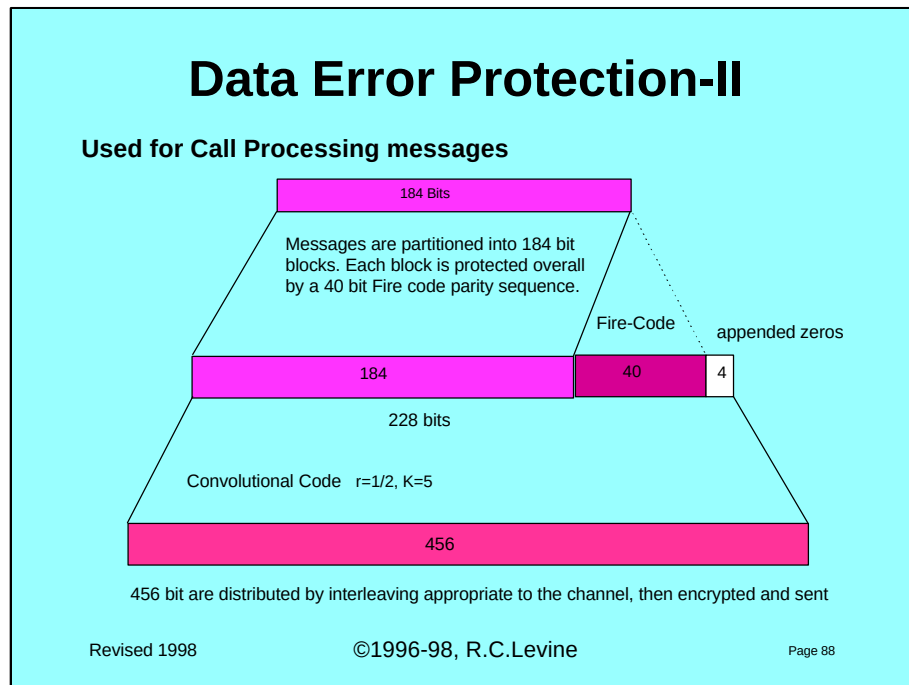
The bits are arranged in order of importance to speech quality by the simple but tedious method of intentionally introducing 50% BER into one selected bit in a recorded voice sample, and comparing the subjective quality with a similarly processed recording which has 50% BER introduced into *another* bit. By ranking the quality of all such samples, the bit with the most importance to good quality is placed at the left in Class 1a, and the bit with the least importance to quality is placed at the right in Class 2. The bits are then divided into three *classes* of importance, since there is a observed larger change in quality between having errors in the last bit in Cl.1a and the first bit in Cl. 1b, and likewise with the last bit in Cl. 1b and the first in Cl.2, compared to the difference between consecutive bits within the classes. (Don't ask me why the three classes are not labeled as Classes 1,2, and 3 !?!)

The 3-bit CRC permits correction of single bit errors in the 50 most protected bits all by itself. The convolution code can correct several bit errors, and detect any bursts of errors which are within a consecutive group of 5 bits. Most of the bits in Classes 1a and 1b are most significant bits of filter coefficients and other numerical bit quantities which have an obvious significant effect on the sound output if they are wrong. Most Cl.2 bits are least significant bits of numeric quantities and some bits describing the excitation waveform.



This a method only applicable to 2.4 kb/s data. Such data could be from a FAX machine (running slower than normal, of course!), or a data terminal with a keyboard and display, or a point of sale terminal, etc. When higher bit rate data such as 4.8 or 9.6 kb/s is used, a different rate convolution code is used, and the interleaving method is different from the interleaving used for digitally coded speech. The 2.4 kb/s example is shown here because its interleaving method is exactly the same as the one used for speech, FACCH and SACCH data bits on the TACH channel.

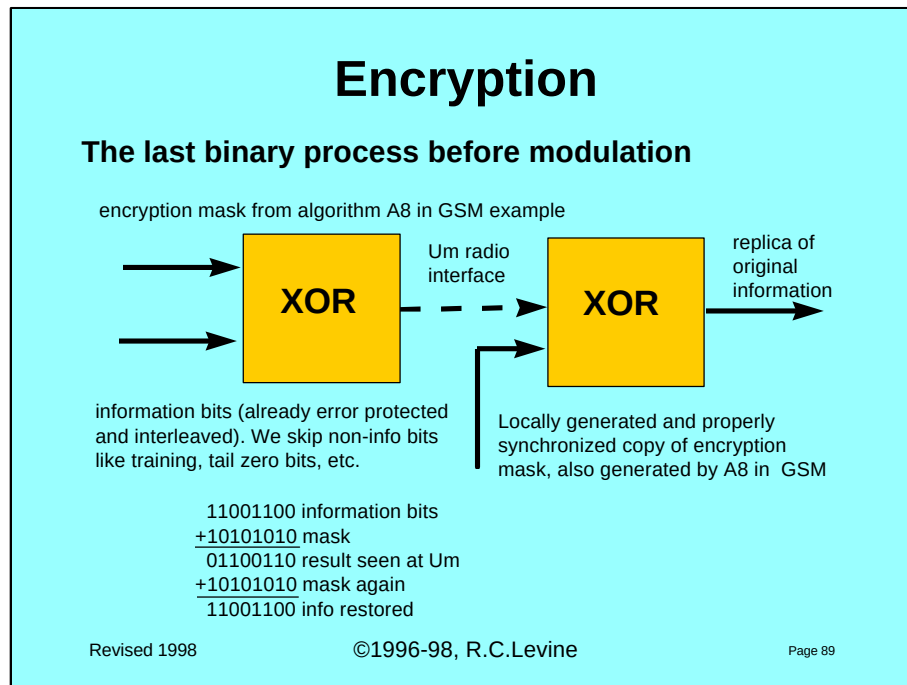
The 24 extra bits allowed in each 20 ms time interval in addition to the 48 data bits may be used by the terminal equipment for packetizing the data (header and terminal-related error protection codes) or any other purpose desired by the terminal. The gross data throughput due to the extra bits is really 3.6 kb/s, and the terminal can use this in any way desired. The GSM/PCS-1900 system is designed to eventually deliver the entire 72 bits at the other end.



The GSM call processing messages may be of any length, in principle, but they are transmitted in blocks of 184 bits, and if necessary are reassembled at the other end. The Fire code using this particular implementation can detect any combination errors of up to 11 bits total in error, regardless of their arrangement..

The description of the convolutional code on each figure shows its rate r and its constraint length K . The rate is merely the ratio of the number of bits of data to the total number of resulting bits. The predetermined multiplier contains a number of bits equal to the difference between the two bit string lengths. Thus, in the $r=1/6$ code used previously for customer data, the 76 bit data block is multiplied by a 380 bit predetermined constant, to produce a 456 bit result. This is similar to the general rule in decimal arithmetic that the number of digits in the product is the sum of the number of digits in the two numbers which are multiplied. Of course, there is no carry used in this modulo 2 or ring sum multiplication, so it is not *true* multiplication in the everyday sense of that word.

The constraint length K is the longest cluster of error bits that this particular code can disclose as an error. A longer cluster of errors will not be properly detected, although multiple error bursts separated by a section of good data *will* all be detected properly.



This same method is used in both GSM/PCS-1900 and IS-54,136. However, the encryption mask is generated by different algorithms in these two families of system designs. The European A8 algorithm is not known to be “crackable,” but the algorithm used in the North American systems was intentionally designed to be simple and can be “cracked” by analysis of samples of data using a reasonably powerful computer. It was only designed as a low level privacy method in order to meet US export restrictions on cryptography.

Short Message Services

- IS-136, IS-95, GSM, PCS-1900 are capable of sending a short message of up to 160 characters (7-bit ASCII code characters)
 - Individually addressed or broadcast
 - Appears (scrolls) on alpha display of handset
 - MS can send short messages as well
 - Select from menu of “canned” messages
 - “Let’s have lunch,” “Your message understood,” etc.
 - Arbitrary message from attached PC, etc.
 - Messages can be broadcast to all, or to a class of recipients
 - Automobile traffic reports, weather warnings, etc.

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SMS makes a MS into both the functionality of a pocket alpha-numeric message pager and a voice telephone. It has the promise of lower overall cost than the use of two separate services of these types using separate customer units for each purpose and separate infrastructure for each type of signal. It is viewed by many industry observers as a very important customer motivator to change over to or begin IS-136, IS=95 or PCS-1900 service.

SMS Connections

SMS messages may originate in many ways

- Call-back number, coming from calling line ID of PSTN, or caller-entered touch tone**
- Alphabetic message from many sources**
 - E-mail to MS user
 - Internet messages to SMS server
 - Dial-in MODEM for SMS messages
 - Attendant typist transcribes verbal telephone messages into text of SMS message
- MS may reply to any of these specifically**
- But SMS is not a real-time 2-way dialog**

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While digital PCS systems offers many sophisticated ways to deliver short messages to an MS, these are all data network infrastructure developments which are beyond the scope of the GSM or IS-xx standards documents. The only direct interaction is the transmission of these messages via the MAP common channel signaling message set, which is a subset of common channel number 7 signaling. CCS7 (which also has numerous other abbreviations) is almost universally used for telephone networks in North America and most other industrialized nations.

All of the methods described here are equally applicable to GSM and competitive services such as IS-136 (which was openly modeled after GSM), CDMA, and also the so-called NPCS (narrow band PCS) paging systems recently licensed on the 900 MHz band.

Network Interactions with Public Switched Telephone Network (PSTN)

- **At present, connections between the PSTN and PCS, cellular or other MSC switches use signaling originally developed for PBX (private branch exchange)**
 - The best version of this is primary rate interface (PRI), which provides better answer supervision
 - The “vanilla” signaling system is A,B bit signaling, which does about the same things at lower cost!
- **Roamer call delivery can be provided by forwarding calls through the home MSC**
 - This is part of the IS-41 system used by North American cellular operators

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The “vanilla” PBX signaling uses so called “in band” signals to indicate when a call is originated and disconnected. It does not indicate specifically when the distant called destination answers the ringing call attempt. PRI does better on that score, but some operators feel that otherwise it costs a lot of money for no additional capabilities. Both systems can provide caller ID by means of different signaling mechanisms.

Neither system gives the MSC access to all the network capabilities which are designed into the European implementation of MAP, the set of messages for handling mobile customers via the CCS7 signaling network. It is likely that the advent of landline local service competition from companies which also own long distance (inter-exchange carrier or IXC) networks as well, like AT&T, MCI (MCI-BT or “Concert” as of 11/4/96), etc., may change this and give MSCs full access to CCS7 signaling and provide MAP implementation on the PSTN (or at least on part of it).

The objection by the public telephone companies to using CCS7 all the way to the MSC has been that it opens up possible methods of fraud such as placing calls which are not billed because they are identified as test calls, etc. There *have* been cases of fraud with existing PBX signaling which lead to this concern.

Promises of MAP

- **MAP (mobile application part) is an extension of CSS7 signaling for mobile services**
 - Uses the same CSS7 network to carry MAP messages as other telephone signaling
 - Compare IS-41 which normally requires a separate parallel data network as well as the public telephone network for voice
- **Allows calls to be routed directly to the present MS location**
 - NOT via the home MSC, as IS-41 does
- **Adoption of MAP in North America was a business/political issue to be settled**
 - FCC requirement for local number portability by cellular/PCS carriers now make CSS7 signaling interworking with the PSTN mandatory

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MAP and CSS7 signaling were specified in detail as a part of the GSM standards and are being implemented in Europe. In principle, with a fully developed MAP system, a call placed from Boston, to an MS which is visiting Boston from a home location in Los Angeles, will be routed entirely within the city of Boston, and the voice channel in the PSTN will never get out of the city, although some MAP data messages go back and forth to Los Angeles as part of the call setup. As the number of roaming cellular and PCS users increases, the traffic load on the long distance networks using the IS-41 call forwarding method will increase exponentially. And the customer annoyance at paying for unnecessary long distance connections when calls actually originate and are answered in the same city will also increase exponentially!

In addition, there is a possible saving in air time, since with positive answer supervision the call could be connected on a TACH only after it is answered by the called destination. One would not need to use the TACH channel to listen to busy or ringing tone.

TDMA vs. CDMA vs. FDMA

- Access technology debates between FDMA, TDMA (and later CDMA) are also called the “religious wars”

- My own conclusions: “Levine’s Laws of RF Access Technologies”

1. The *inherent* traffic capacity of all 3 technologies is the same

Proper Measure= conversations/kHz/km²

2. *Significant* differences in implemented system capacity arise from secondary *non-access* features, for example:

- Speech coder
- Voice activity control (DSI, TASI)

Corollaries: a) there is a corresponding technological problem in every technology for each technological advantage. b) A good engineer can make *any* access technology into a working system

3. The decisions regarding competing technologies depend on overall performance and economic criteria:

Measure: conversations/kHz/km²/\$ (equiv. capital or recurring costs)

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A lower bit-rate digital speech coder of equal quality obviously permits more conversations to share an overall link digital data transmission capacity having a fixed number of total bits per second.

Voice controlled channel assignment (also known as Digital or dynamic Speech Interpolation -- DSI -- or, in an older analog version Time Assignment Speech Interpolation -- TASI) is a technology which re-assigns a physical channel to a different user when the current user pauses during speech. Aside from silence on the part of one participant in a two-way conversation when the other participant is speaking, a typical “continuous” stream of speech is actually about 60% silence, due to pauses between syllables, phrases, etc. In theory, an increase in capacity of almost 2.5 could be achieved by completely utilizing all these silent intervals. In actual systems, the very shortest intervals are not always utilized effectively, so the improvement is under a factor of 2. The application of DSI also requires a large number of conversations to choose from, so the probability of all channels being in actual use instantaneously is very low. Otherwise there will be “clipping” of the beginning of syllables because an idle channel is not always immediately available.

DSI is used extensively on both undersea cable and satellite telephone channels. It is also part of the design of the Qualcomm CDMA system (IS-95) and the Hughes Network Systems E-TDMA system, which is an enhancement to IS-54 and which can also be applied to GSM/PCS-1900 as well.

Note that DSI is not useful for digital data communication of long data transfers, in general. It is only helpful for speech or highly bursty data.

TDMA Advantages

- **Economy of TDMA Base Station**
 - 8-channel transceiver costs about twice the cost of a single channel transceiver
 - Therefore, about 1/4 the cost/channel
- **Mobile Assisted Handoff**
 - Mobile station can tune to nearby RF carrier frequencies during idle TDMA time slots, report signal strength to system
 - No extensive “locating receiver” system as used in analog cellular
- **No simultaneous receive/transmit**
 - Bulk, Cost, Power Savings of RF antenna switching in mobile set
 - Better compared to duplexer filter

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Truly TDMA handsets, as used in GSM, PCS-1900, or IS-136 (digital mode only) can use an electronic antenna switch (usually implemented with a PIN diode) rather than a filter-type antenna duplexer. The PIN diode is smaller in size, somewhat lower in cost, and slightly more power efficient than a filter. The IS-54 dual-mode cellular mobile sets must be able to operate in a simultaneous Tx/Rx mode for the analog-type control channel and the analog voice channel, so they do not use any type of antenna switching.

In the debate between TDMA, CDMA and FDMA, no *major* systems currently use FDMA in the form of one conversation per narrow-band carrier. There are two systems in existence which meet this description, but their respective manufacturers appear to be supporting them to a much lower degree than other standardized approaches of the TDMA or CDMA variety.

One FDMA system is CT-2, and its Canadian second-generation version, CT-2+. The slow roll out of features leaves this in question. CT-2+ uses digital speech coding, and is intended as a low-tier (short range) semi-public PCS system. Its main advantage arises from the present relatively low cost home cordless base station available with the private/public handset. However, the cost of base stations for other technologies which provide public/private service is dropping so that this advantage is eroding. In addition, the full public capability of CT-2+ is only realized when there is an infrastructure of switching software which can provide both mobile destination calls as well as mobile originate calls. This is not yet available for CT-2+, although the handsets are designed to be capable of this when it is available. Meanwhile, systems like IS-91 (GTE Telego, etc.) provide both public and private answering and origination of calls, and thus have this feature before CT-2+.

Motorola's N-AMPS technology is narrow band analog FM voice, and it has been installed in the 800 MHz cellular system in Las Vegas. It is apparently not being promoted as a general cellular or PCS system. Several MicroTAC™ handsets are N-AMPS capable.

Low-tier Systems: DECT/DCT, WACS/PACS, CT2+

- **Outgrowth of British CT-2 systems**
 - Short Range due partly to low RF power
 - Short range also implies simpler design
 - No timing adjustment in TDMA
 - Little or no error protection code
 - No adaptive equalization in handset
- **CT-2 was *not* a business success**
 - But main problems were not technology
 - Late development of a common air interface (CAI) contributed to demise in UK
 - Bad marketing, pricing, timing
 - Still in limited use in Singapore, Hong Kong, France, Germany, etc.

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Low tier systems are presently sold now only for limited range use, such as wireless PBX in an office, or limited use in special areas like the airport or a shopping center. However, due to the significantly lower cost of their infrastructure, they can be a direct competitor to PCS-1900 if sufficient number of networked closely spaced base stations are installed to cover the public areas of the city. They have the advantage that the handset is then a dual-use public/private handset for both office/home and also for public networks.

The original British CT-2 system had the limitation that one could only originate calls in the public domain, but not answer calls, because there was no network facility for call delivery. The original CT-2 handset could both originate and answer when used with a special base unit as a home cordless telephone only. All the new low-tier technologies have designed in capability to both answer and originate calls in the public domain, and all but CT-2+ have already demonstrated network capability to locate the handset and deliver calls to it.

Low-tier Technology survey

- **Objective is low cost, with intentionally less comprehensive service than cellular or high-tier PCS**
 - **Use of same handset as both home/office cordless set and public low-tier handset**
 - **Shorter range of coverage, incomplete geographical coverage in some systems**
 - Service only in heavily used public areas: airports, shopping malls, etc.
 - **Most low-tier systems have theoretical handoff capability, but some installations do not support it at this time**
 - **Most low-tier systems have theoretical originate-answer capability, but some installations (CT-2+) do not support public domain answer at this time**
- **Most Low-tier systems use Time Division Duplex (TDD)**

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Low tier systems are generally designed to provide limited coverage for a high geographical user and traffic density at lower cost than public domain or high tier cellular or PCS systems.

Advantages of time division duplex (TDD)

- **TDD utilizes short RF bursts in alternate directions**
 - Digital storage buffer at each end produces continuous output
 - Burst digital bit rate is twice the continuous bit rate for single channel
 - 8 or 12 times for TDMA/TDD with 8 or 12 channels respectively
 - Paired spectrum channels (as in FDD) not required
 - any adequate contiguous single spectrum chunk will work
 - Use of same frequency in both directions permits use of a base station diversity method only
 - shared base duplexer for multi-channel system is less costly than an equalizer in every handset
 - Handset receiver benefits via base transmitter diversity, but...
 - quality of performance dependent on excellence of base diversity methodology
 - Tx diversity parameters based on prior time slot Rx properties
 - Most low tier systems consequently limited to pedestrian handset speeds
 - ~5 km/h (3 mi/h) is fast walking speed
 - Low tier systems perform well up to about 40 km/h (24 mi/h)

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TDD has many beneficial properties. Its most notable negative property is a limited ability (in existing implementations) to make timing adjustments for changes in propagation distance, and some mutual interference between base and mobile stations, since they both transmit on the same frequency.

Fixed wireless systems and related technologies:

- Too costly via most existing high-tier technologies,
- **Some business exceptions:**
 - special short-term or interim uses
 - legal protection of service area to prevent loss of exclusive franchise
- **BETRS and other rural-radio-telephone systems (Ultraphone, etc.)**
- **Possible use of low-tier systems**
- **Specially designed fixed wireless systems (Ionica, DSC, etc.)**
- **Telephone service via cable TV facilities**
 - could be serious economic competitor

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Many other technologies have been proposed for general public PCS use. Some involve radio, others are alternative methods of wire transmission. Most of the radio systems based on cellular or other higher cost technology cannot compete reasonably with ordinary wire landline telephone. Only in special short term applications is high cost wireless useful. It is often installed only to temporarily provide service until replaced permanently by wired telephone service.

Review of technical and economic points of comparison:

- **Remember Geographic Spectral Efficiency:**
conversations/kHz/sq.km
- **And *Economic* geographic spectral efficiency:**
conversations/kHz/sq.km/\$
 - \$ represents equivalent capital or equivalent total recurring cost of all operations
- **Significance of delivery calendar and product roll-out cannot be forgotten**
- **When heavy price competition breaks out, the most economical system with adequate capacity will dominate**
- **The industry will gravitate to one main PCS technology by about the year 2001**

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Remember these figures of merit for comparison of different systems, or even for comparison of two vendors selling the same technology! What counts is the proportional cost per conversation (and ultimately per customer, although that depends in turn on the amount of traffic load offered by each customer which is beyond the scope of this presentation).

Land Mobile/SMR

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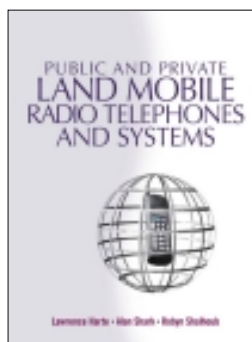
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Land mobile are privately maintained and operated mobile radio systems. Some connect to the public switched telephone network but placing telephone calls is not usually their main function. (In the past many people called all mobile telephone service land mobile. In that case the proper term was Public Land Mobile.) Most land mobile systems keep field workers connected to a main dispatch point, usually to a company headquarters, as well as to other mobiles. A taxi dispatch service uses land mobile as do ambulance companies.

Southern Pacific Railroad uses land mobile to connect their maintenance workers along hundreds of miles of track from San Francisco to Denver. Workers communicate to headquarters and use the system to place telephone calls from areas cellular radio will never serve. That's because SP set up their own radio network along the tracks. Their land mobile network is simple, FM based and analog. All conversations can be heard on a scanner. As with all things, land mobile can get quite complicated, with multiplexed and digitized systems becoming common.

Messrs Lawrence Harte, Alan Shark, Robyn Shalhoub, and Tom Steiner, have written an excellent book on land mobile, called Public and Private Land Mobile Radio Telephones and Systems. The following is from the first chapter of that book. You can download the complete chapter by clicking on the link below.



[This is from Harte's book described herein \(16 pages, 174K in .pdf\)](#)

[Public and Private Land Mobile Radio Telephones and Systems by Harte et. al.
\(external link to Amazon.com\)](#)

Public and Private Land Mobile Radio Telephones and Systems by Harte, Alan Shark, Robyn Shalhoub, and Tom Steiner (2000)

Chapter 1



[This is from Harte's book described herein \(16 pages,](#)

Introduction to Land Mobile Radio

The mobile wireless communications industry easily ranks as one of the most dynamic and fastgrowing if not the fastest growing industries of today. Driving its popularity and growth are the wide variety of services it provides and the tremendous benefits it offers. Around the globe, convenience, improved efficiency, and enhanced productivity have become its trademarks.

Conventional Land Mobile Radio (TwoWay)

Conventional systems dedicate a single radio channel to a specific group of users who share it. As such, privacy is limited. It is possible for a company using a channel to be overheard by other users on the same channel. Some of these listeners might even be competitors! Conventional systems, by limiting a group of users to a specific channel, also limit the total number of customers who can be served by the system. Moreover, because radios on conventional systems transmit and receive on a single channel, the user must wait if the channel is occupied by another conversation. For these reasons, conventional systems are considered spectrally inefficient when compared to trunking systems. Figure 1.1 shows a block diagram of a conventional land mobile radio system.

Trunked systems also offer customers wider coverage areas through 1) interconnection with the public switched telephone network (PSTN), which allows trunked radio users to communicate with any user of the wireline telephone network; and 2) interconnection with other trunked systems, which may or may not be assigned to that user. Figure 1.2 shows a trunked land mobile radio system.

Commercial Trunked Radio

One relatively small, but significant, segment of the overall mobile wireless industry is commercial trunked radio, which has only recently begun to receive worldwide attention. This is because commercial trunked radio systems usually serve a very specific user group, rather than the public at large, and the major growth of the industry has occurred only within the last five years.

Trunked Radio

Trunking systems, using frequencytrunked technology, were developed to use radio spectrum more efficiently, while offering companies a more sophisticated, private, and efficient way of communicating with their mobile workforce. Trunking systems are more expensive than conventional systems, but they also offer significant benefits and improvements in spectralefficiency. Unlike conventional technology, trunking allows for the automatic sharing of multiple radio channels. This means that a group of channels is assigned to a group of users who then share the channels. The advantage of this arrangement is that when a user attempts to make a call with the radio, a trunked system searches for an available channel and assigns it to the call. A different radio channel may be

assigned each time the customer uses the radio; it may even switch during the same conversation. Either way, users are unaware of the swap.

In the event the system is fully loaded and all channels are in use, the user either receives a busy signal or calls are "queued" until a channel is free. After the channel is selected, users have private use of the channel, which reduces interference and eavesdropping. Trunking is considered much more spectrally efficient because switching between multiple radio channels allows less blocking and provides service to more radios per channel. Consider that on a 20channel conventional system, roughly 7001,000 users can be served. In contrast, those 20 channels on a trunked, dispatchtype system can service between 2,000 and 2,500 users! Figure 1.2, Trunked Land Mobile Radio System

Today, a wide range of commercial trunked radio users exist as well as a variety of technologies and services to meet their needs. As word spreads about the industry and regulators allow for it to exist, we will see commercial trunked radio systems being introduced in country after country with increasing opportunities. The term "commercial trunked radio" was created by the International Mobile Telecommunications Association (IMTA) in an attempt to create a universal definition encompassing the many names for the industry and to identify a specific kind of service.

As mentioned above, this small segment of the wireless communications industry has experienced rapid growth primarily outside the United States within the last five years. As the industry is created in each country, there are an increasing number of names and classifications governments use to identify the service. For example, commercial trunked radio is known as Specialized Mobile Radio ("SMR") in the United States and is typically referred to as Trunked Radio Systems ("TRS") in Asia and Public Access Mobile Radio ("PAMR") in Europe. Figure 1.3 shows a commercial land mobile radio system. Because the service is subject to different regulations in each country, it is difficult to create a single "name" for the service without first creating a definition. So, the following was developed.



[This is from Harte's book described herein \(16 pages, 174K in .pdf\)](#)

[Public and Private Land Mobile Radio Telephones and Systems by Harte et. al.
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Resources

At the F.C.C.: <http://www.fcc.gov/wtb/plmrs/>

Handheld landmobile radios:

http://www.icomamerica.com/land_mobile/portablevhf/

U.K. landmobile magazine site with some good files:

<http://www.landmobile.co.uk/>

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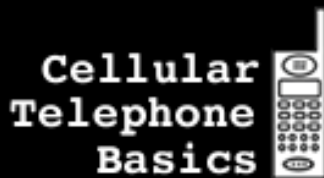
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Why can't I use my cellular phone on an airliner?

[The Question](#)

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Dear Tom:

Almost every news article and TV news channel has reported on the amazing last minute phone calls that the passengers made from the planes once it was hijacked. In fact, there was a whole separate article in Friday's Wall Street Journal on the issue. However, the one thing that no seems to be reporting on is that none of this mobile phone use seemed to interfere with the airplanes navigation system or controls. Yet the FAA would have us all believe that the use of phones while flying is almost synonymous with death by crash. I find it amazing that a whole airplane full of passengers could use their phones, yet there was no problem with any of the planes. Your thoughts?

This is a confusing issue. I think the ban applies to all radio transmitters, not just cell phones. They don't want anyone transmitting any kind of RF signal, other than the airplane itself. Aviation has typically gone under zero risk guidelines, almost to the point of paranoia. Sure, they may not be able to point to any study showing cell phones cause interference, but what about a cell phone out of adjustment? Something transmitting off frequency by accident, that even the user isn't aware of? Are we going to test all cell phones before they go on board? Many think the real reason cell phones are prohibited is because the airlines make huge amounts of money off the on board telephones they provide. They don't want competition, in other words. What's frustrating is the FAA provides cover for their position, deliberately or not, by prohibiting radio use. So the airline can avoid the whole issue by saying "Hey, don't look at us, it's the FAA's decision. (hee, hee, hee)"

Actually, the most practical reason isn't because of airline safety or the airlines, it's because cell phones on airlines interfere with the terrestrial cellular telephone network. Cell phones transmit in nearly straight lines, what we call line of sight. From an airplane a cell phone can connect to nearly any cell in view below, causing much turmoil, especially with a jet moving 500 miles an

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hour, passing by one cell after another far more quickly than the systems were designed for. Here's a little something from the [cellular basics article](#) to clear this up:

Mark van der Hoek describes two people, a businessman using his cell phone in the city, and a hiker on top of a mountain overlooking the city. The businessman's call is going well. But now the hiker decides to use his phone to tell his friends he has climbed the summit.

From the climber's position he can see all of the city and consequently the entire area under cellular coverage. Since radio waves travel in nearly a straight line at high frequencies, it's possible his call could be taken by nearly any cell. Like the one the businessman is now using. This is not what radio engineers plan on, since the nearest cell site usually handles a call, in fact, Mark points out they don't want people using cell phones on an airplane "Knock it off, turkey! Can't you see you're confusing the poor cell sites?"

I don't have a good suggestion here. I think cell phones should at least be allowed on the ground, if not in the air. If cellular radio engineers and carriers think the present cellular network can handle all the calls made from airliners, placing calls haphazardly in one system, then the next, well fine. But I doubt they will approve. While I am not convinced it is a safety issue as the FAA claims, I really would have to see more on all of these arguments before I make a really firm opinion. Does any of this make sense?

Best, Tom Farley

p.s. Make sure to read the Wired article for more details.



[Wired.com \(external link\)](#)

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February 15, 2001

If We Can Fly, Why Can't We Talk? by Elisa Batista

The world is going mobile everywhere except in the air.

A Saudi Arabian army captain received 70 lashes earlier this month for using his mobile phone during an airplane's takeoff.

British oil worker Neil Whitehouse spent a year in jail for refusing to shut off his cell phone during a 1998 British Airways flight from Spain.

See also: Is Phone Interference Phony? Few Options For Yakkin' Flyers Can Cell Phones Crash Planes? Are Airborne E-Devices a Danger? Unwired News: The Next Generation

Swiss investigators believe that mobile phone interference may have helped cause last year's crash of Crossair flight LX498, which went down shortly after takeoff from the Zurich airport, killing all 10 passengers on board.

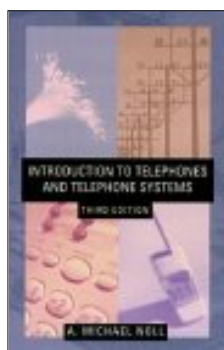
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[B. Land Mobile or IMTS](#)

[C. Early Bell System Overview of Amps](#)

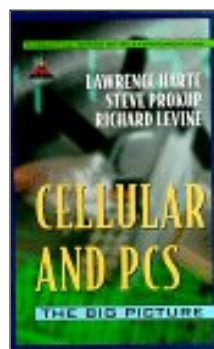
[Introduction to Telephones and Telephone Systems \(external link to Amazon\)](#) (Artech House)
Professor A. Michael Noll



[This is from Professor Noll's book above, it is an excellent, simple introduction to cellular \(32 pages, 204K in .pdf\)](#)



[This is a sample of Professor Levine's writing, co-author of the work below. This .pdf file is a well detailed, advanced guide to cellular \(100 pages, 373K in .pdf\)](#)



[Cellular and PCS: The Big Picture, Harte, Prokup, and Levine \(external link to](#)

A Slovenian flight on the way to Sarajevo made an emergency landing last month after the cockpit fire alarm went off. Investigators say a cell phone left turned on in the luggage compartment triggered the erroneous warning.

To the frustration -- if not incredulity -- of airplane passengers, whose only option to communicate with someone on the ground is airplane seat-installed phones, the aviation industry touted these incidents as more proof that cell phone use in flight is dangerous.

And that belief only reinforces the industry's resolve to keep permanent a ban on using the devices during flights.

"Beyond a shadow of a doubt, (handheld devices) can interfere under very precise circumstances," said John Sheehan, who headed an RTCA study showing that portable electronic devices could interfere with a plane's navigation and communication systems.

"But it's a rare occurrence."

Rules and regulations are increasingly at odds with social, political and economic phenomena. On one hand, there are passengers who would like to see all portable electronic devices banned because they find them annoying -- even the ticking away at a laptop computer's keyboard, said U.S. Rep. John Duncan, Jr. (R-Tenn.). The use of laptop computers is generally allowed for the duration of flight and airplane-seat installed phones can be used any time.

"It's sort of like smoking," Duncan said in a July hearing on whether PEDs really pose a safety hazard to passengers. "When people ask, 'Do you mind if I smoke,' most people are too polite to tell them that they are, even though they hope secretly that they will not smoke. And in the same way, people really find people next to them, or near them, using laptop computers to be an annoying nuisance, too."

Because more people than ever before own cell phones (and are using them everywhere they go), and there are more flights -- and capacity flights -- than ever before, there are also more people wanting to use their cell phones during flights than ever before.

But they can't.

What's more, many of the reasons are unclear, especially since many airlines have FAA-approved, seat-installed cell phones of their own. It costs about \$3 a minute to make an in-flight call in the United States; a 20-minute call costing \$60 doesn't exactly make company accountants jump for joy.

"I question (the prohibition of cell phones in flight) because they have a telephone if you pay for it," said Larry Murphy, vice president of sales and marketing for Flying Food Group.

Besides, Murphy says, "In private jets you can use your own phone."

Then why are cell phones and other wireless devices not allowed during flights? This question is a growing concern because of the increase of business-purpose flights, when many passengers face pressures to maintain constant contact with the ground.

[Amazon.com](http://www.amazon.com))

Both the airline industry and the Federal Communications Commission ban the use of cell phones aboard commercial flights. But they do it for different reasons, reasons which are contradictory and scientifically unsubstantiated, critics say.

Safety is the main concern, which Federal Aviation Administration officials say is reason enough for the ban. And there is plenty of anecdotal evidence, they argue, to strongly suggest that wireless devices can interfere with aircraft instruments.

The FAA used the findings of the RTCA, an independent aeronautics adviser, to justify the ban, although it leaves enforcement up to the airlines. The RTCA's three studies, published in 1963, 1988 and 1996, say handheld devices (excluding cell phones) should be banned during "critical phases of flight," which the airlines have interpreted as takeoffs and landings.

The studies don't include "intentional transmitting devices" such as cell phones and two-way pagers, because the organization did not receive the devices from the cell phone industry, planes from the aviation industry and funding to conduct the study. The RTCA works on a "volunteer basis so we had to rely on these people for the free use" of their equipment, Sheehan said.

The FAA recommendation doesn't extend to private jets, which have different rules.

The FCC has its own cell-phone ban, but it has nothing to do with airplane safety. The FCC says signals emitted by phones in the air could occupy multiple cell towers on the ground and cause interference with calls on the ground. This interference might even allow analog cell phone users to listen to others' conversations on the ground.

However, no study has been conducted to prove this. What's more, the ban does not extend to SprintPCS and AT&T wireless phones because of an FCC "oversight," according to a former FCC engineer.

SprintPCS and AT&T wireless phones use a different frequency than other cell phones. The oversight might imply that a user of either phone could use them in flight, but most, if not all, airlines adhere to FAA guidelines and prohibit all mobile phones anyway.

"You try to write the rules so that they cover everything," said Dale Hatfield, a former FCC engineer who is now telecommunications program director at the University of Colorado in Boulder. "Since the FAA has its own rules, there's not a lot of pressure to fix that."

Airlines generally abide by the FAA's recommendation, but what they don't tell passengers is that no agency -- not even the RTCA -- has come up with definitive evidence of portable electronic devices interfering with a plane's instruments.

Here's one possible explanation: Cell phones and other handhelds operate on different frequencies than onboard instruments. "The issue with cell phones has less to do with interfering with the airplane equipment," said Tim Brown, an

engineering professor at the University of Colorado in Boulder. "It's conceivable that a cell phone may have enough energy spilling into an adjacent band, which could cause a problem."

Brown surveyed a chart detailing the various frequencies of portable electronic devices and airplane equipment and said, "Again, nothing is exactly adjacent to them."

Still, the FAA and FCC say they don't plan on changing the rules, although enforcing them has been a thorn in the side of airlines because passengers often forget to turn off their phones or else are refusing to comply with the policy.

According to the National Aeronautics and Space Administration, the second-leading cause of "air rage" results from passengers being told by in-flight attendants to turn off their PEDs. Whitehouse, the British oil worker who was jailed last year, was using his cell phone.

NASA, which maintains a database of flight problems anonymously reported by pilots, found that 15 percent of air rage incidents are attributed to the prohibition of PEDs, second only to alcohol (43 percent).

The FAA oversees two U.S. flights every second and moves approximately 1.5 million passengers a day. There are over 110 million cell phone subscribers in the United States, according to the Cellular Telecommunications and Internet Association.

"It's becoming hard to control," Forrester Research analyst Galen Schreck said. "Think about all the stuff in your purse that is wireless: my cell phone, my pager, my Palm, which has a wireless connection. Your laptop might have something built into it."

Neither the FAA nor the FCC has plans to provide passengers with alternative ways to communicate with someone on the ground, or implement a mechanism that would detect illegal -- and even harmful PED use. They advise passengers to use plane seat-installed phones.

Passengers can receive incoming calls on the phones by activating them with a PIN number and seat number every time they fly.

Airlines pocket about 15 percent of the profits racked by these phones, according to Sheehan. Neither GTE (now Verizon Communications) nor AT&T, which shares a duopoly on the phones, would say how much money they make off them. But an October 1999 Wall Street Journal article estimated the units' annual revenues at \$150 million.

The FAA denies it implemented its policy based on economic incentives. FAA engineers say the phones are "exhaustively tested" -- making them more expensive to maintain -- to be compatible with onboard equipment.

Unlike other wireless phones, the signals of airplane-installed phones are shielded and controlled. Their calls go to a receiver in the plane's belly and then down to one of 135 ground base stations in North America, according to GTE Airfone, which is part of Verizon Communications.

Calls made 200 miles beyond the U.S. coastline run on a satellite system, where

the calls are routed to a satellite station rather than a radio base station, the company said. Foreign carriers receive a share of the profits generated by international phone calls made on the phones, thus making those calls more expensive.

The cell-phone industry says it has no way of lifting its own ban because it is physically impossible to construct cell-phone towers to accommodate signals traveling 600 miles per hour at 33,000 feet in the air.

"I'm afraid it's simply a matter of physics that phone use in airplanes interferes with other signals," Cellular Telecommunications and Internet Association spokesman Travis Larson said.

None of this may appease today's busy, frantic traveler. "With today's technology, I'm sure they have a way around this," said Flying Food Group's Murphy, furiously pecking away at his laptop at Oakland International Airport.

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Tuesday, November 13, 2001

Too many things to report on. . .

Yesterday my site set new record: 6,574 hits. Thank you all! . . .

The Taliban seemed finished as a ruling body in Afghanistan, may we continue to hunt them down and kill them. . .

The Red Cross says donations will be returned if requested from their special 9/11 fund. This is disturbing and unexpected. Who would have thought the Red Cross could not handle money correctly? I think of all the good they have done over so many decades, with flood, fire, and accident victims. I think the money I donated after September 11 will help someone in need. But I pray the Red Cross will find guidance soon. . . .

I continue writing the GSM call processing article. It is going well but taking my time away from updating other pages. . .

Just starting with telecom? Or are you an IT manager or HR officer who needs to know telecom in general without all the tiny details? APDG Publishing's Telecom

Made Simple is for you, a modern, well laid out book of 438 pages. Tells you what makes up the telephone system without overwhelming you. I think the suggested retail is \$34.95. Lawrence Harte, et. al. Order through Amazon.com or check out their own page: <http://apdg-inc.cyberosity.com/> (external link)

The IEC has new tutorials for you to read. This page takes a long time to load but it is well worth the wait: <http://www.iec.org/online/tutorials/> (external link) These tutorials feature some of the best telecom writing on the web, available in HTML or .pdf, and with no annoying pop up or banner ads. And all for free! I have linked to their site for years; the International Engineering Consortium should be

Thursday, November 8, 2001

Chloe, we all have lots to read :-)

Dear Whom this may concern,

I am 12 years old and i had an assignment to do on the Telephone. I went to Dogpile to look up information on the telephone. Everything there was about, well, if you wanted to buy a telephone or something but then I saw your website. I went into it and I found out everthing I need to know. What it does?, the history, how it works? And who uses it? Thank you very much ! I got a very high score on my project. I would just like to say that if that website was mine I would make a section for the Children because I had to read lots to find what I needed. Yours truly, Chloe

Something wonderful from NTT

I had not seen this graphic before. It speaks for itself and [now has a place in my mobile telephone history series](#):

Year	1987	1989	1991	1993	1995
System	Large city system (April 1989) High-capacity system			Digital system (800MHz)	
Configuration of mobile station and antenna					
	802B:500cc 750g	803B:400cc 640g	Mova:150cc 230g	Digital 150cc Mova : 240g	Ultra-compact 100cc mobile station:150g
Antenna technology	• Bottom end feeding 1/2λ whip	• Side-mounted built-in reverse-F antenna • Small diversity antenna	• Bottom end feeding 3/8λ whip • Retractable whip antenna on the side • Reverse-F antenna • Integrated with filter • Built-in reverse-F antenna installed at the back	• Wide-band whip antenna • Wide-band small plate antenna	

The Song of Roland

I am re-reading Frederick Bliss Luquien's brilliant translation of this nearly 900 year old poem. Not interested in epic poetry? How can you not be after reading the following? Make sure you get the Luquien translation, there is none finer:

Charles the great King, lord of the land of France,

Has fought beyond the hills for seven years,
And led his conquering host to the land's end.
There is but one of all the towns of Spain
Unshattered -- grim Saragossa, mountain-girt,
Held by Marsila, King of Spain, of those
Who love not God and serve false gods of stone
Brought from the shores of Araby. -- Hapless King!
Your hour is come, for all your gods of stone!

Wednesday, November 7, 2001

It was grand

At one thirty in the morning I awoke to hear two hoot owls calling to each other. Both were on top of my house. I kept quiet inside my room, hoping not to make any noise which might disturb them. The glorious calling went on for at least ten minutes, at times they took turns, at other times they hooted together. It was grand.

Who sells equipment to Africa?

I've received three requests in three days from different parts of Africa. All ask about reliable vendors of cellular equipment. E-mail me if your company does business on any part of the continent, I need to field these requests to someone honest.

Call Processing in GSM

It will take at least two weeks to do but I am committed to writing about call processing in GSM. [Send me your comments](#) now on what you would like explained in this subject. I will be using the writing of Macario, [Levine](#), and [John Scourias \(external link\)](#) to guide me. Wish me well, making this subject understandable may be the most difficult project I've ever undertaken.

DoCoMo redoes their website

And a good job they have done: <http://www.nttdocomo.com> [\(external link\)](#) The flash introduction is wonderful and fast paced and the site is now easier to navigate. Take a look at their view of the future soon. It's not Bladerunner just yet, but I think they are working on it.

Thursday, November 1, 2001

Another switch to GSM

ZDNet News' Ben Charny writes that Cingular Wireless will settle on GSM as their single wireless network choice, replacing IS-136 where they were using it. GSM is a TDMA based network, as is IS-136. In five years or so both will be replaced by some kind of standard based on CDMA. That GSM offering will probably be named 3GSM, the three standing for third generation. So what's being discussed here is an interim step, albeit an expensive one. Have I made myself clear?

What's happening is that all of the infrastructure used for IS-136, the successor to the original American cellular system, is being thrown out and replaced by the European originated GSM. In a few years GSM itself will be replaced with a

different system. There's going to be a great deal spent on cellular equipment, even before we get to 3G:

"The world's most popular wireless telephone technology, known as GSM, has won another convert: Cingular Wireless, America's second-largest wireless carrier."

"Cingular Wireless announced Tuesday morning that it will be undergoing an estimated \$3 billion renovation of its current wireless network, now a patchwork of different and competing technologies, so it can offer its customers a phone network that will be 30 times faster. The prevailing standard for the technology switch will be GSM (Global System for Mobile Communications), which is now in an estimated 70 percent of the world's wireless phone networks."

"The announced plans will finally unify the network that Cingular Wireless, a joint venture of BellSouth and SBC Communications, has been using to offer 22 million customers wireless service. The network uses two different wireless technologies. About 30 percent of its network uses GSM. The balance, about 70 percent, uses a technology known as TDMA (Time Division Multiple Access)."

"Tuesday's announcement is another sign of the growing dominance of GSM and its possible approach as the world's primary wireless telephone standard. By most accounts, a half-billion cell phone customers, mainly in Asia and Europe, use GSM networks to make calls. . . ."

<http://www.zdnet.com/zdnn/stories/news/0,4586,5098949,00.html> (external link)

Wednesday, October 31, 2001

Cell phone boosters

Many companies sell a stick on antenna that fits on the underside of the cell phone, beneath or near the battery. These passive cell phone boosters are widely and heavily advertised on American television. I haven't commented on this product because I haven't used it; I won't buy one nor do I want to mess up my cell phone. But I did check out a site run by Rhino which does sell the thing. Based upon what they claim I find the product ridiculous; marginally useful for a few lucky souls and a worthless piece of false hope for the majority. You can't have a non-powered, non-amplifying device do anything useful while tucked inside the phone. Antennas have to be external and much larger than the one they sell to do any good. Check out my page here if you are having cellular reception problems:

<http://www.privateline.com/reception/index.html> (internal link)

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[TelecomWriting.com's Telephone History Page 8 -- 1948 to 1951](#)

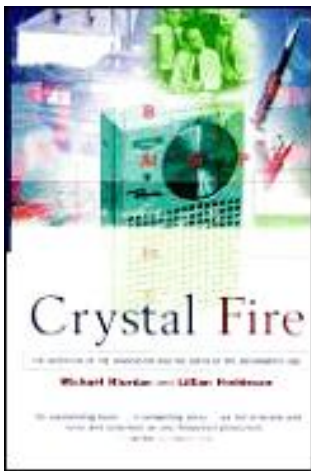
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On July 1, 1948 the Bell System unveiled the transistor, a joint invention of Bell Laboratories scientists William Shockley, John Bardeen, and Walter Brattain. It would revolutionize every aspect of the telephone industry and all of communications. One engineer remarked, "Asking us to predict what transistors will do is like asking the man who first put wheels on an ox cart to foresee the automobile, the wristwatch, or the high speed generator." Others were less restrained.

In 1954, recently retired Chief of Engineering for AT&T, Dr. Harold Osborne, predicted, "Let us say that in the ultimate, whenever a baby is born anywhere in the world, he is given at birth a number which will be his telephone number for life. As soon as he can talk, he is given a watchlike device with 10 little buttons on one side and a screen on the other. Thus equipped, at any time when he wishes to talk with anyone in the world, he will pull out the device and punch on the keys the number of his friend. Then turning the device over, he will hear the voice of his friend and see his face on the screen, in color and in three dimensions. If he does not see and hear him he will know that the friend is dead." [[Conly](#)]Sheesh.

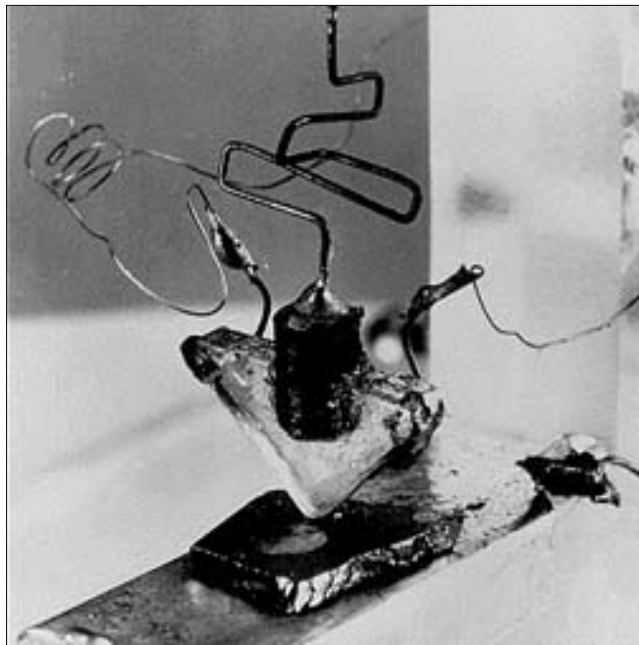


William Shockley
1910 to 1989
John Bardeen
1908 to 1991
Walter Brattain
1902 to 1987

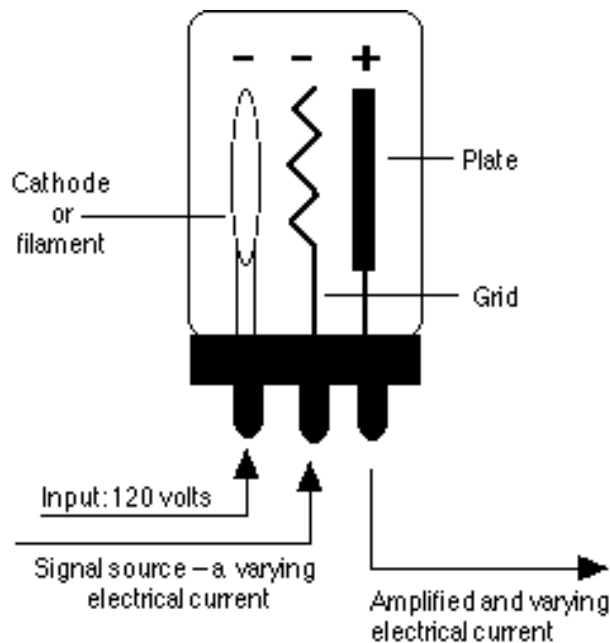


Crystal Fire: The Invention of the Transistor & the Birth of the Information Age by Michael Riordan (\$15.00)

[Read two wonderful excerpts from the book by clicking here](#)



The first transistor looking as crude, perhaps, as the first telephone. Notice how similar the three leads or contacts appear compared to the triode below. The point contact transistor pictured here is now obsolete.



Manufacturing the Future : A History of Western Electric by Stephen B. Adams, Orville R. Butler

Capitalizing on a flowing stream of electrons, much like the vacuum tube, along with the special characteristics of silicon and germanium, the transistor dependably amplified and switched signals while producing little heat. Equipment size was reduced and reliability increased. Hearing aids, radios, phonographs, computers, electronic telephone switching equipment, satellites and moon rockets would all be improved or made possible because of the transistor. Let's depart again from the narrative to see how a transistor works.

Transistor stands for transit resistor, the temporary name, now permanent, that the inventors gave it. These semiconductors, like the triode, control the electrical current flowing between two terminals by applying voltage to a third

terminal. You now have a miniature switch, presenting either a freeway to electrons or a brick wall to them, depending on whether a signal voltage exists. Bulky mechanical relays that used to switch calls, like the crossbar shown above, could now be replaced with transistors. There's more.

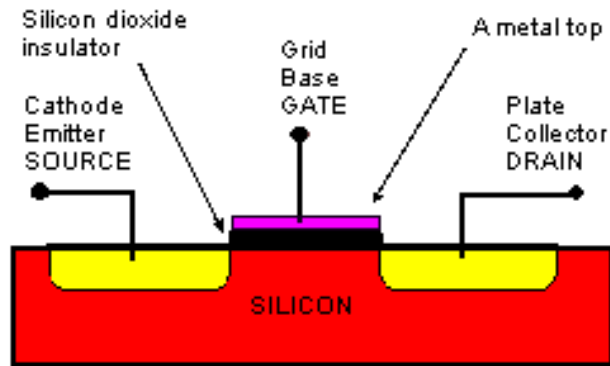
Transistors also amplify. Like the triode described before, a weak signal can be boosted tremendously. Let's say you have ten watts flowing into one side of the transistor. Your current stops because silicon normally isn't a good conductor. You now introduce a signal into the middle of the transistor, say, at one watt. That changes the transistor's internal crystalline structure, causing the silicon to go from an insulator to a conductor. It now allows the larger current to go through, picking up your weak signal along the way, impressing it on the larger voltage. Your one watt signal is now a ten watt signal.

Transistors use the same magnetic principles we've discussed before, "the attractive and repulsive forces between electrical charges." But they also use the properties of semi-conductors, seemingly innocuous materials like germanium and now mostly silicon. Materials like silver and copper conduct electricity well. Rubber and porcelain conduct electricity poorly. The difference between electrical conductors and insulators is their molecular structure, the stuff that makes them up. Weight, size, or shape doesn't matter, it's how tightly the material holds on to its electrons, preventing them from freely flowing through its atoms.

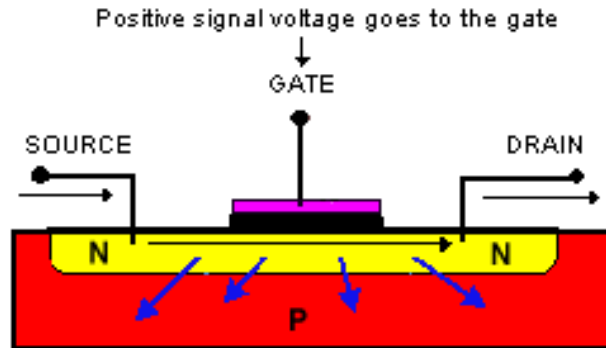
Silicon by itself is an ordinary element, a common part of sand. If you introduce impurities like arsenic or boron, though, you can turn it into a conductor with the right electrical charge. Selectively placing precise impurities into a silicon chip produces an electronic circuit. It's like making a magnetically polarized, multi-layered chemical cake. Vary the ingredients or elements and you can make up many kinds of cakes or transistors. And each will taste or operate a little differently.

As I've just hinted, there are many kinds of transistors, just as there are many different kinds of tubes. I'll describe just one, a particular kind that amplifies, like the [triode tube discussed before](#). It's the triode's solid state equivalent: the field effect transistor or FET. The FET we'll look at goes by an intimidating name, MOSFET for Metal Oxide Semiconductor Field Effect Transistor. Whew! That's a big name but it describes what it does: a metal topped device working by a phenomenon called a field effect.

A silicon chip makes up the FET. Three separate wires are welded into different parts. These electrode wires conduct electricity. The source wire takes current in and the drain wire takes current out. A third wire is wired into the top. In our example the silicon wafer is positively charged. Further, the manufacturer makes the areas holding the source and drain negative. These two negative areas are thus surrounded by a positive.



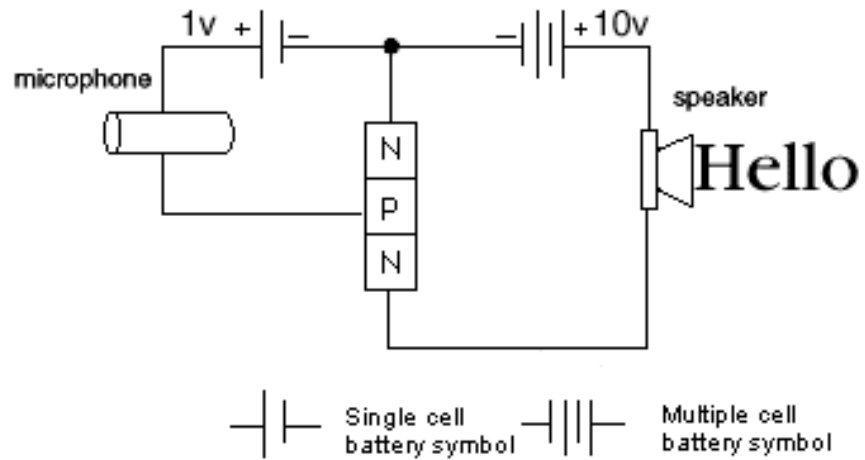
A MOSFET -- one kind of field effect transistor



The two positive charges push each other aside temporarily, letting the current flow through.

Now we introduce our weak signal current, say a telephone call that needs amplifying. The circuit is so arranged that its current is positive. It goes into the gate where it pushes against the positive charge of the silicon chip. That's like two positive magnets pushing against each other. If you've ever tried to hold two like magnets together you know it's hard to do -- there's always a space between them. Similarly, a signal voltage pushing against the chip's positive charge gives space to let the current go from the source to the drain. It picks up the signal along the way. Check out this diagram, modified only slightly from Lucent's excellent site:

<http://www.lucent.com/minds/transistor/tech.html>



As Louis Bloomfield of Virginia puts it:"The MOSFET goes from being an insulating device when there is no charge on the gate to a conductor when there is charge on the gate! This property allows MOSFETs to amplify signals and control the movements of electric charge, which is why MOSFETs are so useful in electronic devices such as stereos, televisions, and computers."

I know that this is a simple explanation to a forbiddingly difficult topic, but I think it's enough for a history article. Thanks to Australia's John Wong for help with his section. If you'd like to read further, check out Lucent's transistor page by searching their site: <http://www.lucent.com>

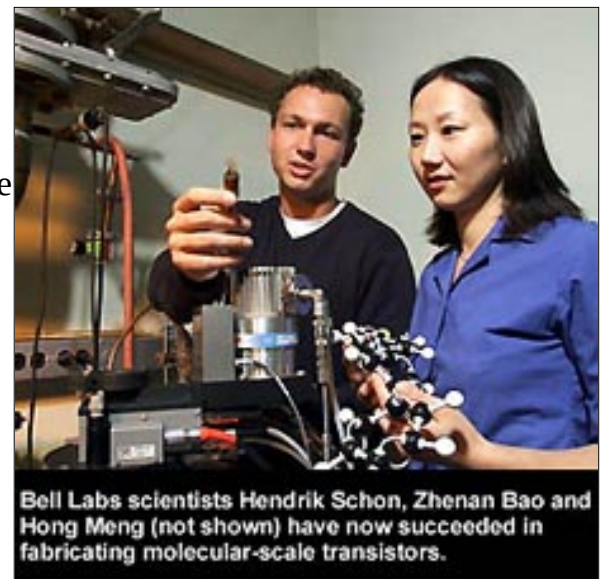
If you have a better explanation or something to add, please [e-mail me](#). And now back to the narrative.

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Special Update, Thursday October 18, 2001, Bell Labs Pioneering Continues

Organic transistors? In a remarkable development, "Bell Labs scientists Hendrik Schon, Zhenan Bao and Hong Meng have now succeeded in fabricating molecular-scale transistors that rival conventional silicon transistors in performance, using a class of organic (carbon-based) semiconductor material known as thiols. 'When we tested them, they behaved extremely well as both amplifiers and switches,' said Schon, an experimental physicist who was the lead researcher."

This technology is difficult to understand but the implications are enormous. I can't point you to an easy to understand treatise on this subject but the October, 2001 Wired magazine has a related article entitled "Ultimate Alchemy: the new science of programmable atoms." If you can understand that piece you might understand the new work Bell Labs has done. But even if we can't understand how they work, we can delight in the marvel of what these new transistors will allow. Some of Bell Labs' press release continues below:



Bell Labs scientists Hendrik Schon, Zhenan Bao and Hong Meng (not shown) have now succeeded in fabricating molecular-scale transistors.

"Using the tiny transistors, which are roughly *a million times smaller than a grain of sand* [emphasis added, ed.], the team built a voltage inverter, a standard electronic circuit module, commonly used in computer chips, that converts a "0" to a "1" or vice versa. Though just a prototype, the success of the simple circuit suggests that molecular-scale transistors could one day be used in microprocessors and memory chips, squeezing thousands of times as many transistors onto each chip than is possible today.

"The molecular-scale transistors that we have developed may very well serve as the [historical 'bookend' to the transistor legacy](#) started by Bell Labs in 1947," said Federico Capasso, physical research vice president at Bell Labs." Check out the full story here:

<http://www.bell-labs.com/news/2001/october/17/1.html> (external link)

Years ago theorists envisioned an [era of ubiquitous computing \(external link\)](#). Information processing everywhere, with a single person relying on many computers. A few years later people talked about wirelessly linking the computers for that age. While these two steps are happening now, progress has been slow and halting. Organic transistors promise a new constellation of miniaturized communications and information handling devices, using extremely low power, enabling the full deployment of ubiquitous computing.

I can imagine a Bluetooth chip made so small and inexpensive it could be placed in every book in a library, or every shirt in a clothing store. "Help, this is the title Keep the Aspidistra Flying. I've just been mis-shelved under the house plant section. Please put me back with the rest of Orwell's work." Or why not an entire computer for each book, containing study notes or a link to the internet, powered perhaps by the action of flipping pages or opening the cover?

(As an aside, I think books in hardcopy will be around forever. For the same reason that you can't do a final proofreading on a screen, you also can't understand what you read on a screen as well as you do on paper. To

comprehend something well, especially of any length, you need to print it out on paper.)

Resources

Conly, Robert L. "New Miracles of the Telephone Age." The National Geographic Magazine. July, 1954. 87 ([back to text](#))

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VIEWPOINT

BY STUART SHARROCK, EUROPE CORRESPONDENT

Gun Control Time

"Portraying WAP as providing the ability to surf the Internet from your mobile is a mistake."

Shooting yourself in the foot is not to be recommended. But it seems to happen regularly within the mobile industry. The self-inflicted injury is almost always the result of a disconnect between the capabilities of a technology and the marketing of that technology.

Sometimes the injury can be fatal. Iridium was a brilliant technological achievement, but a marketing disaster. Stubbornly sticking to a decade-old business plan and failing to acknowledge the unexpected global success of GSM technology had fundamentally changed the market was not a good move. End of Iridium.



Japan's cordless PHS technology has fared somewhat better. Focusing on the superior data rate capabilities of PHS compared with cellular created a market niche for PHS technology. But that niche is now threatened by the success of the cellular i-mode service and will undoubtedly disappear entirely once 3G cellular services are launched in Japan.

Or will it? Will 3G services really sweep away all other alternative technologies lying in their path? The ability of 3G technologies to deliver unprecedented functionality in the mobile data world is not in doubt. What is in doubt is the marketing.

The omens are not good. WAP is already being slated as a disappointment. Again

it is not really the technology that is at fault. It is the marketing. WAP in the GSM world has been launched on circuit-switched networks rather than waiting for GPRS. The resulting long call set-up times make WAP slow and clunky.

And they make it expensive.

Contrast that with the marketing of the packet-based i-mode service from NTT DoCoMo. A rich variety of content was put in place before service launch, it has affordable pricing and consistent branding. I-mode is described in the press as a "high-speed Internet access" service. A remarkable achievement for a 9.6 kilobits per second system that cannot access the full Internet.

Portraying WAP as providing the ability to surf the Internet from your mobile is a mistake. Portraying 3G in the same way is equally mistaken. But that is just what is happening. Vendors and operators alike are talking about 3G enabling the mobile Internet, or the wireless Internet for companies with a U.S. inclination.

Raising user expectations in this way could be a bad mistake. Offering the full Internet experience on a mobile terminal is not what 3G is about. Limitations on data rates and terminal displays mean the mobile environment will never compete on equal terms with broadband fixed access to the desktop. That is not the strength of 3G. The strength of 3G lies in personalized multimedia communications that can only be provided in a mobile environment.

Shooting yourself in the foot is not necessarily the end of the road. You can still hobble along on one foot with the aid of crutches. Characterizing 3G as the mobile Internet is like shooting yourself in both feet and then throwing the crutches away. The road to recovery is less certain in those circumstances.



<http://www.globalwirelessnews.com>

Editor's note: The 'I' in [I-mode](#) stands for information, not the internet. I-mode delivers information mostly from sites selected by [NTT DoCoMo](#). Some say it is more like a corporate intranet run by DoCoMo, rather than the web, although you can, in theory, connect to any web site. To work fully, a site needs to be written in a stripped down HTML code required by the I-Mode terminals. So large companies like Disney have an I-mode compatible site. I think this HTML lite approach gives it an advantage over the off beat WML or wireless markup language WAP uses. Yes, it is slow but unlike WAP, I-mode is [packet switched](#) and awaits only higher wireless data rates to deliver multi-media content.

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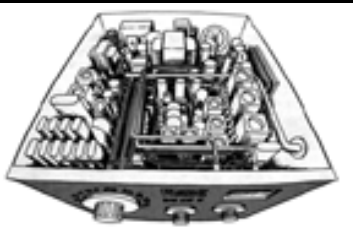
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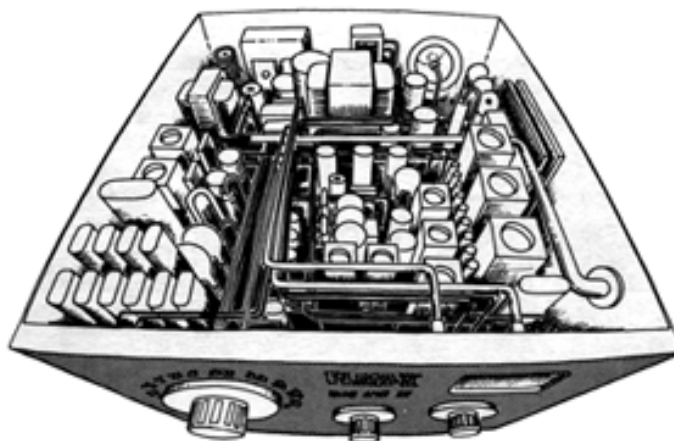
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Journey to the Bottom of Your Rig, Radio Fundamentals explored.
Original article by Houston, Long, Keating, et al, now with comments by Tom Farley

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Okay, folks, it's time for a relaxed tour of your C.B. radio. We'll take our time but we're not going to get bogged down in details. This "inside view" should give you a ballpark idea of how a radio actually works. [next page -->](#)

From *The Big Dummy's Guide to C.B. Radio*, courtesy of [The Book Publishing Company](#) P.O. Box 99, Summertown, TN 38483 (888) 260-8458, (1976). Editors: White Lightning (Albert Houston) WB4BWR, Stringbean WA4LXC (Mark Long), Minnesota

Mumbler WB4KDH (Jeffrey Keating), Ratchet Jaw K4IAP (William Hershfield), Buffalo Bill WA4KCF (William Bradley) Illustrations by Mark Schlichting and Peter Hoyt.

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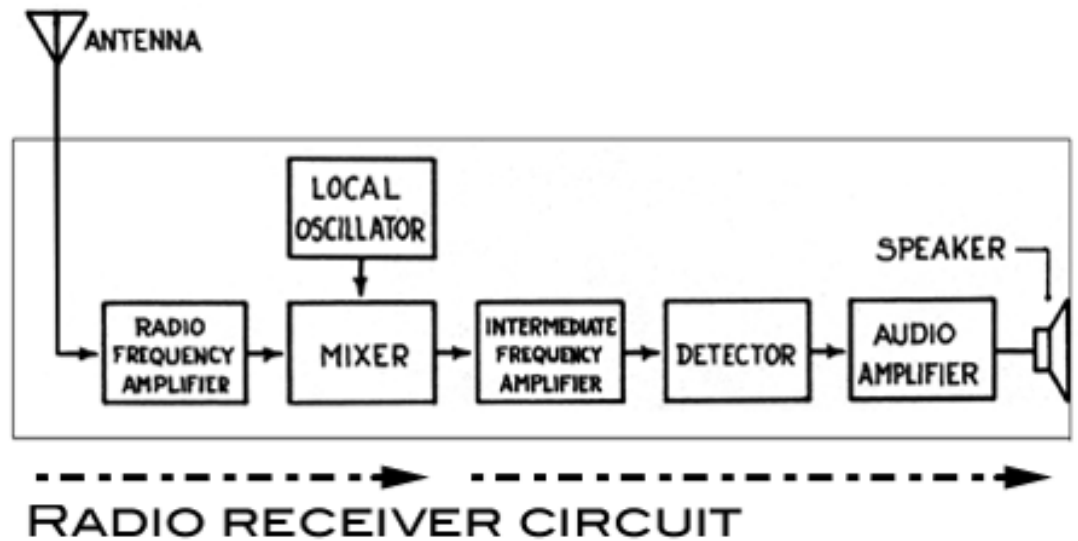
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Original article by Houston, Long, Keating, et al, now with comments by Tom Farley

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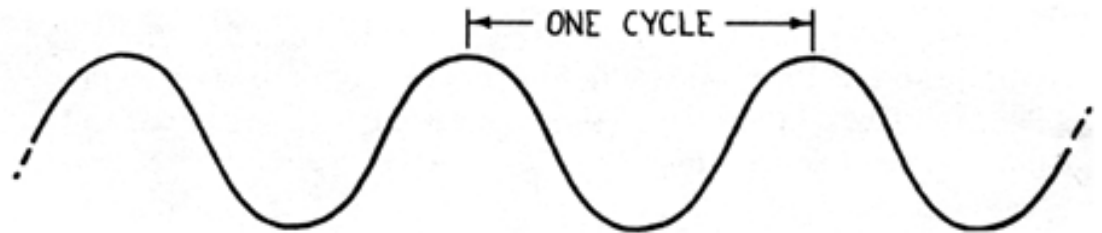
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Let's go over here to the antenna. Let's grab it by that ball at the top and slide down the antenna into the rig. This is like *Fantastic Voyage*! Oops -- watch your step [around that coil](#); it's humming with juice. Okay, now that we're all together, everyone look down at your copy of the tour map through this section of the rig called the receiver.



Our radio frequency slides down the antenna into a *Radio Frequency Amplifier*, where the signal is made a lot stronger. From maybe a few millionths of a volt, our signal jumps to a tenth of a volt or so. When I'm talking about a radio frequency in the Citizen's Band, I mean a regular wave with a frequency of a 27 million cycles per second. That means 27 million waves, 36 feet long, radiate from your antenna each second, traveling at the speed of light. This can be represented by waves like this:



[next page -->](#)



[Editor's note: the coil is that lump of metal you often see on an otherwise straight antenna. We try to approximate the antenna length with the length of the wave that the radio transmits or receives on. In the case of Citizen's Band radio frequencies, 29 Mhz, that's about 36 feet, far too tall for mobile work. So we make a shorter antenna, say four feet in length, and wrap the remaining 32 feet of wire into a coil. While not as efficient as a regular antenna, a loading coil does maintain the correct electrical length and is better in getting out your signal than an unloaded antenna. For more good info on antennas, click on the link below.]

http://members.tripod.com/~cb_antennas/antenna_basics.html

[next page -->](#)

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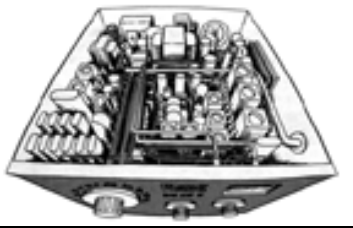
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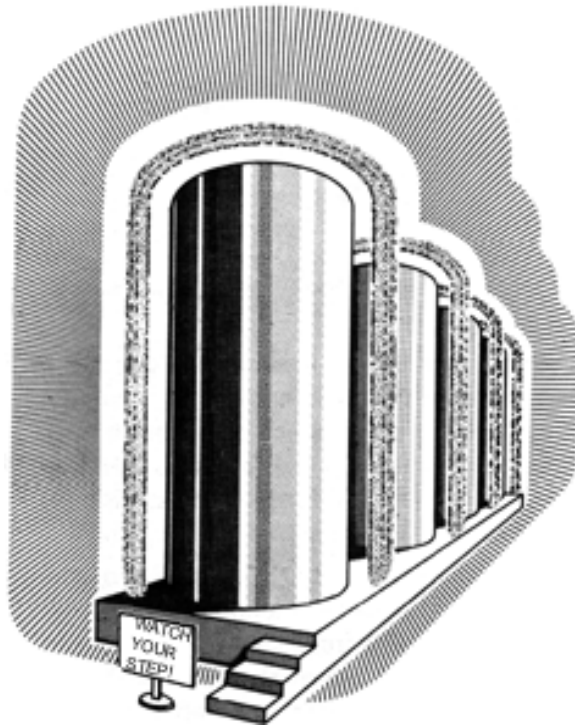
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Original article by Houston, Long, Keating, et al, now with comments by Tom Farley

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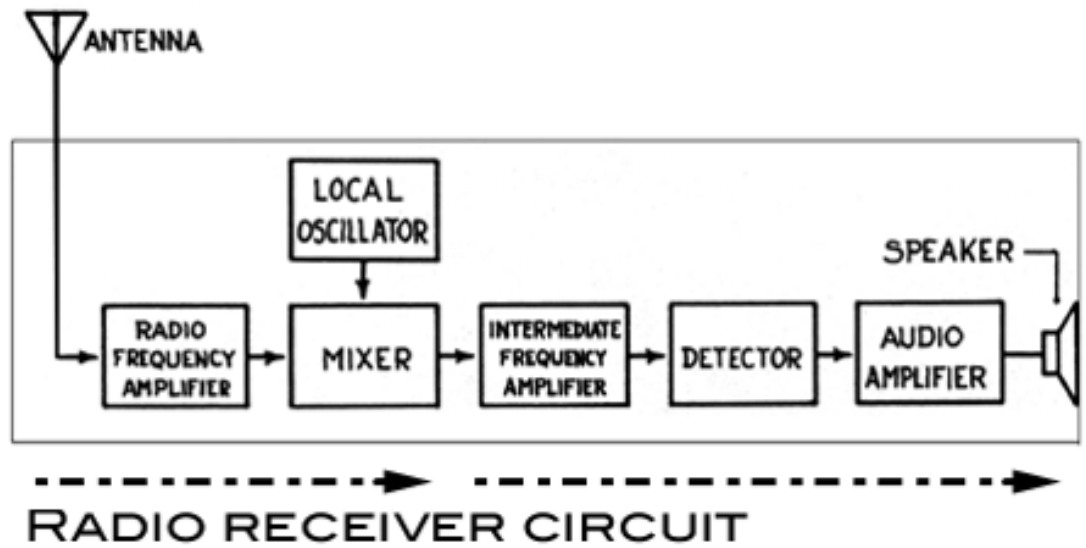


Let's continue to follow the energy though the rig. Stay here with me; you folks are walking toward the power supply and there's some capacitors over there that are charged up to 500 volts, so be careful not to touch them! They'll knock your socks off!

Old-fashioned radios used to take the amplified high frequency signal we've got now and ["peel" the voice frequencies right off it.](#) [\[explanation here\]](#) But newer radios first reduce the incoming frequency to an *intermediate frequency*. This frequency is 455 thousand cycles per second. That's quite a step down from 27 million! The reason for an intermediate frequency is that it helps your receiver give clearer

reception.

That's the "why" of intermediate frequency. The "how" is that we run the signal through a *mixer circuit*, where we also shoot in another high frequency signal. These two signals mix together and produce a third signal, just like mixing red and blue painting will give you purple. This third frequency is the intermediate frequency. Mixing two signals like that is called *heterodyning*. [next page -->](#)



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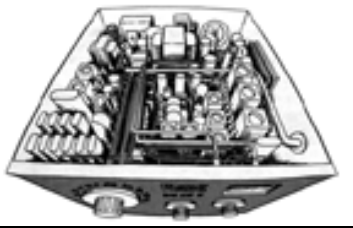
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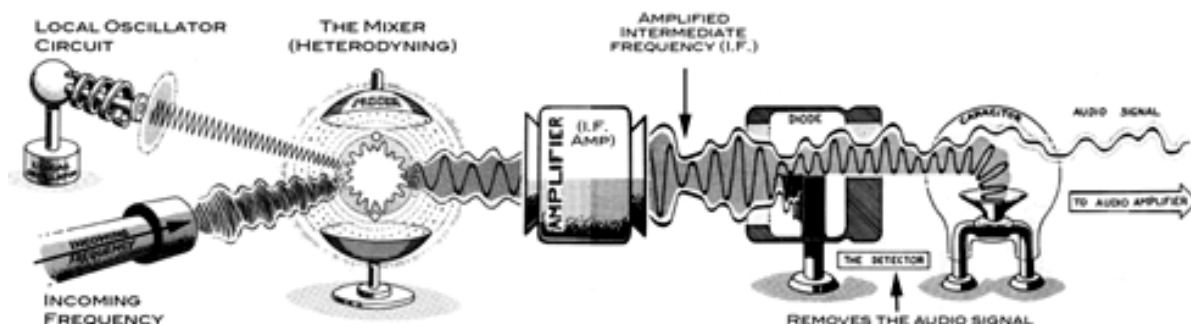
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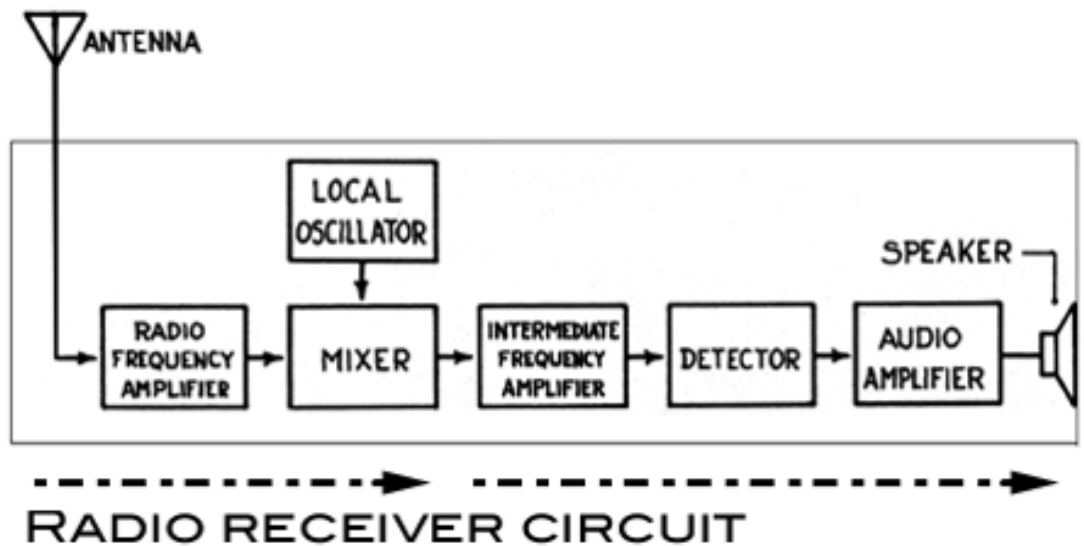
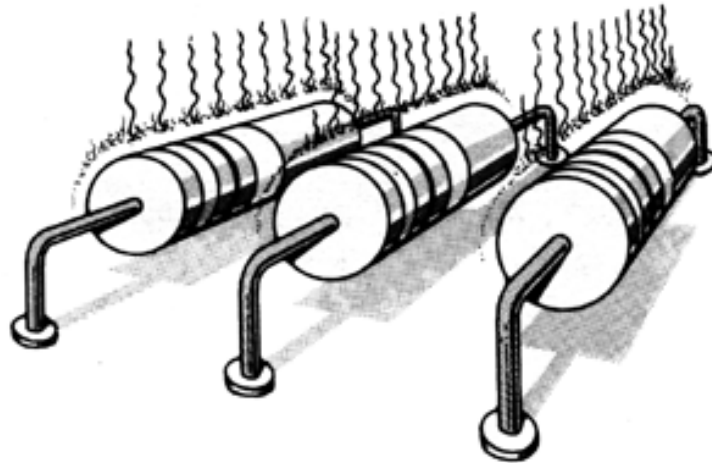
By the way, that second frequency is made by a circuit called a [local oscillator](#); local because the signal is made right in your rig as opposed to the incoming signal which comes from tens, hundreds, or even thousands of miles away. It's also an oscillator because electricity oscillates back and forth in this circuit. It goes back and forth so fast that it becomes a radio frequency.

So, now we have a much slower signal coming out of the mixer, at usually 455 thousand cycles a second. Once again we kick up the voltage by running this frequency through an I.F. (intermediate frequency) amplifier, which also purifies the signal and selects just the frequency we want. It surely is easier to amplify a signal at 455 thousand cycles a second than 27 million, for sure!



We're most all the way through our receiver now. If y'all want to rest, you can sit down on those resistors below. Warm, ain't they? That's because some juice goes through them and resistors just use juice up as heat. So, get comfortable while I tell ya about the next mind-boggling circuit!

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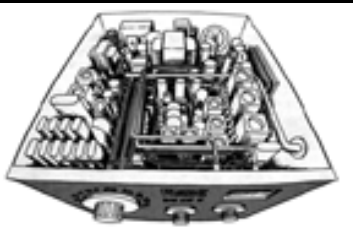
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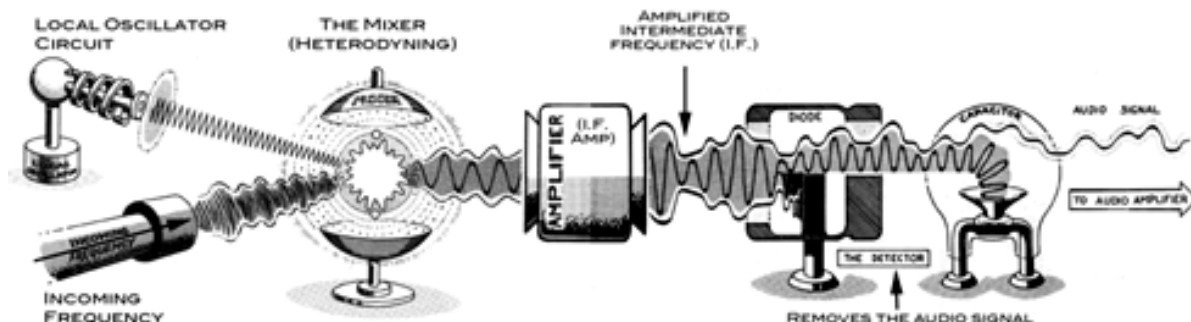
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If you can, please go to the [wide screen edition of this page](#) for a much clearer, bigger diagram. That page has the same text as this one and you can continue this discussion from there.

This little beauty [of a circuit] is called a *detector* and it's job is to take the audio signal off of that intermediate frequency that we just saw amplified. The audio is contained in the I.F. frequency just like it was in the original radio signal that came in the antenna behind us. We reduced the incoming signal to an intermediate frequency, but that didn't affect the voice frequencies at all. This detector has the ability to pass all the voice energy on and discard the radio frequency energy. The radio signal brought the voice through the ozone but now that we got it, we have no further use for it.

[Editor's note: the detector is badly named and its role explained somewhat poorly. Think *demodulator* and not detector. Click here for my [explanation of the detector](#) and what it does.]



That's why the radio frequency energy is called a carrier, because the voice is the information, and once it is delivered, the carrier has served its purpose. It's like when you bring home a pizza from the take-out place; it's the goodies that you're interested in, not the container.

Coming out at the far side of the detector is a voice signal, just like when it left the mouth of the person transmitting it to you. We then run this audio signal through an audio amplifier or two so it's comfortably loud, and then it goes right into a speaker where the signal is turned from electrical waves back into sound waves that we can hear. Now before any of you go slipping out the speaker and onto the floor, let's turn and go back into the radio, and find out how this contraption *transmits*.

[Editor's note: Can you follow our progress? We've gone through the receiver part of the radio and now we're going to look at what the transmitting portion does. So, we'll be looking at another block diagram soon, this time for the transmitter and *not* the receiver, as pictured on this and previous pages.]

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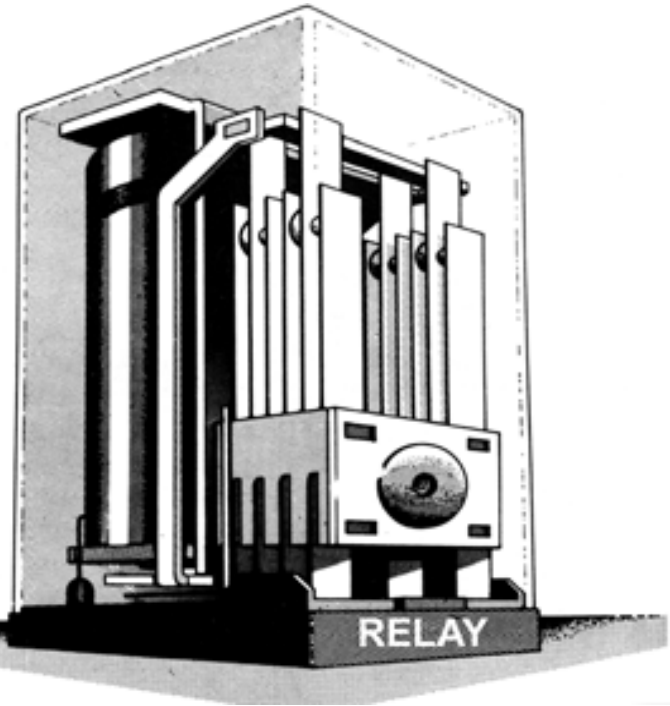
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Everybody rested up from going through the receiver? We're actually over halfway done, because a lot of the circuits we've walked through do double duty in both the transmit and receive parts of the trip.

We're sitting in the right place to start, since this time we'll follow the juice back from the microphone that's connected to that black cord we see running over the circuit board. See that big plastic container

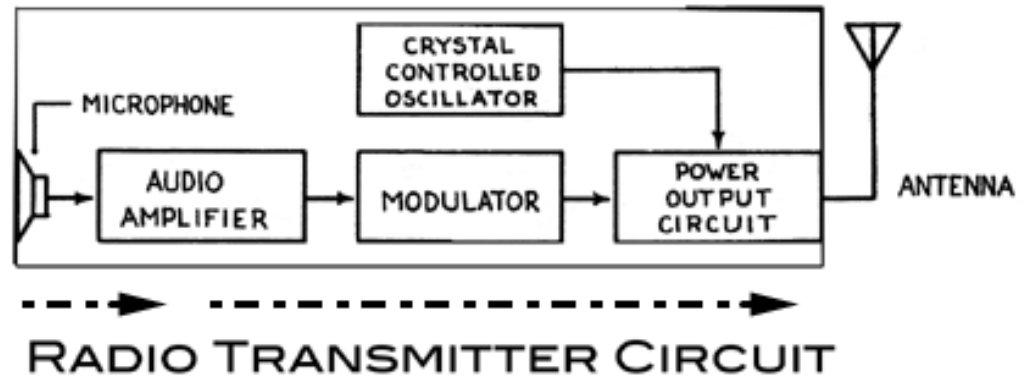
over there? That's the *relay*. The relay is a kind of switch which connects either the transmit or the receive circuits together. It's controlled by the push button on the microphone. That's how the parts common to both transmit and receive are switched back and forth from one to the other.

[Editor's note: Citizen's Band radios and many walkie talkies use a "push to talk" microphone which manually trips the relay. Cellular telephones use a voice activated transmitter which automatically trips the relay. Why the difference between the two? A cellular phone uses one frequency to transmit on and another one to receive on. This lets both callers talk in a normal, back and forth fashion,



just like a regular land line telephone. The term is "full duplex communications." Since walkie talkies use a single frequency to both talk on and listen, each party must wait their turn to transmit. A voice activated microphone would not work well since you might start transmitting when the other party is speaking, consequently, you would not be heard. A push to talk button reminds each person that only one caller can talk at a time.]

Okay, everybody. Let's take a gander at our tour map so we all know where we're going. Let's stay together and not get lost through all these twists and turns. ([Next page -->](#))



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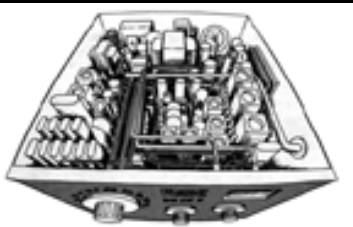
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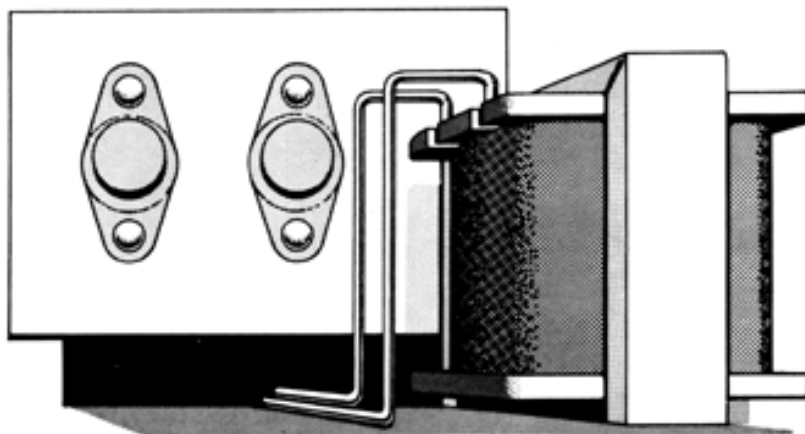
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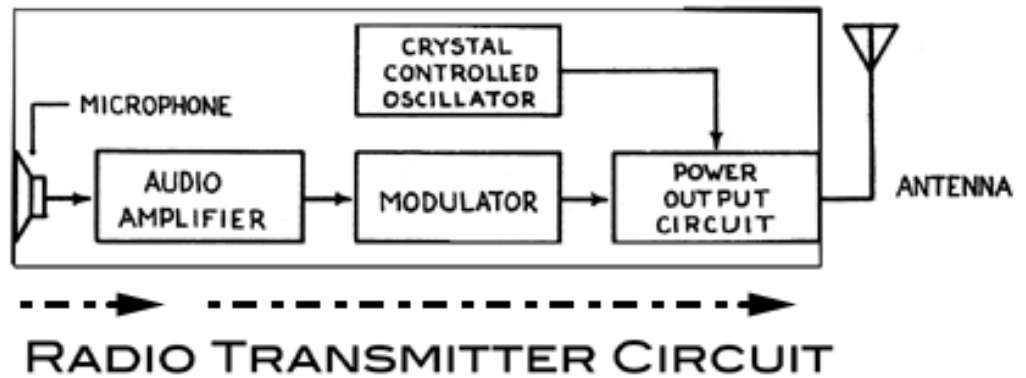
The amplifier that the microphone talks into is probably the same audio amplifier you use in your receiver. I'll bet that if you've got a transceiver, which is a transmitter and a receiver in one handy squawk box, that it uses a lot of circuits for both sections. After all, transmitting is just receiving in reverse. Walk over here with me to this bunch of glowing electrical machinery.

This here is the modulator, and it's another audio amplifier. "[Modulation](#)" is detection in reverse: we mix our voice signal with the radio frequency signal which will carry it out into the air. It doesn't matter how much we amplify an audio signal, it just won't radiate off your antenna, it's too low a frequency. That's why we need a carrier, and we'll see how it is produced in a minute.



Modulator and amplifier

I'll have to ask you kids over there not to spill your soft drinks on the circuit board -- you'll make everything sticky and the guy who owns this rig we're talking through won't know what's happening next time he opens it up! ([Next page -->](#))



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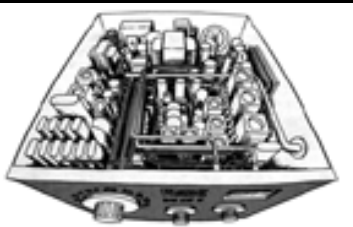
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If you'll look where I'm pointing, that's where the radio frequency is produced. That circuit is called the crystal controlled oscillator. That square tin can over there contains a sliver of quartz crystal which puts out only one frequency, determined by the thickness of the crystal.

A crystal is just what it says. It is a piece of quartz crystal (a "rock" in a can) It operates on the same principle as a tuning fork. When you hit a tuning fork, it will vibrate at a particular frequency. The tone or frequency depends on how the tuning fork is constructed. A crystal operates in a similar way. When hit with the application of electricity, the crystal will vibrate at a frequency. Depending on how the crystal is cut, the frequency will vary.



Some rigs have up to 23 crystals or more to transmit on every CB channel. Other rigs save a lot of space (and money) by using only a few crystals and running the

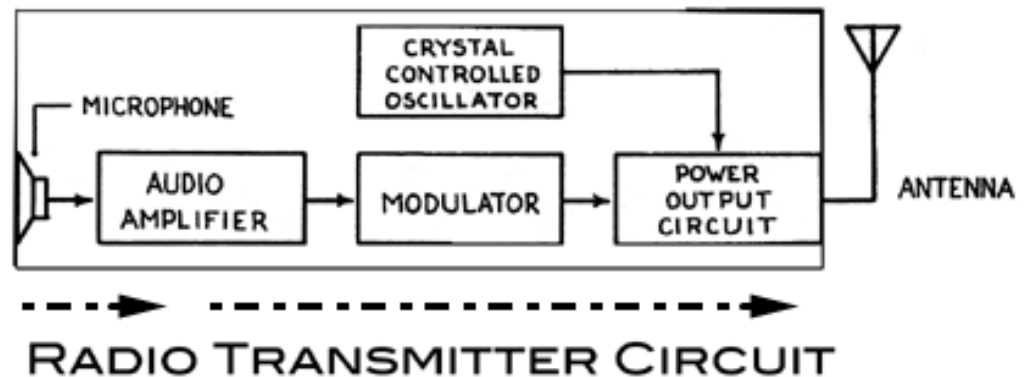
frequencies they produce through some mixing circuits so as to get all 40 channels. Pretty fancy, huh? This circuit is called a synthesizer.

The voltage put out by a crystal vibrating is very small, a few millionths of a volt. The signal generated by the crystal gets boosted by another part of the oscillator so that it has enough voltage to drive the power amplifier. The modulator over there makes the juice in the power amplifier change with your voice. The power amplifier is where your carrier gets kicked up to that 5 watts to go out the antenna plug.

Well, here we are again at the antenna. We've kind gone all the way through this maze and come back round to the beginning. That power amplifier was the last circuit.

[Editor's note: please send comments: tom@privateline.com --- I will be adding more soon.

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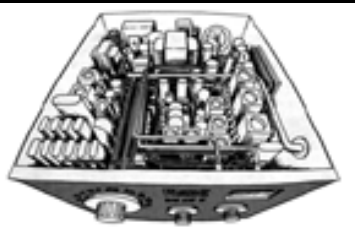
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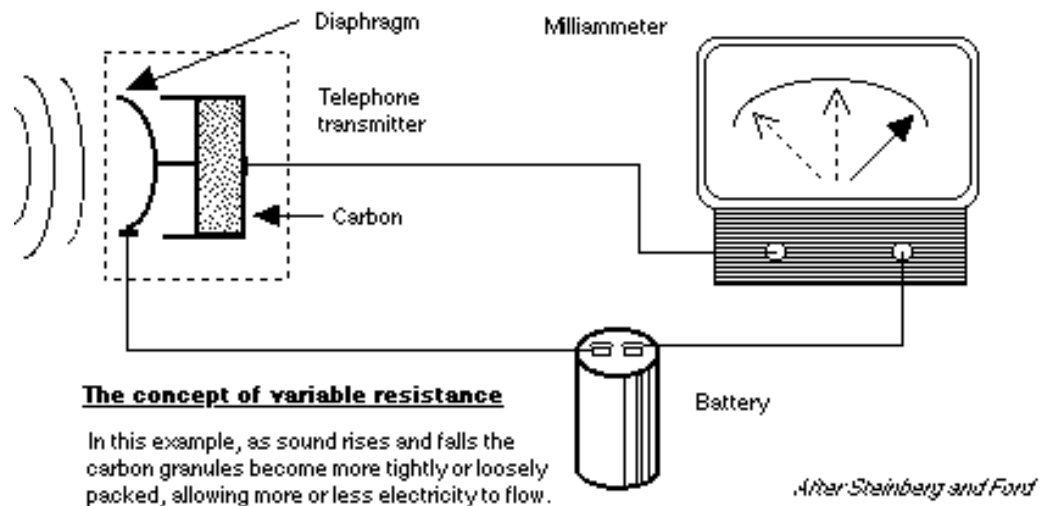
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Peeling off, Detecting, or Modulation

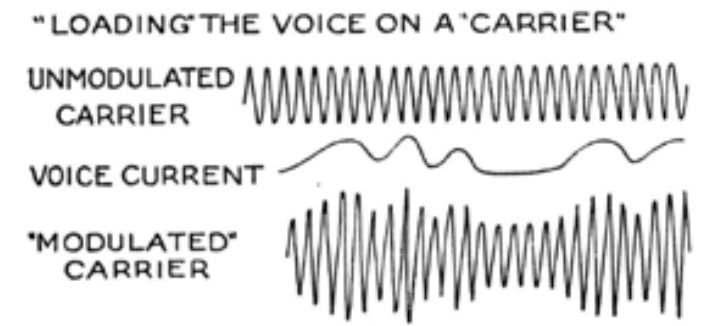
The authors mentioned how older radio receivers "peeled" the incoming, low frequency audio signals right off the much higher radio frequencies. Let's start at the beginning.

We can't hear radio signals without help. Radio frequency signals are way beyond our range of hearing. We can hear voice or audio signals up to about 15,000 to perhaps 20,000 cycles per second. Think of a tuning fork or a piece of fine crystal. Strike either and hear them resonate, vibrating at thousands of cycles. A radio frequency, though, can oscillate at millions of times a second! So, we need to process a radio signal before we can hear what the radio wave carries. One part in processing is called *detection* or *demodulating* the carrier. But before we understand demodulating, we need to know what modulating is, how voice signals get turned into electricity. Hang in there, it is simpler than it sounds.

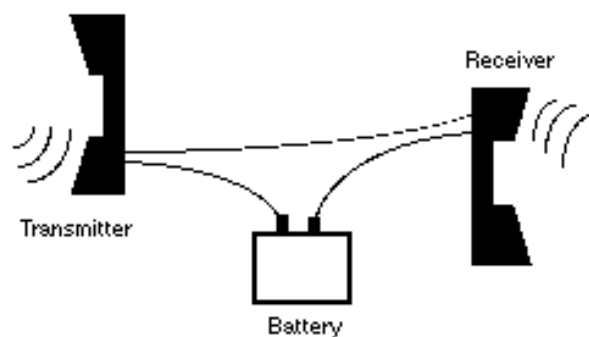


The most important principle in radio and telephony is the concept of variable

resistance, pictured above; it is how everything gets started. Your voice is sound in motion. Speaking causes sound waves. Hold a piece of binder paper by its corners close to your mouth. Loudly and firmly say "I don't understand any of this!" Feel that paper vibrate? That's sound in motion. Telephone and radio transmitters convert that acoustic pressure into electrical pressure. That's why the electrical tester above shows a rise and fall as sound waves rise and fall. A radio or telephone receiver at the other end of our call then takes the electrical reading or signal it gets and throws the process into reverse. It works a speaker by the changes in the electrical signal, that is, a speaker now vibrates in sympathy with the oscillations it receives. Now let's add some terms to what we've already learned.



An unmodulated carrier in telephony is simply the electricity your phone operates on, the steady and continuous current the telephone company provides. It carries the conversation. Remember, the telephone is an electrical instrument; electricity works the phone *and* it carries your voice. Speaking into the telephone's transmitter varies or modulates the electricity supplied. Similarly, with radio, we produce a radio carrier for our call to travel on. This invisible electrical path is a very high radio frequency. Speaking into the radio's transmitter varies or modulates the carrier wave. Get it? Isn't radio pHun? Now that we know about modulating, we can get back to learning about detecting or demodulating. But first, one last comment.

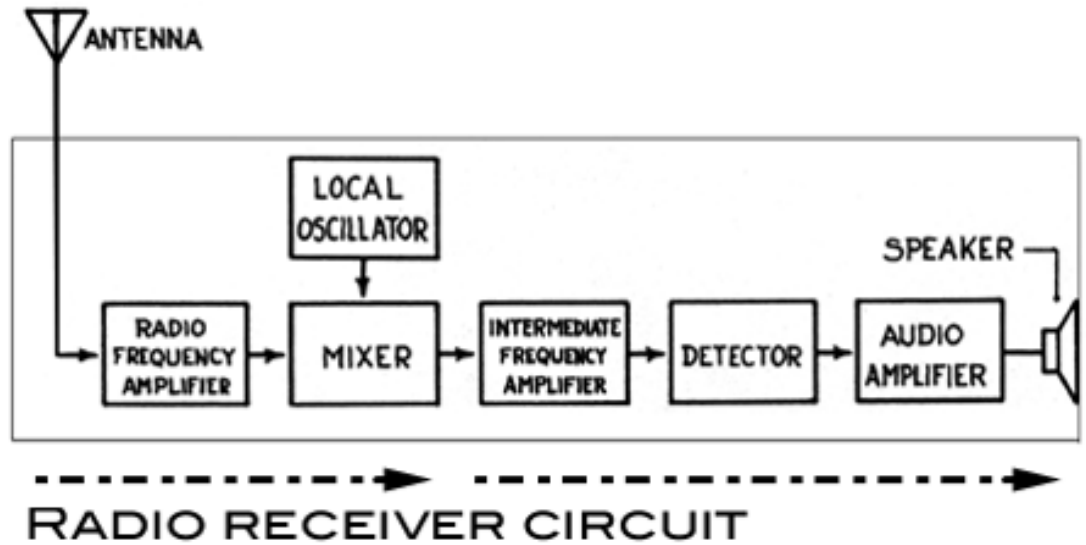


The telephone is an electrical instrument

Speaking into the transmitter makes its diaphragm vibrate. This varies the electric current, causing the receiver's diaphragm to vibrate. This duplicates the original sound.

The radio technique I just described is called A.M. or amplitude modulation. I didn't want to scare anyone by calling it by its real name. A.M. simply means that a carrier wave is modulated in proportion to the strength of a signal. The carrier rises and falls instantaneously with each high and low of the conversation. Just

like we've seen, the voice signal produces an immediate and equivalent change in the carrier. [Okay, back to the article](#) and remember, when you see a reference to a detector, think demodulator!



From *The Big Dummy's Guide to C.B. Radio*, courtesy of [The Book Publishing Company](#) P.O. Box 99,Summertown, TN 38483 (888) 260-8458, (1976). Editors: White Lightning (Albert Houston) WB4BWR, Stringbean WA4LXC (Mark Long), Minnesota Mumbler WB4KDH (Jeffrey Keating), Ratchet Jaw K4IAP (William Hershfield), Buffalo Bill WA4KCF (William Bradley) Illustrations by Mark Schlichting and Peter Hoyt.

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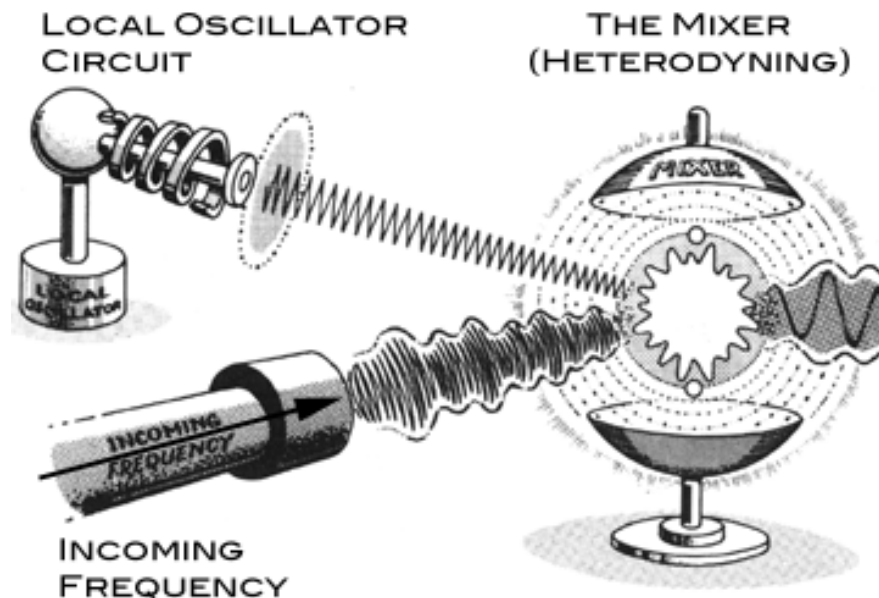
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Journey to the Bottom of Your Rig, Radio Fundamentals explored.
Original article by Houston, Long, Keating, et al, now with comments by Tom Farley

Pages: [\(1\)](#) [\(2\)](#) [\(3\)](#) [\(4\)](#) [\(5\)](#) [\(6\)](#) [\(7\)](#) [\(8\)](#) [Modulation page](#) // [Oscillator Page](#)

The Oscillator and Beat frequency



Oscillator is Australian for "I'll see you later." :-) Actually, an oscillator or does what its name implies, it sets up an electrical current that races back and forth, oscillating, until it produces a radio frequency within the radio. The mixer then combines the two radio signals, the incoming frequency, and the one produced by the local oscillator, into a single, intermediate frequency. In many radios that frequency is 455,000 cycles per second. The radio then processes that so called IF

frequency with steps we will see later. But back to the oscillator.

We saw on the [modulation page](#) that old radios used direct conversion, whereby anything sent from the antenna got passed on to the amplifier. No finishing or real control like in the superheterodyne circuit we've been discussing. Direct conversion isn't too efficient because it deals with a huge range of frequencies. Whatever the radio is tuned to, up or down in the radio band, the radio must accommodate. This makes it tough for a radio engineer to design a circuit for the best sound quality and reception. In a superhet circuit the radio receiver deals with just this one frequency, purposely made with the help of the oscillator. It's like the difference between driving a car with a manual transmission instead of an automatic. The automatic deals with the changing road conditions, gearing the car appropriately for the conditions. An oscillator likewise helps gear down and smooth out the raw signal coming from the antenna. Let me try one more overly simple explanation.

Remember what I said about the [loading coil on an antenna](#) and how it was a compromise?, that ideally we would like the antenna length to match the length of the radio wave it is supposed to pick up or transmit on? Well, the superheterodyne receiver we're discussing is also a compromise. Ideally we would like a receiver tuned for each frequency it is supposed to pick up. That isn't practical, with most radios needing dozens, and in the case of cellular radio, hundreds of frequencies, to receive on. So we design a circuit like this where we change the frequency of the the current flowing through our receiver to a common, pre-determined frequency for our radio to amplify.

Although beyond this discussion, a beat frequency oscillator is a sort of super oscillator, a variable type you can control. It's in addition to the normal oscillator that is always present in modern radio. A BFO circuit allows really fine tuning of a signal, so much that you can listen to what's called single side band transmission or SSB. It's the most efficient way [to transmit A.M. signals](#) but you need a special receiver to make the signal intelligible.

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1

Basic Concepts

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This chapter defines basic telecommunications terms. Terms such as analog, digital and bandwidth are used in the context of services that touch the everyday work experiences of professionals. Understanding fundamental terminology creates a basis for learning about advanced telecommunications services. A grasp of such fundamental concepts as digital, analog, bandwidth, compression, protocols, codes and bits, provides a basis for comprehending technologies such as high speed digital services, convergence and wireless networks. These technologies, in addition to the Internet, are changing the way Americans do business, spawning new telecommunications services and creating a smaller, linked, worldwide community.

Protocols are an important ingredient in enabling computers to communicate with each other. Protocols may be likened to etiquette between computers. Just as etiquette spells out who shakes hands first, how people greet each other and rules for how guests should leave parties, protocols spell out the order in which computers take turns transmitting and how long computers should wait before they terminate a transmission. Protocols handle functions such as error correction, error detection and file transmissions in a common manner so that computers can “talk” to each other. A computer sends data to another computer using a protocol such as IPX, Novell NetWare’s protocol designed for communications between local area networks (LANs).

Computers, printers and devices from different vendors also need to be able to send information such as electronic mail and attachments across networks. This is the role of architectures and protocol suites. Architectures tie computers and peripherals together into a coherent whole. Layers within architectures have protocols that define functions such as routing, error checking and addressing. The architecture or protocol suite is the umbrella under which the protocols and devices communicate with each other.

Computers located in firms' offices are physically connected together by local area networks (LANs), which are located within a building or in a campus environment. LANs connect computers, printers, scanners and shared devices such as modems, video conferencing units and facsimile units. LANs are connected to other LANs over metropolitan area networks (MANs), and wide area networks (WANs). The growing number of devices and peripherals on LANs is adding congestion to data networks. Workers encounter network congestion when there are delays in transmission and receipt of, for example, e-mail and database look-ups. This chapter reviews why there is congestion on local area networks and ways companies can eliminate this congestion.

One solution to traffic jams on wide area networks is the use of multiplexing. Multiplexing enables multiple devices to share one telephone line. For example, T-1 provides 24 communications paths on one high-speed link. Newer multiplexing schemes add even more capacity. T-3 provides 672 communications paths on one telecommunications link. These multiplexing schemes provide private and non-profit organizations with ways to carry increasing amounts of data, video and imaging traffic between sites. T-3 is an important way for large call centers, such as airlines, to handle large volumes of incoming calls.

Another way to add capacity for applications such as graphics, x-ray images and Internet-based video is the use of compression. Compression squeezes large amounts of data into smaller sizes, something like putting data into a corset. As a matter of fact, the availability of affordable video conferencing systems is made possible by advances in compression. Compression makes the video images "fit" onto slower speed telephone lines than those required without compression. Before advances in compression were developed, the high-speed telecommunications lines needed for video conferencing were prohibitively expensive.

Compression has made a major impact on the nature of the Internet, particularly its use in streaming media. The Internet is no longer a place for only text and graphics. Compression in combination with more powerful computers and faster modems is making it possible to hear reasonable quality audio over the Internet. The quality of video over the Internet will continue to improve as higher speed digital telephone lines become more prevalent.

ANALOG AND DIGITAL

The public telephone network was originally designed for voice telephone calls. The telegraph, invented in 1840, was used for short text messages. When the telephone was invented in 1876, it was used to transmit speech. Spoken words are transmitted as analog sound waves. People speak in an analog format, waves. Telephone calls were transmitted in an analog form until the late 1960s. While much of the public telephone network is now digital, there are still many analog services in use, and portions of the

telephone network are analog. The majority of telephones that plug into home telephone jacks are analog instruments. Most TV signals and telephone lines from homes to the nearest telephone company equipment are analog, as are cable TV drops, the cabling portions from subscribers to their nearest telephone pole.

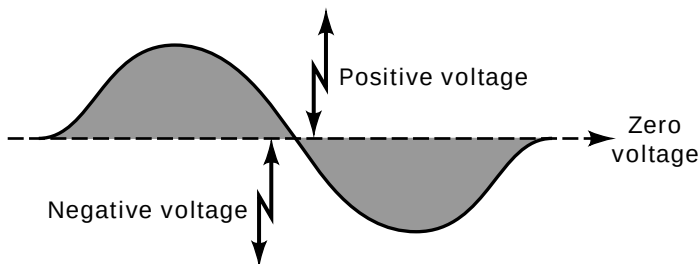
As more people use their computers to communicate, and as calling volume increases, the analog format, designed for lower volumes of voice traffic, is proving inefficient. Digital signals are faster, have more capacity and contain fewer errors than analog waves.

High-speed telecommunications signals sent on ISDN service, within computers, via fiber optic lines and between most telephone company offices, are digital. With the exception of most current TV and portions of cable TV wiring, analog services are used for slow-speed transmissions. Analog services are mainly plain old telephone service (POTS) lines used by residential and small business customers.

Analog Signals

Frequency on Analog Services

Analog signals move down telephone lines as electromagnetic waves. The way analog signals travel is expressed in frequency. Frequency refers to the number of times per second that a wave oscillates or swings back and forth in a complete cycle from its starting point to its end point. A complete cycle, as illustrated in Figure 1.1, occurs when a wave starts at a zero point of voltage, goes to the highest positive part of the wave, down to the negative voltage portion and then back to zero. The higher the speed or frequency, the more complete cycles of a wave are completed in a period of time. This speed or frequency is stated in hertz (Hz). For example, a wave that oscillates or swings back and forth ten times per second has a speed of ten hertz or cycles per second.



One cycle looks like a “resting” letter S

Figure 1.1

One cycle of an analog wave, one hertz.

Analog services, such as voice, radio and TV signals, oscillate within a specified range of frequencies. For example, voice is carried in the 300 to 3300 Hz range. The bandwidth, or range of frequencies that a service occupies, is determined by subtracting the lower range from the higher range. Thus, the range that voice travels at within the public network is 3000 hertz (3300 minus 300), also expressed as Hz or cycles per second.

The frequencies that analog services use are expressed in abbreviated forms. For example, thousands of cycles per second are expressed as kilohertz (KHz), and millions of cycles per second are expressed as megahertz (MHz). Analog transmissions take place in enclosed media such as coaxial cable, cable TV and on copper wires used for home telephone services. They are also transmitted via “open” media such as microwave, home wireless telephones and cellular phones. Particular services are carried at predefined frequencies. Examples of analog frequencies are:

- kilohertz or kHz = thousands of cycles per second
Voice is carried in the frequency range of .3 kHz to 3.3 kHz, or 3000 Hz.
- megahertz or MHz = millions of cycles per second
Analog cable TV signals are carried in the frequency range of 54 MHz to 750 MHz.
- gigahertz or GHz = billions of cycles per second
Most analog microwave towers operate at between 2 and 12 GHz.

The 3000-cycle bandwidth allocated to each conversation in the public network is slow for digital computers when they communicate on analog lines via modems. Modems, which enable digital computers and facsimile machines to communicate over analog telephone lines, have methods of overcoming some of the speed limitations in the public, analog portion of the network. (See Chapter 7 for information about modems.)

Impairments on Analog Services

Sending an analog telephone signal is analogous to sending water through a pipe. Rushing water loses force as it travels through a pipe. The further it travels in the pipe, the more force it loses and the weaker it becomes. Similarly, an analog signal weakens as it travels over distances whether it is sent over copper, coaxial cable or through the air as a radio or microwave signal. The signal meets resistance in the media (copper, coaxial cable, air) over which it is sent, which causes the signal to fade or weaken. In voice conversation, the voice may sound softer. In addition to becoming weaker, the analog signal picks up electrical interference, or “noise” on the line. Power lines, lights and electric machinery all inject noise in the form of electrical energy into the analog signal. In voice conversations, noise on analog lines is heard as static.

To overcome resistance and boost the signal, an analog wave is periodically strengthened with a device called an amplifier. Amplifying a weakened analog signal is not without problems. In analog services, the amplifier that strengthens the signal cannot tell the difference between the electrical energy present in the form of noise and the actual transmitted voice or data. Thus, the noise as well as the signal is amplified. In a voice telephone call, people hear static in the background when this happens. However, they can generally still understand what is being said. When noise on data transmissions is amplified, the noise may cause errors in the transmission. For example, on transmitted financial data, the received sales figures might be \$300,000 whereas the sent information was \$3 million.

Digital Signals

Digital signals have the following advantages over analog:

- higher speeds
- clearer voice quality
- fewer errors
- less complex peripheral equipment required.

Clearer Voice, Fewer Errors

Instead of waves, digital signals are transmitted in the form of binary bits. The word binary simply means being composed of two parts. In telecommunications, the term binary refers to the fact that there are only two values for transmitted voice and data bits, on and off. On bits are depicted as ones, the presence of voltage, and off bits are depicted as zeroes, no voltage. The fact that digital transmissions are only on or off is one reason why digital services are more accurate and clearer for voice. Digital signals can be recreated more reliably. It is more complex to recreate a wave that can have multiple forms than a bit that is either on or off.

Both analog and digital signals are subject to impairments. They both decrease in volume over distance, fade and are susceptible to interference, such as static. However, digital signals can be “repaired” better than analog signals. Figure 1.2 illustrates that when a digital signal loses strength and fades over distance, equipment on the line to regenerate the signal knows that each bit is either a one or zero and recreates it. Noise, or static, is discarded. The noise is not, as in an analog signal in Figure 1.2, regenerated. People who first used digital wireless telephones rather than analog cellular service commented on the improvement in voice clarity over analog cellular service.

In addition to clarity, digital signals have fewer errors. In analog transmission, where noise is amplified, receiving equipment may interpret the amplified signal as an

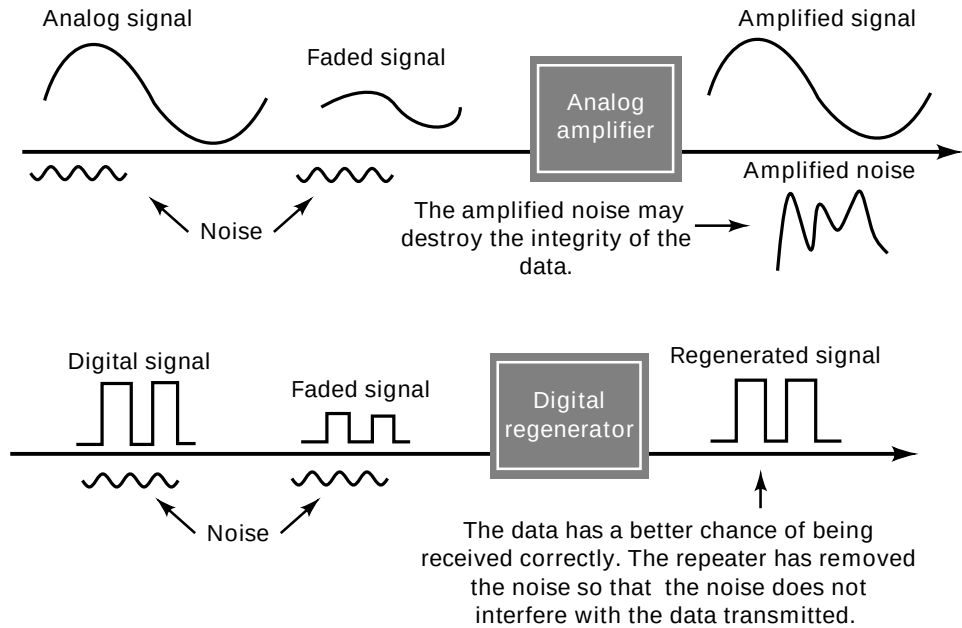


Figure 1.2

Noise amplified on analog lines; eliminated on digital service.

information bit. People using modems to transmit data often receive garbled data. In digital transmissions, where noise is discarded, garbling occurs less frequently; thus there are fewer errors in the transmission.

Digital Television—An Example of Digital Transmission to Enhance Clarity

The FCC approved analog television standards in 1941 for black-and-white television. (Widespread television introduction was delayed by World War II.) Color TV standards set by the National Television Standards Committee (NTSC) were approved in 1954. As people with analog broadcast television know, “snow” and “ghosts” are frequently present along with the television images. TVs located far from broadcast antennas have the most problems with clarity. This is a function of analog signals fading or weakening. “Snow” seen on TV screens is interference on the television channel when the noise or interference becomes stronger than the signal. The further from the broadcast antenna, the greater the amount of noise relative to the picture being transmitted.

A factor in improved picture quality with digital television is the elimination of noise. With digital television, error correction code is sent along with the TV signal.

This additional 10% of error correction code provides digital TV with the same clarity 50 miles from an antenna as 5 miles from an antenna. The error correction code checks the signal and eliminates errors. The error correction code “corrects” the signal from within the TV receiver. Thus, the clarity of the digital signal is uniform throughout the range of the antenna.

Moreover, digital signals degrade or weaken less over distance than analog signals. A digital signal must travel further before it starts to weaken or fade. However, once a TV is out of range of a digital tower, the signal is lost altogether. The transition in terms of quality from analog to digital television is analogous to the change in quality from analog audiotapes to digital compact discs (CDs). Digital TV provides studio-quality audio and image on home screens.

Broadcasters in the top ten markets in the United States began airing high definition television (HDTV) signals in November of 1998. Top 30 areas have until November of 1999 to air digital broadcasts. (According to CableLabs®, the research and development consortium of the Cable TV industry of North and South America, digital cable television signals will be compatible with HDTV by the start of the year 2000.) The deadline for all broadcasters is May 2003. Networks are required to broadcast analog as well as digital transmissions. By 2006, networks must return analog spectrum to the federal government if 85% of the consumers in each broadcasting area have access to digital broadcasting. At the end of this simulcasting term, analog frequency channels will be sold by the FCC at public auctions.

DIGITAL TELEVISION—TVS ACT LIKE PCs

High-definition digital television allows broadcasters to transmit secondary, non-programming information, as well as television signals. A 20 megabit per second data channel has been set aside to bring information services such as weather forecasts, home automation, audio for audio's sake and stock quotes into homes. This ancillary channel can be used in conjunction with interactive, remote control devices. For instance, a user can be given the choice of downloading technical specifications, pricing and warranty notices in conjunction with a car commercial.

Just as personal computers manipulate bits in the form of word processing, spreadsheet and financial programs, digital televisions receive and manipulate a stream of bits. In essence, whether used by cable television or commercial broadcast television, digital television sends digital bits into peoples' homes. The bits will be audio, video or text images. The TV receiver, or in the case of cable TV, a set top device, acts as a computer and manipulates the signals to be viewed on the home screen. In telecommunications, a bit is a bit whether the source is the Internet, corporations or entertainment services.

Higher Speeds and Reliability

In addition to improved clarity, digital transmissions are faster than analog transmissions. This is because digital signals are less complex to transmit. They are either on or off bits, whereas analog signals take the form of complex waves. Whereas the highest speed projected for analog modems is 56,000 bits per second when receiving data and 33,600 bits when sending data, new routers, which are digital, now run at terabit-per-second speeds. A terabit is equal to a thousand gigabits.

Finally, digital service is more reliable than analog. Less equipment is required to boost the signal. Analog signals weaken and fade at shorter distances than digital signals. At every point that a signal fades, amplifiers or regenerators are required. Each amplifier is a place for a possible failure. For example, water can leak into a telephone company's manhole or the amplifier itself might fail. Organizations that use digital lines such as T-1 often experience only one or two brief failures in an entire year. High reliability results in lower maintenance costs for the telephone companies that support digital circuits.

DIGITAL SERVICES IN THE BELL SYSTEM

Digital technology was first implemented in the public network in 1962. It was implemented, not in routing calls (central office switches), but rather in the transmission of calls within the long distance portion of the AT&T network. Coaxial cable between the central offices first carried digital calls. Because the digital technology was faster and was capable of carrying higher volumes of calls than analog technology, digital service was implemented as a way to save money by decreasing the amount of cabling required to carry high volumes of traffic. Fewer copper or coaxial lines were needed to carry equal volumes of digital rather than analog traffic.

Northern Telecom introduced the first digital telephone system switch for routing calls in 1975. However, to cut its financial risk, it first introduced the switch as a customer premise switch rather than a central office switch. At that time, telephone systems installed on customer premises were highly profitable and it was felt that there was less financial risk in introducing a smaller digital telephone system for end-users, rather than a larger, more expensive telephone company central office switch.

Significant dates for digital services are:

1962: T-1 on two pairs of telephone cable carried 24 voice or data calls in digital format.

- 1975: *The first digital telephone system (PBX), the Northern Telecom SL-1.*
- 1976: *AT&T's #4 ESS toll office switched calls between central offices.*
- 1977: *Northern Telecom's central office switch, DMS 10, was installed in Canada. It was not installed in the U.S. until 1981.*
- 1982: *AT&T's #5 ESS central office switched calls from central offices to local homes and businesses.*

Digital Telephone Company Equipment— Saving Money on Maintenance and Space

Prior to the 1960s, both the transmission of calls and equipment to route calls were analog. Beginning in the 1960s, calls were first carried in digital format on cabling between central offices with analog switches. It was cumbersome to connect digital call traffic to analog for processing by analog central office switches. Devices called channel banks were needed to convert digital signals to analog to be handled within the analog central offices and to convert analog central office signals to digital to be carried on digital coaxial cable running between central office toll switches. Converting to digital central offices eliminated the requirement for this analog-to-digital and digital-to-analog conversion equipment. This saved telephone companies money on:

- **maintenance** on channel banks for the analog-to-digital conversion, and vice versa.
- **space** required in the central offices for channel banks.

BAUDS, BITS, BYTES AND CODES— GETTING DOWN TO BASICS

Overview

Computers communicate using digital signals called bits. Bits are binary. They take two forms, on and off. Computers can “read” each others’ communications when these bits are arranged in a standard, predefined series of on and off bits. All English-language IBM and Mac computers use variations of the same type of codes. The main

code, ASCII, is used when personal computers communicate over telephone lines. IBM minis and mainframes use a different code, EBCDIC.

People use the terms bits, baud rate and bytes interchangeably. Their meaning, however, differs significantly. The signaling speed on analog lines is the baud rate. The baud rate is measured differently than bits per second. Bits per second are the actual number of bits sent in a given time from point A to point B. It is the amount of information or data transmitted on the electrical waves in analog telephone lines.

Baud Rate vs. Bits per Second— Signal vs. Amount of Information Sent

A baud is one analog electrical signal or wave. One cycle of an analog wave equals one baud. A complete cycle starts at zero voltage, goes to the highest voltage and down to the lowest negative voltage and back to zero voltage. A 1200-baud line means that the analog wave completes 1200 cycles in one second. A 2400-baud line completes 2400 wave cycles in one second. The term *baud rate* refers only to analog electrical signals. It does not indicate the amount of information sent on these waves.

The public switched network runs at 2400 baud. If the public network could carry only 2400 bits in one second, data communications users would be severely hampered in retrieving and sending information over analog lines. To achieve greater capacity, modem manufacturers design modems capable of adding more than one bit to each analog wave or baud. Thus, a 9600 bit per second modem enables each analog wave to carry four bits of data per wave ($9600 \div 2400 = 4$). It is correct to state that the 9600 bps modem runs at 2400 baud. A 28,800 bit per second modem puts twelve bits of data onto each electrical signal or wave. It still uses a 2400-baud line.

Baud rate refers to analog, not digital transmission services. Digital services do not use waves to carry information. Information is carried as on or off electrical signals in the case of copper wires, and on or off light pulses on fiber optic lines. On digital services, 56,000 bit per second lines can carry 56,000 bits in one second. The speed is 56 Kbps, or 56 kilobits per second.

Codes—Adding Meaning to Bits

To enable computers to converse in a common “language,” digital bits are arranged in codes such as ASCII for personal computers and EBCDIC for IBM mainframes and mini-computers. Codes allow computers to translate binary off and on bits into information. For example, distant computers can read simple e-mail messages because they are both in ASCII. ASCII (American Standard Code for Information Interchange), is a seven-bit code used by PCs. ASCII code is limited to 128 characters. Extensions to ASCII support eight-bit codes. Most PCs now use extended ASCII. These characters

Table 1.1 Examples of ASCII Code

Character	ASCII Representation
!	0100001
A	1000001
m	1101101

include all of the upper- and lower-case letters of the alphabet, numbers and punctuation such as !, “ and : (see Table 1.1).

Because there are only 128 or 256 with ASCII extended characters, formatting such as bolding, underlining, tabs and columns are not included in ASCII code. Specialized word processing and spreadsheet programs add their own code to ASCII to include formatting and specialized features. Thus, Microsoft® Word® documents, for example, need to be “translated” if they are to be “read” by a WordPerfect® program. Each program uses a different arrangement of bits, for example, to format columns, tabs and footers. They each add proprietary formatting code to standard ASCII code. Sending documents between computers in ASCII allows them to be read by all PCs. However, specialized formatting such as tabs, tables, columns and bolding are not included in the transmission.

SENDING ATTACHMENTS WITH E-MAIL

E-mail is the most widely used application on the Internet. However, e-mail has format limitations. It only sends ASCII code. The limitation with ASCII is that it has just 128 characters. These characters do not include bold characters, images, tables or spreadsheet formats. This is a problem for people who want to conduct business or exchange complex documents.

For example, for my teaching at Northeastern, students send me their finals and I send consulting proposals and completed reports to clients and prospective clients. These files are usually in Microsoft® Word® or Microsoft® Excel® formats. Salespeople may send or receive presentations composed in the Microsoft PowerPoint® format. It is possible to exchange video, audio and JIF or JPEG image files.

To overcome ASCII limitations, mail protocols allow users to send attachments over communications lines. The mail protocol, MIME (multipurpose mail extensions), adds special bits to the beginning of the attachment which contains the word processing, spreadsheet or image

file. These special bits tell the receiving computer when the attachment begins and ends and the type of encoding used—for example, word processing program, spreadsheet, image, etc. The receiving computer then opens that particular program (spreadsheet, PowerPoint, JPEG or video) and decodes the attachment so that the recipient can read the document.

Bytes = Characters

Each character of computer-generated code is called a byte. A bit is only an on or off signal. The entire character is a byte. A one-page document might have 250 words with an average of five letters per word. This equates to 5×250 , or 1250 bytes or characters. It would, however, contain 8,750 bits if each character were made up of seven bits. To summarize, a byte is a character made up of seven or eight bits. A bit is an on or off signal. Table 1.3 contains definitions of various network terms.

BANDWIDTH—MEASURING CAPACITY

In telecommunications, bandwidth refers to capacity. Bandwidth is expressed differently in analog and digital transmissions. The carrying capacity of analog media, such as coaxial cable, is referred to in hertz. Hertz is a way of measuring the capacity or frequency of analog services. For example, someone might say coaxial cable has a bandwidth of 400 MHz; 400 MHz means four hundred million cycles per second. The capacity of the cable can be stated as a frequency of 400 MHz. The bandwidth of an analog service is the difference between the highest and lowest frequency within which the medium carries traffic. Cabling that carries data between 200 MHz and 300 MHz has a bandwidth, or frequency, of 100 MHz. The greater the difference between the highest and lowest frequency, the greater the capacity or bandwidth.

On digital services such as ISDN, T-1, and ATM, speed is stated in bits per second. Simply put, it is the number of bits that can be transmitted in one second. T-1 has a bandwidth of 1.54 million bits per second. Bandwidth in terms of bits per second or hertz can be stated in many ways. Some of these include:

- Individual ISDN channels have a bandwidth of 64 thousand bits per second, 64 kilobits per second or 64 Kbps.
- T-1 circuits have a bandwidth of 1.54 million bits per second, 1.54 megabits per second or 1.54 Mbps.

- One version of ATM has the capacity for 622 million bits per second, 622 megabits per second, or 622 Mbps.
- Another version of ATM has the capacity for 13.22 billion bits per second, 13.22 Gigabits per second or 13.22 Gbps.
- One thousand Gigabits is called one terabit; 10 terabits per second = 10,000,000,000,000 bits per second.

Narrowband vs. Wideband—Slow and Fast

In addition to bits per second and hertz, speed is sometimes referred to as narrowband and wideband. Just as more water fits into a wide pipe and moves faster, wideband lines carry more information than narrowband lines, and the term wideband refers to higher speed services than narrow band. Again, digital speeds are expressed in bits per second and analog speeds are expressed in hertz.

The definition of wideband and narrowband technologies differs within the industry, as can be seen in Table 1.2.

Table 1.2 *Wideband and Narrowband Telecommunication Services*

<i>Narrowband</i>	<i>Wideband</i>
T-1 at 1.54 Mbps 24 voice or data conversations on fiber optics, infrared, microwave or two pairs of wire.	Broadcast TV services— uses 6 MHz per channel Newer digital high-definition TV (HDTV) offers enhanced clarity over analog TV.
Analog telephone lines at 3000 Hz Plain old telephone service (POTS). Modems enable analog lines to carry data from digital computers.	Cable TV (CATV) and Community antenna television at 700 MHz Broadcasts local and satellite TV. Also available for data communications and access to the Internet.
BRI ISDN at 144 Kbps Two paths for voice or data, each at 64 Kbps. One path for signals at 16 Kbps.	ATM—up to 13.22 GBPS, gigabits A very high-speed service capable of sending voice, video and data.
	SONET—Up to 13.22 Gbps, Gigabits An optical multiplexing interface for high-speed transmission. Used mainly in carrier and telco networks.
	T-3 at 44.7 Mbps, megabits (equivalent to 28 T-1 circuits) A way of transmitting 672 conversations over fiber optics or digital microwave.

Television and cable are carried at wideband speeds. Lines connecting telephone offices together use wideband services. Voice calls, video and data transported within carriers' networks are generally carried at wideband speeds. However, most traffic from central offices to individual homes and businesses are carried at the slower, narrowband speeds.

Protocols and Architectures

Protocols—A Common Language

Protocols allow like devices to communicate with each other. They provide a common language and set of rules. Devices communicate over the Internet using a suite of protocols called TCP/IP. For example, the IP, or Internet protocol portion of TCP/IP, allows portions of messages called datagrams to take different routes through the Internet. The datagrams are assembled into one message at the receiving end of the route. Other protocols, such as Ethernet enable communications among personal computers within an organization's building. The Internet uses HTTP (HyperText Transport Protocol) for end-users' computers to access documents and Web pages on the Internet. Apple's Mac computers can be connected to each other over the Apple Talk protocol.

Examples of protocol functions are:

- Who transmits first?
- In a network with many devices, how is it decided whose turn it is to send data?
- What is the structure of the addresses of devices such as computers?
- How is it determined if an error has occurred?
- How are errors fixed?
- If no one transmits, how long is the wait before disconnecting?
- If there is an error, does the entire transmission have to be resent or just the portion with the error?
- How is data packaged to be sent, one bit at a time or one block of bits at a time? How many bits are in each block? Should data be put into envelopes called packets?

Protocol structures have implications on speed and efficiency. The following protocols illustrate this point:

- SLIP (Serial Line Interface Protocol): Enables computers to use IP to access their Internet Service.

- PPP (Point-to-Point Protocol) has largely supplanted SLIP. It can be used in non-TCP/IP environments and has improved security functionality over SLIP. It is used to access the Internet and to tie dispersed networks together.

Architectures—Communications Framework for Multiple Networks

Architectures tie dissimilar protocols together. Standards bodies and dominant companies, like IBM develop architectures. By the mid-1970s, IBM had sold its customers a variety of printers, terminals and mainframe and mini-computers. These devices communicated with each other by a variety of incompatible protocols. An architecture was developed by IBM to enable its devices to talk together. This architecture is called SNA, and it is specific to IBM.

During the same time period, an architecture was developed by the International Standards Organization, or ISO. This architecture, Open System Interconnection (OSI), was developed to allow devices from multiple vendors to communicate with each other. It is an open architecture.

While OSI has not been widely implemented, it has had a profound influence on telecommunications. It laid the foundation for the concept of open communications among multiple manufacturers' devices. The basic concept of OSI is that of layering: Groups of functions are broken up into seven layers, which can be changed and developed without having to change any other layer. Both LANs and the Internet are based on concepts developed by the OSI for a layered architecture.

Layer 1 is the most basic layer, the physical layer. It defines the electrical interface (plugs) and type of media, for example, copper, wireless and fiber optics. Layer 1 also defines the electronics (e.g., modulation) for getting the signal on and off the network. In modems that work on analog lines, modulation changes the computer's digital signal to analog and at the receiving end, the analog signal to digital.

Layer 2 is the data link layer. LANs, networks within corporations, correspond to Layer 2 of the OSI model. They provide rules for error control and gaining access to the local area networks within organizations. Layer 2 devices are analogous to the postal system's routing mail all the way to an end-user's residence.

Layer 3 is called the network layer. It has more complex rules for addresses and routing and more error control than Layer 2. Communications between networks generally adhere to protocols corresponding to Layer 3 of the OSI. Layer 3 protocols are responsible for routing traffic between networks or sites. Layer 3 is analogous to a local post office routing an out-of-town letter by zip code. It only looks at the zip code not the street address. Layer 3 is also known as the routing layer. It is used to route IP (Internet protocol) traffic.

Layer 4 is the transport layer. Layer 4 devices let networks differentiate between different types of applications. Layer 4 devices route by content. For example, video or voice transmissions over data networks might receive a higher priority or quality of service than e-mail. Layer 4 devices are also responsible for security in routers connected to the Internet or to virtual private networks, VPNs. (For VPNs see Chapter 9.) Filters in routers allow or deny access to networks based on the sender's IP address.

Layer 5 is the session layer. Layer 5 manages the actual dialog of sessions. For example, can both ends send at the same time? Can transmissions be half-duplex, one-way-at-a-time sending? It can also define a session such that only one side is able to send.

Layer 6 is the presentation layer. Layer 6 controls the format or how the information looks on the user screen.

Layer 7 is the application layers. Layer 7 includes the application itself plus specialized services such as file transfers or print services.

The Internet suite of protocols, TCP/IP, corresponds to the functions in Layers 3 and 4 of the OSI model. These functions are addressing, error control and access to the network. The TCP/IP suite of protocols provides a uniform way for diverse devices to speak to each other from all over the world. It was developed in the 1970s by the U.S. Department of Defense and was provided at no charge to end-users in its basic format. Having a readily available, standard protocol is a key ingredient in the spread of the Internet.

COMPRESSION AND MULTIPLEXING

Compression—Manipulating Data for More Capacity

Compression is comparable to a trash compactor. Just as a trash compactor makes trash smaller so that more can be packed into a garbage barrel, compression makes data smaller so that more information can be packed into telephone lines. It is a technique to get more capacity on telephone lines.

Modems—Using Compression to Get Higher Throughput

With compression, data to be transmitted is made smaller by removing white spaces and redundant images, and by abbreviating the most frequently appearing letters. For example, with facsimile, compression removes white spaces from pictures and only transmits the images. Modems use compression to achieve higher rates of transmitted

information, or throughput. Throughput is the actual amount of useful data sent on a transmission. When modems equipped with compression transmit text, repeated words are abbreviated into smaller codes. For example, the letters E, T, O and I appear frequently in text. Compression will send shortened versions of these letters with 3 bits rather than the entire eight bits for the letters E, T, O and I. Thus, a page of text might be sent using 1600 bits rather than 2200 bits.

Modems use compression to send greater amounts of computer data in less time over analog lines. For example, if a word processing file is ten pages long, compression that eliminates white spaces, redundant characters and abbreviates characters might compress the document to seven pages. Seven pages of data take less time to transmit than ten pages. This is an example of compression increasing throughput, or the amount of information sent through a line in a given amount of time. Telecommuters who access and send data to corporate locations often use modems equipped with compression to transmit files more quickly. Matching compression is needed at both the telecommuter's home and the corporate site (see Figure 1.3).

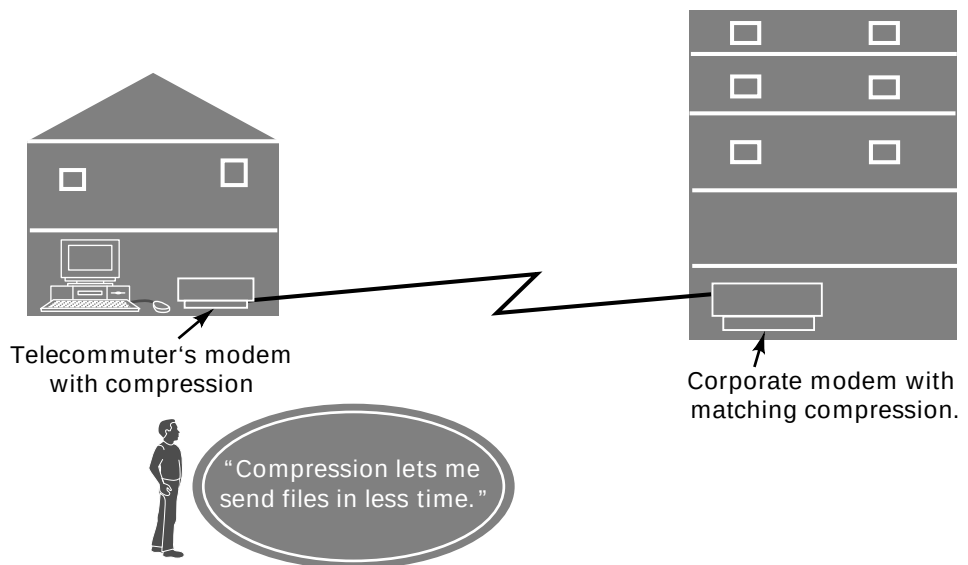


Figure 1.3
Compression in modems.

Video—Compression Made Video Conferencing Commercially Viable

In video, compression works by transmitting only the changed image, not the same image over and over. For example, in a videoconference meeting with a person who listens, nothing is transmitted after the initial image of the person listening until that person moves or speaks. Fixed objects such as walls, desks and background are not repeatedly transmitted. Another way video compression works is by not transmitting an entire image. For example, the device performing the compression, the coder, knows that discarding minor changes in the image won't distort the viewed image noticeably.

Improvements in the mid-1980s in video compression spawned the commercial viability of room-type video conference systems. It made it economical to use video by requiring less bandwidth, which translates into cheaper telephone lines. The older compression systems required a full T-1 for video. This inhibited the sales of room-type video systems until the late 1980s. New compression techniques in the 1980s from companies such as PictureTel required only 56 Kbps to 128 Kbps for acceptable picture quality.

Thus, video conferencing became affordable to a wide range of organizations. For example, instead of using a T-1 at hundreds of dollars per hour, organizations could use a service from someone such as MCI Worldcom for as low as \$14 per hour and still have acceptable video capability. New compression algorithms meant that slower speed digital lines were an acceptable choice for video meetings. A new industry boomed.

Compression Standards = Interoperability

There are many types of compression methods. Companies such as AT&T, Motorola, PictureTel and Compression Labs have all designed unique compression schemes using mathematical algorithms. A device called a codec (short for coder-decoder) encodes text, audio, video or image using a compression algorithm. For compression to work, both the sending and receiving ends must use the same compression method. The sending end looks at the data, voice or image. It then codes it using a compression algorithm. The receiving end of the transmission decodes the transmission. For devices from multiple manufacturers to interoperate, compression standards have been agreed upon for modems, digital television, video teleconferencing and other devices. See Appendix for compression standards.

Streaming Media

Speeding Up Internet Connections

Streaming media, also called streaming video and streaming audio, is software used to speed up transmission of video and audio over the Internet. When graphics and text are sent to an Internet user's browser, the text can be viewed as soon as it is on the PC. The graphics are filled in as they are received.

Pornography is the biggest application to date for streaming video. It was the first to use cameras to record live action. However, many experts think streaming media will turn the Internet into another medium for communications. Mainstream corporations use streaming media to disseminate speeches and corporate events. Universities are using the technology to make their offerings more widely available. In particular, continuing education students at many universities take courses to keep up with developments in their field without traveling to distant campuses.

Web sites are starting to offer their customers the ability to generate their own audio and video clips. For example, GeoCities announced on March 1, 1999 that they would deploy RealNetworks server software on GeoCities site. End-users will be able to use the RealNetworks tools to produce their own audio and video clips. However, they will be charged for data-storage if they use more than the minimal amount offered at no charge.

Streaming vs. Downloading and MPEG Standards

When text or graphics are downloaded, the entire file must be downloaded before it can be viewed. With streaming technology, as soon as a URL is clicked, it starts to be viewable by the end user. Streaming is an important feature of browsers. When Web pages with both text and graphical ads are downloaded, the text reaches the end user's computer faster than the graphics. For example, someone reading the online edition of the Wall Street Journal can start reading articles while the ads are being received.

MPEG standards are used for streaming audio and video. The ITU (International Telecommunications Union) formed the Moving Picture Experts Group in 1991 to develop compression standards for playback of video clips and digital TV. MPEG3 came to be used for streaming audio. MPEG and proprietary streaming media compression schemes are asymmetrical. It takes more processing power to code than to decode an image. Streaming compression algorithms assume that the end-user will have less processing power to decode than developers and broadcasters that encode the video and audio.

The two most prevalent streaming media software products are those developed by RealNetworks Inc. and Microsoft Corporation. RealNetworks has a larger share of the market than Microsoft. RealNetworks' products are RealSystem® and

RealPlayer®. Microsoft's product is NetShow services. Streaming media is an important force in the Internet's move toward becoming a mass media vehicle. Rob Glaser, Chief Executive of RealNetworks, said in response to AtHome Corporation's announcement that it will deliver television quality video clips to its cable modem customers: "[This is] another crucial step forward in enabling the Internet as the next mass medium for both consumers and content providers." (*The Wall Street Journal*, "AtHome to Use RealNetwork in Video Clips," Jan. 15, 1999, p. B-6)

Both Microsoft and RealNetworks give away their streaming media software for free in the hope that they will become de facto standards and that developers will purchase server-based products from them.

Processing Power: A Factor in Streaming Media's Improvement

The increasing power of personal computers as well as improvements in compression is increasing the use of streaming audio and video over the Internet. As a matter of fact, Intel Corporation, in September of 1998, licensed the technology to RealNetworks to develop their streaming media software. Intel hoped to encourage people to buy more powerful computers. Streaming video and audio requires powerful chips, such as Pentium®, to decode streams fast enough to run the streaming software.

Intel Corporation and Microsoft Corporation, in April of 1998, announced that Intel's software program Intericast® will be included in Microsoft's operating system Windows 98®. Intericast® enables broadcasters to include data in the form of statistics along with TV programming. Examples of these data streams include sports statistics and electronic shopping announcements. Windows 98® also includes support for TV tuner cards within the PC. PCs also need antennas to receive digital broadcasts. To date, few PC manufacturers have made these tuners. Matsushita Electric Industrial Company's Panasonic unit and Philips Electronics NV both announced that they would have tuner cards for digital TVs available in 1999.

PCs ACT LIKE TVs

SoftCom Inc and Broadcast.com Inc. are two companies that use streaming media in the core of their business. SoftCom works with universities and broadcasters to make their videos accessible to people with personal computers connected to the Internet. SoftCom creates the software for organizations to publish their videos and create interactive applications. For example, a nursing school offers its continuing education courses on the Internet so those students can take courses from their home without driving to a campus.

Once the streaming video application is completed, it is located on a SoftCom server at an Internet Service Provider. The server is a computer put inside a three by six-foot cage at the ISP's premise. Nursing students' calls, when viewing these courses, are directed to the ISP host's site. Three ISPs that specialize in hosting include Exodus Communications, Frontier Communications and Globix Corporation.

Broadcast.com, part of Yahoo! Inc., offers live radio and TV broadcasts via the Internet. The Broadcast.com Web site includes 370 radio stations and 30 TV stations. College and professional sports broadcasts are a TV specialty. In addition, they broadcast live business events. These events include shareholder meetings, speeches and earnings calls to stock analysts. To hear or see these businesses broadcasts, users click on a Broadcast.Com URL in the Internet. This address takes the caller to the Broadcast.com server located in Dallas Texas. The Dallas site is connected to the Internet by a T-3, 44.5 million bit per second telephone line.

Digital Television—Sending Studio-Quality Pictures with Compression

Compression squeezes video and analog signals into small enough units so that studio-quality television can be sent on standard digital television channels. The analog standard for television is set at 525 scan lines, or 525 lines of image. HDTV (high-definition television) enables a TV screen to display 1080 horizontal scanned lines and 1029 vertical scanned lines. A higher number of scan lines results in a clearer, studio-quality TV picture. Additional "lines" of image result in a denser, higher resolution of detailed images on the screen. This is done through computer manipulation of the video and audio portions of the television signal. Computerized compression takes out the redundancy and images in the picture that don't change. This reduces the signal that needs to be transmitted from 1.5 Gigabits to 19.3 megabits. However, the person seeing the TV image perceives the image to be almost as clear as the originating program. Because of powerful compression and decompression tools, very little is lost to the viewer. The quality on digital television is such that people watching television in their homes perceive the quality to be like that of movies at theaters.

Multiplexing—Let's Share

Multiplexing combines traffic from multiple telephones or data devices into one stream so that many devices can share a telecommunications path. Like compression, multiplexing makes more efficient use of telephone lines. However, unlike compression, multiplexing does not alter the actual data sent. Multiplexing equipment is located in

long distance companies, local telephone companies and at end-user premises. It is associated with both analog and digital services. Examples of multiplexing over digital facilities include T-1, fractional T-1, T-3, ISDN and ATM technologies.

The oldest multiplexing techniques were devised by AT&T for use with analog voice services. The goal was to make more efficient use of the most expensive portion of the public telephone network, the outside wires used to connect homes and telephone offices to each other. This analog technique was referred to as *frequency division multiplexing*. Frequency division multiplying divides the available range of frequencies among multiple users. It allowed multiple voice and later data calls to share paths between central offices. Thus, AT&T did not need to construct a cable connection for each conversation. Rather, multiple conversations could share the same wire between telephone company central offices.

Digital multiplexing schemes also enable multiple pieces of voice and data to share one path. Digital multiplexing schemes operate at higher speeds and carry more traffic than analog multiplexing. For example, T-3 carries 672 conversations over one line at a speed of 45 megabits per second (see Figure 1.4). With both digital and analog multiplexing, a matching multiplexer is required at both the sending and receiving ends of the communications channel.

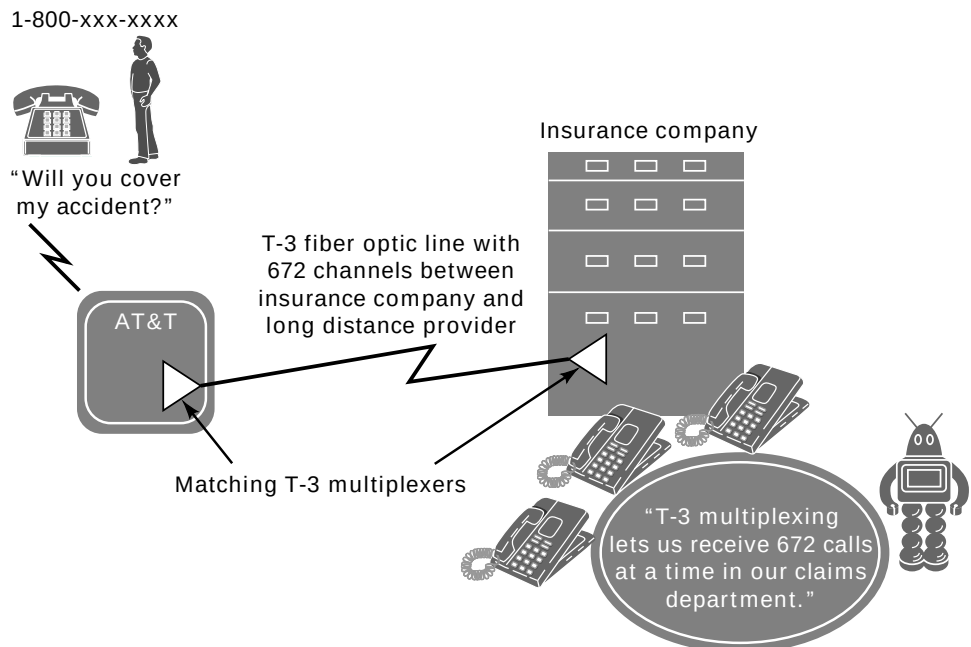


Figure 1.4
Multiplexers for sharing a telephone line.

While T-3 is used for very large customers and for telephone company and Internet service provider networks, T-1 is the most common form of multiplexing for end-user organizations. T-1 is lower in both cost and capacity than T-3. T-1 allows 24 voice and/or data conversations to share one path. T-1 applications include linking organization sites together for voice calls, e-mail, database access and links between end-users and telephone companies for discounted rates on telephone calls. Like T-3 services, matching multiplexers are required at both ends of a T-1 link.

LANs, MANS, AND WANS

The difference between LANs, MANs and WANs is the distance over which devices can communicate with others. As the name implies, a local area network is local in nature. It is owned by one organization and is located in a limited geographic area, usually a single building. In larger organizations, LANs can be linked together within a complex of buildings on a campus. Devices such as computers linked together within a city or metropolitan area are part of a metropolitan area network. Similarly, devices that are linked together between cities are part of a wide area network.

Table 1.3 LANs, MANs and WANs—What’s the Difference?

Term	Definition
LAN (Local Area Network)	A group of data devices, such as computers, printers and scanners, that can communicate with each other within a limited geographic area such as a floor, department or building.
MAN (Metropolitan Area Network)	A group of data devices, such as LANs, that can communicate with each other within a city or a large campus area covering many city blocks.
WAN (Wide Area Network)	A group of data devices, such as LANs, that can communicate with each other from multiple cities.
Hub	The intelligent wiring center to which all devices, printers, scanners, PCs, etc., are connected within a segment of a LAN. Hubs enable LANs to be connected to twisted pair cabling instead of coaxial cable. Only one device at a time can transmit via a hub. Hubs provide a point for troubleshooting and relocating devices. Speed is usually 10 Mbps.
Switching Hub	Switching hubs allow multiple simultaneous transmissions on a LAN segment. Total speeds range from 10 Mbps to 100 Mbps (megabits per second).

Table 1.3 *continued*

Term	Definition
Backbone	Wiring running from floor to floor in single buildings and from building to building within campuses. A backbone connects to hubs located in wiring closets on each floor.
Bridge	Bridges connect multiple LANs together. They have limited intelligence and generally only connect a few LANs together. Bridges were in limited use as of the early 1990s when the price of routers dropped.
Layer 2 Switches	Bridges with multiple ports are able to switch data quickly between local area network segments. Layer 2 switches provide a dedicated connection during an entire data transmission.
Router	Routers connect multiple LANs. They are more complex than bridges and can handle a greater number of protocols and LANs. Routers select the best available path over which to send data between LANs.
Routing switches	Routing switches are faster than traditional routers. They do not look up each packet's address in the CPU's memory. Routing is done in chips on each module or card.
Server	A centrally located computer with common departmental or organizational files, such as personnel records, sales data, price lists, student information and medial records. The server connects to a hub or layer 2 switch. Access may be restricted.

LANs—Local Area Networks

Examples of devices within LANs that communicate are: shared printers, PCs, alarm devices, factory automation and quality control systems, shared databases, factory and retail scanners and security monitors (see Figure 1.5). A discrete LAN is typically located on the same floor or within the same department of an organization.

The growth of LANs grew out of the proliferation of PCs. Once people had PCs on their desktops, the next step was to connect these PCs together. LANs first appeared in 1980. The initial impetus for tying PCs together was for the purpose of sharing costly peripherals, such as high-speed printers. LANs are now the building blocks for connecting multiple locations together for the purpose of sending e-mail and sharing databases with remote locations and telecommuters. These e-mail and corporate information files are located in specialized computers called file servers. Access to file servers can be limited by password to only certain users.

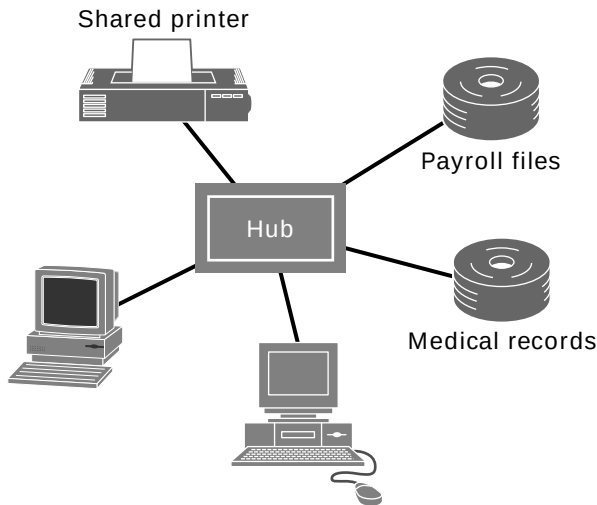


Figure 1.5
A local area network.

The software that runs local networks is called *LAN network operating systems* and is located on servers connected to the LAN. Most operating systems in use today are built on the client-server model. Clients (PCs) request services such as printing and access to databases. Applications called servers run access to services (e.g., printers and databases). The network operating system controls access to the LAN where resources such as files, printers and modems are located. Examples of client-server-based LAN network operating systems are Microsoft NT and Novell NetWare.

Devices on local area networks are all connected to the LAN. Each device on a local area network can communicate with every other device. The connections between devices may be any of the following: twisted pair, coaxial cable, fiber optics or wireless media. For the most part, devices are connected to a LAN by twisted pair cabling that is similar to but sometimes of a higher quality than that used to tie business telephones together. (Media options are covered in Chapter 2.)

When local area networks became popular in the 1980s, many individual departments purchased their own LANs independent of the central computer operations staff. As the need arose to tie these LANs together for e-mail and file sharing, compatibility between LANs from different manufacturers became a problem. The TCP/IP suite of protocols became a popular choice for overcoming these incompatibilities. Devices called bridges and routers were also developed to send data between LANs.

Hubs

Hubs enable devices on LANs to be linked together by twisted copper pair wire instead of the heavier, thicker coaxial cable typically used in the cable TV industry. When LANs were initially implemented, they were installed using coaxial cable to interconnect devices on the LAN. Coaxial cable is expensive to install and to move. It is not unusual in large organizations for entire departments and individuals to move at least once a year. The use of coaxial cabling resulted in running out of space in dropped ceilings and conduit for the cable.

With a hub, instead of wiring devices to each other, each node or device is wired back to the hub in a star pattern. Using a hub changes the topology of a LAN. The hub creates a star design or topology. (Topology is “the view from above”—in the case of hubs, a star where each device is connected to a central device.) Without a hub, each

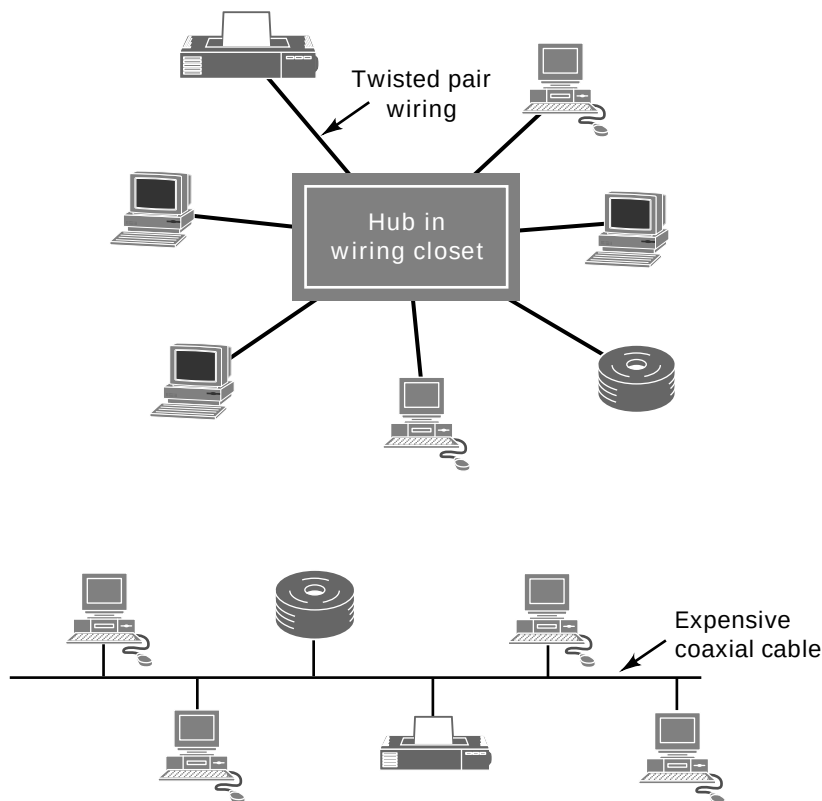


Figure 1.6

*Top: LAN with a hub to link devices with twisted pair wiring.
Bottom: LAN without a hub.*

device in a LAN is wired to another device in a “bus” arrangement. In the bus topology, if one device is taken out of the line or bus, or if there is a break in the line, each device is affected. Conversely, by employing a hub, moving a device does not impact the other devices. A hub is kept in the wiring closet of each floor within a building, as shown in Figure 1.6.

Bridges

Bridges became available in the 1980s as a way to connect a small number of LANs together. They were used most often in the mid-1980s. Bridges provide one common path over which multiple LANs may be connected together (see Figure 1.7). For example, if an organization has two locations in different cities that need to exchange data, a bridge can be used. Bridges can connect two Ethernet LANs, or an IBM token ring network to an Ethernet LAN. In addition to connecting distant LANs to each other, bridges were used extensively in the mid-1980s to connect LANs in the same building or campus.

The advantage of bridges is that they are easy to configure. There are a limited number of choices in configuring a bridge. Each piece of data sent via a bridge takes the same path. This is also a disadvantage. Each piece of data not only takes the same path, it is also sent to each device on the network. The lack of routing and congestion control puts bridges at Layer 2 in the OSI model. Only the device to which the message is addressed takes the message off the network. This broadcast feature of bridges can choke the network with too many messages, slowing down the network for everyone. As LANs proliferated and router prices dropped, people turned to routers rather than bridges.

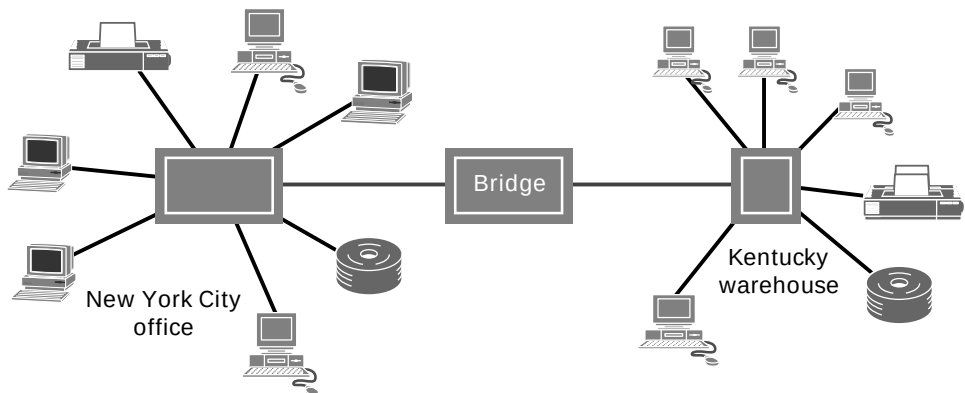


Figure 1.7

A bridge connecting two local area networks.

Routers

Routers are also used to connect multiple local area networks. These LAN connections are usually between LANs located in distant buildings on a campus or in different buildings in diverse cities. However, routers also connect multiple LANs within large campuses spread out across cities. Routers are more sophisticated and have additional capabilities not available in bridges. A major advantage of routers is their ability to forward differing protocols from varied departmental local area networks. It is important to note that routers do not translate application protocols. A UNIX computer cannot read a Microsoft Windows word processing document. The router merely allows differing LAN protocols to be transported via a corporate network infrastructure.

Router capabilities include:

- **Flow control:** If the path the data should take is congested, the router can hold the data until capacity is available on the path between the routers.
- **Path optimization:** The sending router selects the best available path. It checks routing tables contained within the router for this information.
- **Sequencing:** Routers send data in packets, or envelopes. These packets may arrive out of order at the end router. The receiving router knows by information in the packet the correct order and arranges the data accordingly.
- **Receipt acknowledgment:** The receiving router sends a message to the sending router letting it know that data was received correctly.

The intelligence inherent in routers leads to two major disadvantages. In the first place, routers are complex to install and to maintain. Every router in an organization's network must have up-to-date address tables. Each device on a LAN is called a node and has an address. For example, if a printer or PC is moved from one LAN to another, the router table must be updated or messages will not reach that device. To illustrate the complexity of managing routers, it is common to hear of consultants with full-time contracts to update router tables for organizations. Secondly, routers are slower than bridges. The need to look up tables within the router slows down the router's speed. The above functionality of congestion control, sequencing and receipt acknowledgment make routers network Layer 3 devices in the OSI model.

Switching Routers

Switching routers are faster than non-switching routers. They do not look up each address of each packet that they route in the router's table. Rather they place each packet's address in silicon on the circuit pack. Most new routers installed on LANs are switching routers. Some new routers are so fast that they are referred to as terabit routers. They operate at a thousand gigabits per second.

WANs—Wide Area Networks

The term WAN refers to connections between organizational locations over long distances via telephone lines. For example, a warehouse in Alabama connected to a sales office in Massachusetts by a telephone line is a WAN, or wide area network connection. In contrast to a local area network, a WAN is not contained within a limited geographical location. The variety of WAN connections available is complex. Selection of an appropriate WAN connection depends on the amount of traffic between locations, quality of service needed, price and compatibility with the computer systems located within the organizations. WAN technologies and WAN vendors are reviewed in Chapters 6 and 7. These include ISDN, T-1, T-3, ATM and frame relay, as well as wireless services.

MANs—Metropolitan Area Networks

Metropolitan area networks, or MANs, are connections between local area networks, which occur within a city or over a campus. Campus MANs are spread out over many blocks of a city. Examples of MANs are those of large hospitals and university complexes. For example, a hospital in downtown Boston keeps its x-rays and other records in a nearby section of the city. Instead of trucking records and x-rays between the two sites, the hospital leases high-capacity telephone lines to transmit records and images. The connections between these two sites are metropolitan area connections. These connections can be leased from a telephone company or constructed by the organization. They may be fiber optic, copper or microwave-based services. They may also include the same services mentioned for WANs, such as ISDN and T-1.

LAN and WAN Congestion

New, High-Bandwidth Applications

Original LAN designs lent themselves to “bursty” traffic. Bursty traffic includes e-mail and text messages. Bursty traffic is not a steady stream of data. With typical LAN protocols, such as Ethernet and token ring, only one message at a time can be carried on a LAN that has a speed of ten megabits. New applications are causing delays and congestion on LANs. Applications adding high-traffic volumes to LANs are desktop video conferencing, computer-aided design, computer aided manufacturing and graphics downloaded from the Internet.

Not only are these applications adding traffic to LANs, but the traffic is no longer the short, bursty type of traffic. Bursty traffic sends a group of messages and then has a pause. This pause gives other devices that share the network a chance to transmit data. Video, however, is an application that requires constant use of the network. People participating in a conference don’t want a blank screen while someone

else on the LAN accesses the Internet. Video requires constant network capacity during the video conference.

More Powerful PCs

In addition to applications which require large amounts of data to be transmitted over organizations' LANs, the capability of PCs impacts LAN requirements. In the 1980s when LANs were first implemented, people had computers with 286 chips on their desks with small amounts of memory and hard disks. In recent years, staffs have Pentium computers with 64 megabits of memory and Gigabit-sized hard drives. These powerful PCs have multimedia capability. This allows them to participate in desktop video conferences, download large files from the Internet and share large spreadsheet files. All of this traffic is carried over the LAN.

Sharing the LAN

Router-based and hub-based campus networks and LANs are shared media networks. Everyone has a turn to send and receive data, but sharing is required. Only one message at a time can be carried. The speed on these networks is high—10 megabits. But the assumption is that messages will be bursty, allowing other transmissions to send without causing large delays. When LANs were first implemented, in addition to assumptions regarding burstiness, it was assumed that applications such as e-mail would not require immediate response. This is not true for newer applications such as Internet access. People do not want delays when downloading information from the World Wide Web. For these reasons Layer 2 switches and switching routers with dedicated bandwidth for individual users are being implemented in LANs.

Congestion within LANs, LAN-to-LAN and LAN-to-WAN

Congestion on networks occurs both within a local area network, between LANs in a building or campus and between a LAN and a WAN. New technologies are emerging which provide greater capacity in these areas.

Higher Speed Services for LAN Traffic (All Require Hub Upgrades)

- **Fast Ethernet:** Fast Ethernet is a shared protocol. However, it has a speed of 100 megabits—ten times the speed of standard Ethernet, the most prevalent LAN protocol. Standard two pair wiring is used. New cards are required in each PC to access the LAN.
- **100 megabit Switched Ethernet:** Switched Ethernet is a non-sharing service. Devices with high transmission needs are given their own dedicated paths within a LAN. Standard wiring, bridges and routers can be used. This frees up high bandwidth users from “hogging” LANs.

Higher Speed Services for LAN-to-LAN Backbone and LAN-to-WAN Traffic

- **Gigabit Ethernet:** Works with existing LAN protocols. Because of its high speed, 1000 megabits, gigabit Ethernet requires either Fiber optic cabling or extended level 5 unshielded twisted pair. On LANs, it is mainly the servers that have the high-capacity gigabit Ethernet connections because of the high traffic levels to servers.
- **Routing Switches:** Routing switches forward packets on a packet-by-packet basis. They put the first of a series of packet addresses in the silicon memory of a card in the router to avoid having to look up each address in the router’s table. Routing switches perform Layer 2 as well as Layer 3 switching. The Layer 3 functions route between networks and network segments. The Layer 2 function routes the packet to the end node—that is, PC or printer. Nortel Networks, through their acquisition of Bay Networks, supplies these routing switches.
- **Tag Switching:** Supported by Cisco. A proprietary protocol based on multi-protocol label switching to increase the speed of connections between LANs. In tag switching, bits representing the address are placed in the router’s short-term cache memory. A fixed-length tag is added to each packet. Subsequent routers do not have to examine the entire header of the packet. They merely look at the tag for routing instructions. This shortens the amount of time required to route packets. It speeds up routing.

New Devices for Carrier and Internet Service Provider Networks

Manufacturers are developing new high-speed routers for the anticipated growth in the amount of data versus voice carried in the public network. They envision a network of the future that will carry a preponderance of data, video and audio rather than voice traffic. Data communications equipment manufacturers such as Cisco Systems and 3Com are developing high-speed routers that they would like to sell to carriers and Internet service providers. They see their equipment as being primarily designed for data traffic but also fast enough to carry voice and video without any degradation in the quality of the voice or video.

Traditional manufacturers of central office equipment designed to carry voice are developing new equipment to carry data more efficiently. These manufacturers include Siemens AG, Lucent Technologies and Nortel Networks. All of these organizations have purchased companies who specialize in equipment that can carry high-speed data services. For example, Lucent has purchased Yurie Systems and Ascend Communications. Ascend Communications had previously bought Cascade, a manufacturer of ATM switches, and Stratus. Nortel bought Bay Networks and Aptis. It also owns a 20% stake in Avici Systems, a developer of terabit routers. Avici System's routers are described below. Avici is introducing their routers on the market in mid-1999.

AVAILABILITY VS. RELIABILITY

When carriers purchase telephone company equipment, key criteria for purchases are reliability and availability.

- *Reliability refers to how often a device breaks. Carriers typically require NEBS Level 3 compliance on equipment they purchase. NEBS stands for Network Equipment Building Standards. Bellcore, the former R&D arm of the Regional Bell Operating Companies developed NEBS standards. The standards include compliance with thermal, electrical, redundancy and earthquake resistance tests.*
- *Availability refers to how long it takes to repair equipment or to having the equipment in service even though part of it is not working. For example, if ports are inoperable, the other ports should be available to route calls normally handled by the inoperable ports. In the same vein, back-up central processing units, CPUs, should be able to automatically take over if the main CPU goes down.*

Terabit Routers

The term terabit router was coined by Avici Systems in 1997. Terabit routers route packets at trillions of bits per second (1,000,000,000,000). Terabit routers are generally geared toward the Internet service provider and carrier market. In planning for and designing their routers, Avici Systems spoke with carriers who stated that they wanted hardware that would be capable of handling the huge amounts of data they expected on the public network from applications such as virtual private networks. (See Chapter 9 for VPNs.) They felt that VPNs would be handling a large amount of e-commerce, extranet and Intranet traffics in the near future.

Avici's terabit routers are computers made on the model of super computers. The switching fabric is made up of up to 560 routers in a single device. If any one of the 560 computers fail, the router will still function and use the input/output ports associated with the remaining computers. The router uses MPLS, multi-protocol label switching. The smaller headers associated with MPLS enable routers to forward packets at high speeds. With MPLS, short, fixed-length "labels" tell the router how to route each packet so that the router does not have to examine the entire header of each packet. Avici Systems envisions their terabit routers replacing ATM switches in the backbone of service providers' networks. ATM switches switch voice, data and video in the backbone of the public network. The backbone is the high-traffic area of a network into which lower usage paths are routed. Avici routers simultaneously support 100 OC 192, plus 400 OC 48 streams of traffic. The term OC stands for Optical Carrier speeds that are transported over fiber optic cables. OC 48 = 2,488 million bits per second and OC 192 = 10,000 million bits per second.

Other manufacturers of new high-speed routers include Torrent Networking Technologies, Pluris, NetCore Systems, Unisphere Solutions, Inc. and Juniper Networks, Inc. Many of these router manufacturers are vying to replace traditional central office equipment with their routers. They envision a programmable switch (see Chapter 9 for programmable switch), converting public network voice traffic to Internet Protocol (IP) packets and handing them off to high-speed routers to be transported over high-capacity fiber optic networks. (See Chapter 2 for dense wave division multiplexing on fiber optic networks.)

Edge Routers

Edge routers connect organizations' networks to carriers' switches and routers. They are located at the edge of both carrier and enterprise networks. Ennovate Networks, Inc. of Boxborough, MA manufactures a new edge router that they market to carriers for use in their IP data networks. The router has what the company calls *virtual router architecture* composed of up to 80 routing tables. Standard routers have one routing table. Ennovate states that multiple routing tables gives their equipment the flexibility and capacity to offer many more IP addresses to large customers who may want to use carriers for VPN service. Some VPNs require that customers change their computer

addresses because of limitations in the router-based address tables. VPNs (virtual private networks) have most of the functionality of private networks. However, the network provider manages the network for the customer.

Security is also an issue. Ennovate feels that large customers’ traffic will be more secure if their computer addresses are in tables separate from other customers. Moreover, the Ennovate router provides carriers with the capacity of multiple devices in one “box.” It obviates the necessity of carriers having to support multiple routers.

APPENDIX

Compression Standard	Description
MNP 5	Microcom Network Protocol compression protocol developed by Microcom for modems. Provides 2:1 compression.
V.42bis	Data compression protocol for modems. Provides 4:1 compression.
H.320	A family of standards for video adopted by the ITU (International Telecommunications Union). Quality is not as high as proprietary video compression algorithms. Most video codecs employ both proprietary and standard compression algorithms. The proprietary compression is used to transmit to another “like” video unit and the standard algorithm is used when conferencing between differing brands.
H.323	A family of standards for video adopted by the ITU (International Telecommunications Union) for sending video over packet networks. Microsoft Corporation and Intel Corporation adopted the standard in 1996 for sending voice over packet networks. It is installed on Windows® based personal computers and used to packetize and compress voice when callers with PCs make calls from their computers over the Internet. See Chapter 9.
MPEG3	Moving Picture Experts Group 3 is Layer 3 of MPEG1. It is a compression standard for streaming audio. MPEG3 is the compression algorithm used to download audio files from the Internet. For example, some Internet e-commerce sites allow people with compression software to download samples of music so they can decide if they wish to purchase a particular CD. In addition, people with multi-media computers are playing CDs on their computers or on CD burners and distributing copies to friends without paying royalties.
MPEG2	A Moving Picture Experts Group standard approved in 1993 for coding and decoding video images. MPEG2 uses past images to predict future images and color and transmits only the changed image. For example, the first in a series of frames is sent in a compressed form. The ensuing frames send only the changes. A frame is a group of bits representing a portion of a picture, text or audio section.

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a given area, to make the most economical use of the radio spectrum. No matter how the radio **works**, be it **PCS** or conventional cellular, no matter the enabling transmission ...

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were published. Pre-dating American **PCS**, the United Kingdom asked for and got a GSM plan for higher frequencies. The Digital Cellular System or DCS1800 **works** at 1.8 ...

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either TDMA or CDMA, two different transmission technologies. Usually it is either IS-136, a TDMA system, or IS-95, a CDMA based system. Analog cellular might use ...

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and 1800 MHz in many parts of Europe and in England. **Works** at 1900 MHz in some parts of the United States. TDMA based. See below. **PCS** Personal Communications Service. ...

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works, let's look at eight frequencies in a single cell of a single carrier. Assume for the moment that this is one of 21 cells in either an AMPS or or IS-136 system. ...

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VI. Transmission and multiplexing

Introduction

Transmission in telephony means sending information on electricity or light from one point to another. Voice or data makes up the transmission. We call the device or matter that the information travels on, be it wires, cable, or radio waves, the transmission media.

FDM, TDMA, and CDMA are different transmission technologies. Wireless folks call them transport mechanisms or access technologies. Whatever. They make up part of the overall operating system a cellular carrier uses. No transmission scheme stands by itself, that is, these techniques are not by themselves operating systems. They are part of one. When someone asks, "Is IS-136 TDMA?" they usually mean, or should mean, "Is IS-136 TDMA based?" Let's make this more concrete.

American PCS operating systems may use either TDMA or CDMA, two different transmission technologies. Usually it is either IS-136, a TDMA system, or IS-95, a CDMA based system. Analog cellular might use conventional frequency multiplexing division. GSM only works in TDMA.

Wireless systems use many ways to transmit information. Here are some:

1. Frequency division multiplex or FDM, used in analog cellular; where calls are separated by frequency
2. Time division multiple access or TDMA, used in digital cellular and PCS; where calls are separated by time
3. Code division multiple access or CDMA, used mostly for PCS; where calls are separated by code

2. Frequency Division Multiplexing

Analog cellular use frequency division multiplexing or FDM. It's much simpler than its name suggests. [As we've seen](#), a carrier's assigned radio spectrum is divided into specific frequencies, each separated by space. Like AM radio, which

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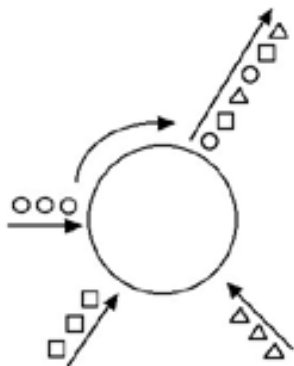
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Appendix

[Wireless' systems chart](#)

[Cellular and PCS frequencies chart](#)



Multiplexing combines several different calls into one coherent stream.

is divided into 10 KHz chunks. Radio station 810, 820, 830, and so on. That's all FDM is. Think of FDM as a single train running on a single track, pulling just one freight car. But what if you've run out of frequencies to handle your customers? What if you need more capacity? You can either separate your existing frequencies by narrower amounts or you can separate your calls over time.

Motorola's Narrowband Advanced Mobile Phone system or NAMPS, used precise frequency control to divide the 30 KHz AMPS channel into three subchannels. Each call takes up just 10KHz. But NAMPS had the same fading problems as normal AMPS, lacked the error correction that digital systems provided and it wasn't sophisticated enough to handle encryption or advanced services. To increase capacity most cellular carriers moved instead to a digital solution, one separating conversations by time or by code.

[Look to my [cellular basics article](#) for more information on the now defunct NAMPS.]

3. Time Division Multiple Access

In TDMA first digitizes calls, then combines those conversations into a unified digital stream on a single radio channel. Time division multiple access or TDMA divides each cellular channel into three time slots. In conventional cellular or AMPS a single call takes up 10KHz. In TDMA based D-AMPS or digital AMPS, three calls get put on that single frequency, tripling a carrier's system's capacity. GSM, D-AMPS, and D-AMPS 1900 (IS-136), and Motorola's iDEN all use or can use TDMA. This scheme assigns a specific time slot, a regular space in a digital stream, for each call's use during a conversation.

Think of a not so drunken cocktail party, with each person speaking in turn. Everyone gets to speak over time. Or think of a train pulling three freight cars. In a TDMA analogy, each caller puts their supplies or payload, their part of the conversation, on every third boxcar in a long train. No need for three separate frequencies like in FDM. With TDMA a single radio channel is not monopolized, rather, it efficiently carries three calls at the same time.

An anonymous writer summed TDMA like this, "Effectively, the IS-54 and IS-136 implementations of TDMA immediately tripled the capacity of cellular frequencies by dividing a 30-kHz channel into three time slots, enabling three different users to occupy it at the same time. Currently, systems are in place that allow six times capacity. In the future, with the utilization of hierarchical cells, intelligent antennas, and adaptive channel allocation, the capacity should approach 40 times analog capacity." [Webproforum](#) 40 times analog capacity! That's quite a hope. Almost as hopeful at the old, unrealized promises that CDMA would increase capacity 20 times.

4. Code division multiple access

CDMA is another transmission technology. Rather than separating frequencies by space as in FDM, or by time as in TDMA, CDMA separates calls by code. Every bit of every conversation gets tagged with a specific code. The system receives a call, seeming at first like so much radio hash, and reassembles the conversation from the coded bits. Like at a cocktail party with most people speaking English but two people speaking French. The French speakers can easily understand each other above the din of the English. That's because they are speaking in a different



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language or code. To further punish you with the railroad analogy, think of shipping companies filling every boxcar with packages seemingly at random. Their order doesn't really matter since they each have a unique label on them, like a shipping number, and thus can be sorted out accordingly at the other end.

CDMA's greatest benefit is that it can use all cellular frequencies in every cell. We saw how TDMA and FDM [carefully assigns channels to each cell](#) in advance to prevent interference. But CDMA codes are so specific that interfering radio signals are treated like noise and disregarded. So you can increase capacity, theoretically, by making all frequencies available at all times. We'll see why that promised capacity doesn't quite work out in practice later. For now, let's look at the operating systems these transmission technologies are placed in.

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wires, seeking a pair that were free . When they were found, Lars Magnus would crank the dynamo handle of the telephone, which produced a signal to an operator ...

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XII. Channels

Now that we've looked at frames and time slots, let's look more closely at channels. They have many definitions. Borrowing heavily from the good folks at Webopedia, a channel is a "communications path between two computers or devices." Most commonly a channel describes a pair of radio frequencies, one to receive on and one to transmit. They link the mobile to the nearest base station. 879.360 Mhz might be a transmit frequency and 834.360Mhz might be the receive frequency. Those paired radio frequencies make up a channel. Find out more by [skipping ahead](#).

In a digital discussion, however, a channel is also a communications path within a data stream. A specified place in all those 1s and 0s going back and forth between the mobile and the computerized base station transceiver. In IS-54, now IS-136, voice traffic is digitized and put within the digital traffic channel as you see below.

Different data channels in a bit stream run beyond the base station to a mobile telephone switch and out to the greater telephone network at large. All conveying voice, signaling, and administrative information. And if you talk to another digital phone user on your mobile then the entire conversation has gone digital from one end of the telephone system to the other. Let's look again at the D-AMPS digital traffic channel. It carries data, voice, and some signaling:

The Digital Traffic Channel in Digital-AMPS)

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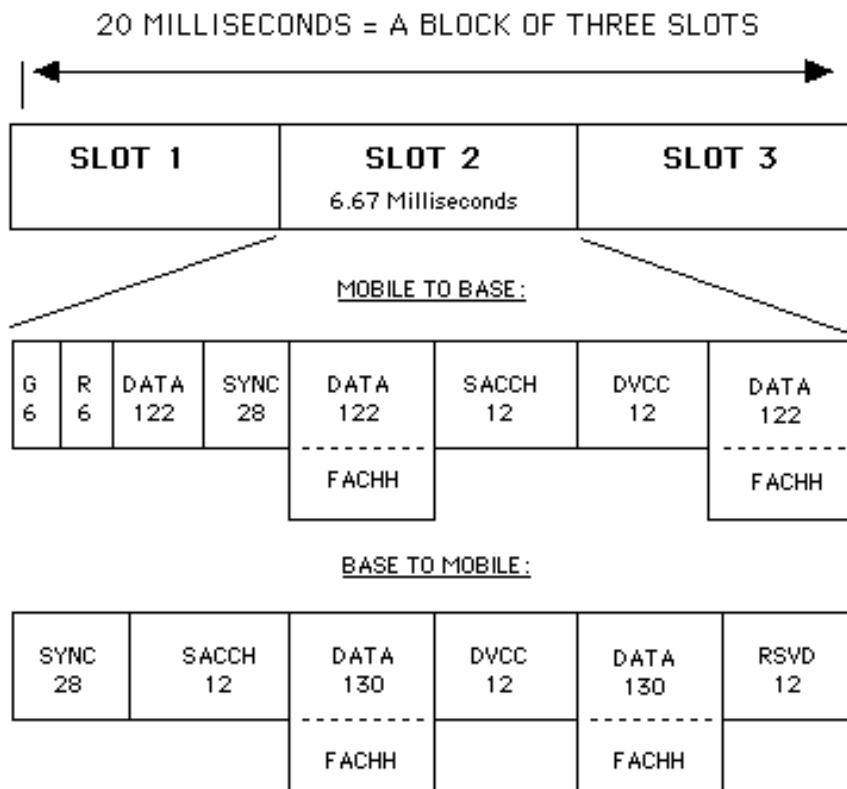
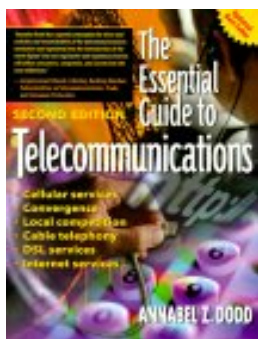
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A conversation's data bits makes up the **DATA** field. Six slots make up a [complete IS-54 frame](#). DATA in slots 1 and 4, 2 and 5, and 3 and 6 make up a voice circuit. **DVCC** stands for digital verification color code, arcane terminology for a unique 8-bit code value assigned to each cell. The DVCC acts like a digital marker, similar to the supervisory audio tone in AMPS, keeping a mobile on frequency.

G means guard time, the period between each time slot. As you might guess, **RSVD** stands for reserved. SYNC represents synchronization, a critical TDMA data field. Each slot in every frame must be synchronized against all others and a master clock for everything to work.

(1) How the Digital Traffic Channel Works

Let's see how these strange terms and abbreviations come together by describing handoffs -- what happens when you go from one cell to another. Again, this is an AMPS discussion. If you want call processing in GSM you should download [Levine's GSM/PCS .pdf file](#). First things first. As we'll see in call processing, the mobile idles on the analog control channel or ACC waiting for a call. That's a radio channel, usually the first in a cell's set of frequencies.

Once a call comes in the mobile switches to a different pair of frequencies; a voice radio channel which the system carrier has made analog or digital. This pair carries the call. If an IS-54 signal is detected it gets assigned a digital traffic channel if one is available. The mobile stays there for the call, returning to the ACC only after the conversation is done. The fast associated channel or FACCH performs handoffs during the call, with no need for the mobile to go back to the control channel. As shown above the fast associated channel is embedded within the digital traffic channel. The DTC is in turn carried on a radio channel. Got it?

The slow associated control channel or SACCH does not perform handoffs but conveys things like signal strength information to the base station. The SACCH runs together with the slot's voice traffic. It's called an associated channel since it

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is "associated" with the slot that carries the voice. In other words, signaling and voice traffic smoothly together.

The fast associated control channel or FACCH, on the other hand, runs in a blank and burst mode. It transmits during handovers or when the slow associated channel can't send information quickly enough.. Like when entering a tunnel or possibly when a large truck gets in front of you. At that point the data link might be broken so the FACCH acts quickly. As an engineer puts it, "The FACCH overrides the voice payload, degrading speech quality to convey control information." This keeps Mr. Mobile linked to the base station.

All of this goes on while retaining a backward compatibility with analog phone service or AMPS. Don't have digital service in your area? No problem. Your IS-136 phone will still work, just in analog mode and without the fancy features. Speaking of features, IS-136 is now the standard TDMA cellular technology. It adds a digital control channel to the bit stream., enabling features that IS-54 doesn't have, and presenting true competition for Personal Communication Services. So let's keep talking about channels.

SACCH



Life in the slow lane . . .

The slow associated control channel.
A sub channel of the Digital Traffic Channel. Puts messages in the same slot containing error correction and digitized voice.

FACCH



Number 5 and barely alive . . .

The fast associated control channel.
Another sub-channel of the DTC.
Sends messages in a hurry, if needed, using a blank and burst routine. Like when handoffs occur. Voice traffic in a slot is "blanked out" while a "burst" of data gets sent through.

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XIII The Digital Control Channel (DCCH) in IS-136

We just looked at the digital traffic channel in IS-54, now IS-136. Now let's look at the digital control channel in IS-136, which, again, is the most prominent TDMA based cellular system in America. At least for now, with AT&T saying they will convert their networks to another TDMA technology, GSM, in the years ahead. The digital control channel is the most important feature of IS-136.

The DCCH handles only signaling but it is not the only thing handling signaling in IS-136. Follow me? The digital traffic channel in [IS-136](#), for example, uses sub-channels to signal things associated with it. Like messages needed to hand over an active call from one cell to the next. The digital control channel, on the other hand, uses signals for administrative work and providing services. Like sending cell system information to mobiles or relaying text messages.

The digital control channel builds on IS-54 practices, to some extent, but includes many new things. Among the possibilities:

- Caller ID
- E-mail
- Sleep mode
- Voicemail message waiting indicator
- Text paging (2-way short messaging)
- Normal paging
- Advanced fraud protection
- International mobile station identification

Blah, blah, blah, blah!

The DCCH also permits properly equipped IS-136 mobiles to act as an extended cordless phones in private systems, small wireless networks for in-building and on campus use. So how are all these new features achieved?



[Click here for wonderful information on IS-136. It's from a chapter in IS-136 TDMA Technology, Economics, and Services, by Harte, Smith, and Jacobs \(1.2mb, 62 pages in .pdf\)](#)

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Digital Wireless Basics:

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[Wireless History](#)

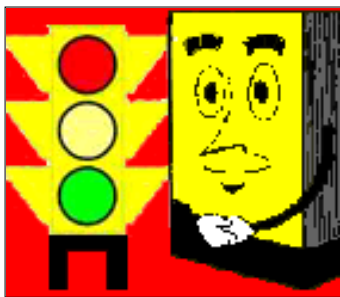
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Download R.C. Levine's comprehensive, somewhat easy to read work on cellular and PCS by [clicking here](#). It's a 368K download in .pdf format. 100 pages.



Your friend in learning . . .

The digital control channel or DCHH. You were expecting Syd Charisse?

Modulation

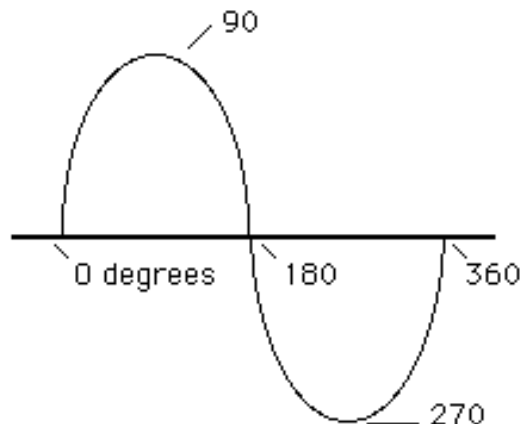
A different [modulation scheme](#) provides more capability. Modulation means putting information on a telephone wire or a radio wave. ([Here's more on modulation](#)) How that's done has a big impact. AMPS uses frequency shift keying or FSK to send control information. FSK sends data by slightly shifting frequencies. Frequency shift keying uses the existing carrier wave, say, 879.990 MHz. The data rides 8kHz above and below that frequency. It's just like the earliest modems. 0's and 1's. 0's go on one frequency and 1's go on another. They alternate back and forth in rapid succession. FSK gives you only two states to send information.

The DCCCH transmits data not with frequency shift keying, but rather with the awesomely titled differential quadrature phase shift keying or DQPSK. This scheme, used by most high speed modems, allows quicker data transfer than FSK. It gives you four states to send information.

Differential quadrature phase shift keying changes a sine wave's normal pattern. It shifts or alters a wave's natural fall to rest or 0 degrees. By forcing changes in a sine wave you can convey information. You don't stop or abbreviate the sine wave, you change its shape or angle of attack. Ever watch Star Trek? And seen someone who is supposed to be out of phase? They appear ghostly, with much of their body set off at an angle. That's out of phase.

With the digital control channel we're discussing a fully digital system. That means bits, 0's and 1's, on and off pulses of electrical energy. This staccato beat of electrical pulses gets sent through the atmosphere on radio waves. What might not be clear is how or why we need an analog like looking wave to send digital information. We form the wave to *carry* digital information. A carrier wave. The original signal, which are electrical pulses, doesn't have anything to do with the way we *shape* the carrier wave which actually transports the signal. Get the difference?

Remember the [digital basics page](#)? We saw how a normal landline digital phone call after sampling takes up 64,000 bits. And how better techniques for wireless exist, which reduce bandwidth to 7,500 bits. That's efficient. Similarly, [differential quadrature phase shift keying \(external link\)](#) is more efficient than FSK, with at least four possible states to carry information in every wave.





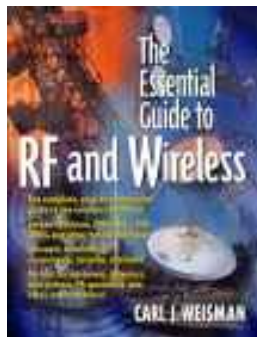
Alan J. Rogers' [excellent introduction to electromagnetic waves, frequencies, and radio transmission](#). Really well done. (19 pages, 164K in .pdf)

[Ordering information for the book above, Understanding Optical Fiber Communications by Alan Rogers \(external link to Amazon.com\)](#)

[Principles of Modern Communications Technology \(external link to Amazon\)](#) (Artech House) Professor A. Michael Noll



[This .pdf file is from Noll's book pictured above: it is a short, clear introduction to signals and will give you background to what you are reading here.](#)



[Click here for a selection from Weisman's RF & Wireless](#). Easy to read, affordable book on wireless basics. (12 pages, 72K in .pdf)

[Ordering information from Amazon.com \(external link\)](#)

A continuous wave produced to transmit analog or digital information. The many phases or angles of a sine permit different ways to modulate

To review, and to quote someone I now cannot find my reference for, three modulations schemes exist:

"Three methods of digital signal modulation. A digital signal, representing the binary digits 0 and 1 by a series of on and off amplitudes, is impressed onto an analog carrier wave of constant amplitude and frequency."

"1) In amplitude-shift keying (ASK), the modulated wave represents the series of bits by shifting abruptly between high and low amplitude."

"2) In frequency-shift keying (FSK), the bit stream is represented by shifts between two frequencies."

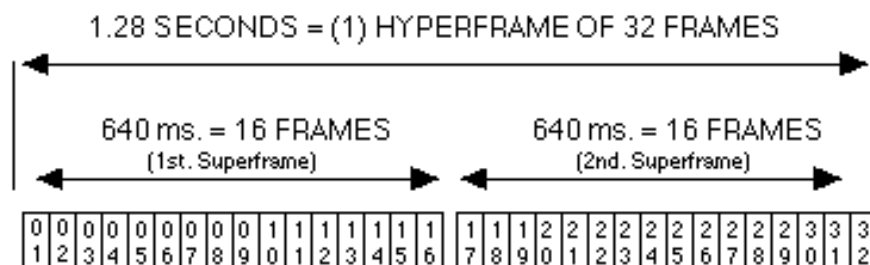
"3) In phase-shift keying (PSK), amplitude and frequency remain constant; the bit stream is represented by shifts in the phase of the modulated signal."

Don't be put off by the many abbreviations and strange concepts; PCS and GSM use related techniques so what you learn here will definitely help later. These modulation types work in either the 800 MHz cellular or the 1900 MHz PCS band. They are not frequency dependent. IS-136, though, is backward compatible with analog AMPS service. You can buy a dual mode phone, dual band phone, for example, that hunts for an IS-136 signal at 1900 Mhz, moves to 800 Mhz if not found, and then uses analog service as a last resort. So coverage is improved, even if you don't have all its features everywhere. It's what AT&T's "nationwide" Digital One Rate Service is based on.

Maintaining backward compatibility with existing services while adding new ones was a major task. But IS-136 lets TDMA cellular carriers offer advanced wireless services to compete against rival and incompatible PCS systems. GSM uses similarly elaborate data structures to provide its features.

We've looked at how frames, slots and channels make up what goes in a bit stream. In IS-136 frames are organized into hyperframes, an extended collection of frames, all working together to provide the extra information IS-136 needs. Don't worry about how complex this is. I'll cover the highlights and you can go further [elsewhere \(external link\)](#). The example below depicts a hyperframe and its time slots. Two so called superframes make it up.

IS-136 hyperframe and super frame structure



To repeat our [previous discussion](#), one slot happens every 6.67 seconds. Six slots make up a frame. A frame happens every 40 milliseconds.

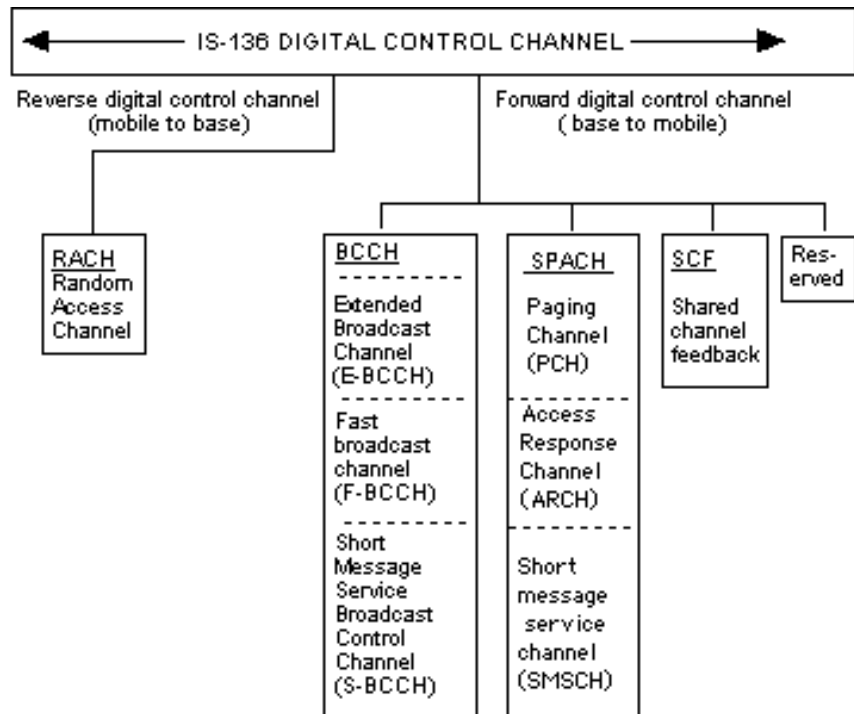
Complex, eh? You haven't seen anything yet. What makes up the individual digital control channel within a time slot is amazingly complex. Sub-channel upon sub-channel run together, like a layer cake with swirls. To describe this data structure engineers use an artificial construct, a framework of ideas called a layered model. What's known as the [OSI Model. \(external link.\)](#) While layers and how they work are beyond the scope of this article, we can first look at what these sub-channels do. And then in the call processing article we'll see how they work. The diagram below is based on one from a PCS article at the Web Proforum, the best place for wireless writing on the web: <http://www.iec.org/online/tutorials/> [\(external link\)](#)



[Click here for wonderful information on IS-136. It's from a chapter in IS-136 TDMA Technology, Economics, and Services, by Harte, Smith, and Jacobs \(1.2mb, 62 pages in .pdf\)](#)

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IS-136 Digital Control Channel



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Thursday, July 19, 2001

A major change in the United States cellular radio landscape began this week in Seattle, Washington. AT&T began a transition from the technology they invented, IS-136, to GSM, a technique originally European that has now gone global.

Both IS-136 and GSM are digital or second generation cellular systems. Both are TDMA based. But AT&T has gone beyond second generation to 2.5G, since their

newest offering includes GPRS or Global Packet Radio Service. Only for Seattle business customers right now, GPRS is an advanced [packet switched data network](#) that promises more services and higher data transfer rates than the original Cellular Data Packet Data or CDPD technology common across America.

The official name then for AT&T's new service is GSM/GPRS. In a confusing press release short on facts,

http://www.attws.com/press/releases/2001_07/071701.html, AT&T left many questions unanswered. I want to know how the GSM/GPRS system will co-exist with the existing IS-136/CDPD service which AT&T will continue to support.

One good white paper on GPRS is here:

http://www.cisco.com/warp/public/cc/so/neso/gprs/gprs_wp.htm

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[3rd-Generation Cell Phones Tested](#)

[NTT's Press release](#)

[My concerns about 3G and 4G](#)

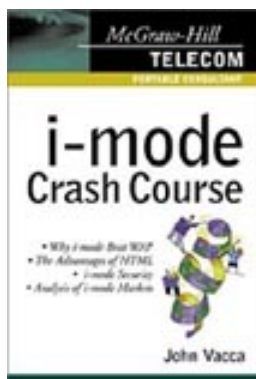


I-Mode is an information and entertainment service enabled by DoCoMo's

wireless technology, administration, and marketing. The 'I' stands for information, not the internet. That information or content comes from independently developed sites approved and monitored by DoCoMo. I-Mode exists as a premium or add on service to a customer's regular cellular bill. I-mode's expensive mobiles are a phone and data terminal in one. [Click here for a great FAQ all about it.\(external link\)](#) Voice traffic gets handled by DoCoMo's conventional cellular radio channels, while a packet switched network overlaid on that system handles the data work. Over 25 million Japanese have signed up for i-Mode, one fifth the population.

As I said, the I-mode network delivers information from sites approved by [NTT DoCoMo \(external link\)](#). Some say it is more like a corporate intranet run by DoCoMo, rather than the web, although you can, in theory, connect to any web site. To work fully, a site needs to be written in a stripped down HTML code required by the I-Mode terminals. So large companies like Disney have an I-mode compatible site; a normal web site won't display or operate properly on an I-mode phone. I think this HTML 'lite' approach gives it an advantage over the off-beat WML or wireless markup language WAP uses. Site development is quick and easy compared to making WAP sites. Yes, i-mode is slow at 9600 bps but unlike WAP, I-mode is [packet switched \(internal link\)](#) and awaits only higher wireless data rates to deliver more advanced, multi-media content.

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[by John Vacca, McGraw Hill](#)
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(external link to Amazon.com)

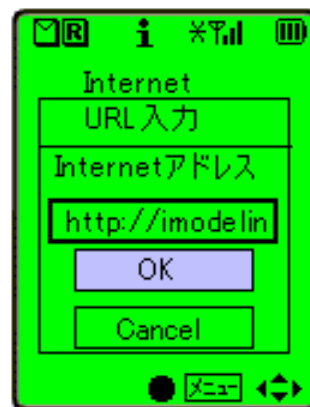
From the cover: Why i-Mode
Beat Wap, The Advantages of
HTML, i-Mode Security, Analysis
of i-Mode Markets. Vacca writes
extensively on all things
communications.

In the September 2001, [Wired \(external link\)](#), Frank Rose wrote a great column on i-Mode entitled "Rocket Monster." He explained how the service works. Corporate site developers create free or subscription content for DoCoMo's i-Mode network. There are currently 47,000+ sites. Subscribers check weather, sports, horoscopes, play games, and so on. Customers pay for each packet transmitted, so even free site usage means income for DoCoMo. About one fourth cent for each packet.

To make sure that traffic continues DoCoMo oversees all i-mode sites to guarantee a uniform look and feel, and to guard against customer disappointment. These sites get policed more than an AOL chat room. Got a subscription site? DoCoMo does not allow any subscriptions over 300 yen a month, roughly \$2.50 American. They don't want high prices to keep people from signing up for those sites. DoCoMo handles a site's billing, charging a nine percent fee. DoCoMo also promotes and advertises for the network. The key is traffic, selling packets, keeping people on-line. Japanese cellular bills now average \$80 a month.

So what do we have? i-Mode really isn't technology by itself, it is wireless infrastructure but it is management and marketing as well; it is an expertly thought out business plan for the Japanese. Will i-Mode make it in America? That's hard to say because we don't know what it will look like, how it will be offered, or what will be charged for it. AT&T Wireless has the rights to deploy this service in America, in whatever form it takes. AOL is also involved. But since neither company knows how to charge cheaply for any service I think i-Mode may be doomed from the beginning.

If these companies can hold prices down then it will be interesting to see whether Americans accept a finite number of sites and services. They have before, of course, when years ago AOL and CompuServe and Plodigy were not connected to the internet, making them their own electronic islands. People back then enjoyed each of those service providers. I think, though, that Americans always want more and anything less than the full internet, especially at the prices that will certainly be charged for i-Mode, will not make many people happy. I think the more likely possibility is that AOL will use i-Mode as a basis for a wireless AOL. That might make sense.



Screen display

[July 2, 2001: Current article on I-Mode in Japan is here \(external link to unstrung.com\)](#)

Who needs a video phone?

No sooner [did I question the merits of a wireless video phone \(internal link\)](#) than NTT announced 1200 of the devices would be released [for a public trial \(internal link\)](#). Similar to that pictured below, the units will allow people to see each others' faces' on the phone screens. I can't imagine data rates faster than 64Kbps, and, along with delays because of network congestion, a jittery, Max Headroom effect should be the best you can hope for. I'm still wondering about the appeal and whether the quality will be good enough to please people. It may be that people will enjoy the wireless video phone for the same reason people put up with early telephones, that is, because it is a miracle that they work at all.

An August 15, 2001 report on the high speed rollout was discouraging, with many problems inhibiting use:

<http://www.japantimes.co.jp/cgi-bin/getarticle.pl5?nb20010817a1.htm> (external link)

Perhaps due to these problems and high cost of service [Asia Business Tech \(external link\)](#) reported on October 15, 2001 that only 5,700 people signed up for the new high speed access scheme after the first three days. This rate that should have been muc higher after so many months of marketing effort. Of those people "2,300 users chose the 'P2101V,' a highly efficient type that enables use of TV telephones."

The I-Mode video handsets use Toshiba's new "video chip" , permitting 15 frames per second. That's compared to typical video which operates at 25 fps. You can [read about it in Toshiba's detailed press release archived here. \(internal link\)](#) Or check out what [Samsung is doing as a competitor \(internal link\)](#).



The photo on the above left is probably a [Sanyo SCP 5000 \(external link\)](#), an IS-95 (CDMA) phone, capable of downloading still pictures but possessing no built in camera. In other words, not a true video phone. But you get the idea . . .

3rd-Generation Cell Phones Tested -- Original Press release

May 31, 2001

by YURI KAGEYAMA AP Business Writer (Copyright 2001 the Associated Press)

TOKYO (AP) -- The world's first third-generation wireless phone service began in Japan on Wednesday, but only as a limited rollout of 3,300 handsets in the Tokyo area.

Eager Japanese gadget fans -- chosen from 147,000 applicants -- lined up for models at an office of the nation's top mobile carrier, NTT DoCoMo. It didn't seem to matter that the most glamorous of the new phones, the video-phone, had been delayed for up to a month for software glitches.

The only models available were an upgraded, speedier version of NTT DoCoMo's current Net-linking i-mode phones and a computer-card model for data transmission.

"My first impression is it's great," said Shintaro Yanagisawa, 24, a marketing company employee, who got an i-mode upgrade. "It's so fast."

The third-generation cell phones -- which promise to relay video and eventually allow music downloads -- zip data up to 40 times faster than current mobile phones.

NTT DoCoMo is hoping 3G phones will become the portable wireless computers of the future for cybersurfing, corporate data transmission and electronic commerce.

The company had initially promised full commercial 3G service for the Tokyo area for late May but delayed that to October because of software bugs.

NTT DoCoMo already received government approval for the 3G phones' voice capabilities, but the company needs to submit more test results to show data and video transmission also works properly before Oct. 1, said Mitsuhiro Shiozaki, a government official overseeing telecommunications.

"It's clear NTT DoCoMo is falling behind schedule. I don't know whether they can have everything ready before Oct. 1," he said.

What began Wednesday is a test-run to collect feedback on how the phones work, which will allow the company to sift out the problems.

The handsets are free. Users pay transmission fees of between 100 yen (80 cents) and 150 yen (\$1.25) for three minutes -- nearly double the charge for i-mode phones.

Yanagisawa and others were amply warned about possible glitches. When the cell phone screen freezes, NTT DoCoMo officials said, turn off the phone and start again.

NTT DoCoMo plans to expand 3G to the rest of Japan by 2002 and is promising to offer 3G in Europe and the United States as well.

Twelve hundred video-phones -- which allow callers to see each other's faces on the phone screens -- will be gradually handed out over the next month, NTT DoCoMo said.

NTT DoCoMo officials have acknowledged they don't expect 3G to take off for

another couple of years, forecasting just 150,000 people will sign on to the service in the first year.

Revenue from i-mode is still NTT DoCoMo's money maker. For the fiscal year ending in March, NTT DoCoMo earned 365 billion yen (\$3 billion), up 45 percent from a year ago on sales surging 26 percent at 4.7 trillion yen (\$39 billion), largely on the success of i-mode.

I-mode has attracted 23 million Japanese, who use their cell phones to exchange e-mail, read news or restaurant guides and play electronic games.

AP-NY-05-30-01 1049EDT<

05/30/2001

NTT's Press release

TOKYO, JAPAN, May 25, 2001 --- NTT DoCoMo, Inc. announced today that from May 30, 2001 the company will begin distributing 4,500 mobile phones equipped for third-generation (3G) services to monitors participating in the introductory phase of the company's "FOMA" 3G service rollout. Applicants selected to serve as monitors will be notified by May 29, 2001.

NTT DoCoMo had initially planned to distribute 4,000 mobile phones, but later decided to raise the number to 4,500 after it received 147,000 applications. The 4,500 total includes 2,000 mobile phones for individual monitors and 2,500 mobile phones for about 700 corporate monitors (companies).

The breakdown includes 1,400 standard phones, an upgraded version of the current i-mode cellular phone featuring sound quality similar to that of a fixed-line phone, 1,200 "visual" phones equipped with a video screen, and 1,900 "data-card" phones for dedicated mobile high-speed data transmission.

Individual monitors will be provided with 600 standard phones, 700 "visual" phones and 700 "data-card" phones. Corporate monitors will use a total of 800 standard phones, 500 "visual" phones and 1,200 "data-card" phones.

Although distribution of the mobile phones will begin from May 30, 2001, the "visual" model will be delivered no later than the end of June 2001. The model required a debugging of its embedded software (completed) and is now undergoing final re-testing.

The I-Mode video handsets will use Toshiba's new "video chip" , permitting 15 frames per second. You can [read about it in Toshiba's detailed press release archived here.](#)

My concerns about 3G and 4G

Although I'm normally a big proponent of future technology, I am worried that 3G and 4G will provide us with expensive, balky services we may not want. Are we working on a wireless version of the video telephone? That landline telephone project, the most spectacular failure of the Bell System, cost them and their rate payers hundreds of millions of dollars over three decades. It produced a technology available only in a few cities, appealed to just a few people, and could

be afforded by fewer still. A wireless video phone is the logical counterpart to the original video phone and is what 3G and 4G will enable. But will it work? For whom? At what cost?

We're still having problems keeping wireless calls connected and that will remain a problem with future services. Data intensive technology like video will only increase the difficulty. People rarely wanted to see each other face to face while communicating with the video phone and we must assume that preference will remain the same today. The business video conferencing market might want it, as well as parents keeping track of their kids, or emergency services monitoring those it must rescue, aid, or kill. It will be expensive. I'm not sure how this will work out. Whatever happens, we will stumble and fumble our way to the future, one tenuous wireless link at a time. Hmm.

[Mark van der Hoek](#) offers these opinions:

"In general, overlay is slapping another network on top of your existing system. We did this with CDMA in 800 MHz. We cleared some of the analog spectrum, and used it for CDMA. That's almost certainly what AT&T will do. Since the channel bandwidths are incompatible, they'll clear out some TDMA channels and use that spectrum for GSM. They'll offer the new services on those channels, but customers will need to buy a new phone to make use of them. As they shift enough customers to the new service, they'll clear another band of TDMA and install another GSM channel(s). It's not fun, because you have to clear the spectrum (crowding your existing customers into what's left) before you can offer the new services."

"My view is the the "demand" for 3G services, especially data, is largely in the minds of the industry - the analysts and marketing boobs - rather than in the minds of the customers. Yes, there is some market for it now, and that will grow, but most of it is hype right now. Witness Metricom's fiasco. How is it a mobile data technology with no handoff?"

"I think something similar is going on with mobile data. Because the Internet is The Big Thing, people are simply assuming that it will translate to mobile. That's not necessarily true. How many ordinary people really want to run around with a laptop? "Oh, but you won't need a laptop! You'll surf the 'Net with your phone!" Bull. Even if you can get the needed bandwidth, even if you can get the needed processing power, you still have that tiny screen. Until there are some major breakthroughs in that area, mobile Internet is going to be a niche."

"And, it is a fundamental change in the way people use phones. Phones are for talking to other people. That's the mindset. It can change, but not overnight. And talking can be done while walking the mall or driving the freeway. (NY notwithstanding.) Talking can go with the flow of what you are already doing - that's why cellular took off. But surfing the net requires almost exclusive attention - it does not lend itself to multitasking very well. Surfing requires you to Stop What You Are Doing And Do Something Else. Analysts are not recognizing that. It's not just another use of the phone. It's a fundamentally different thing. In terms of mindset, it's not a phone at all."

"Will it come? Probably. There IS a market for more than 5 computers on the face of the earth. ;-) But there's not a market for 10 billion right now, and there's not a

big market for mobile data. Japanese techies who buy every gadget that comes along may be the future of the western world, but it's not the present. . ."

[^^top of page^^](#)

[I-Mode Enabling Technology: The Video Chip](#)

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 were less restrained. In 1954, recently retired Chief of Engineering for AT&T, Dr. Harold Osborne, predicted, "Let us say that in the ultimate, whenever a baby is ...
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 revolution began only after low cost microprocessors and digital switching became available. The Bell System, producers of the finest landline telephone system in ...
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- 26: [TelecomWriting.com: Telephone History by Tom Farley, Page 1, Pre-history to 1830](#) 85% 
 Graham Bell invented the telephone. Thomas Watson fashioned the device itself; a crude thing made of a wooden stand, a funnel, a cup of acid, and some copper wire. ...
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site equipment provides each sector with its own set of channels. In this example, just below , the cell site transmits and receives on three different sets of channels, ...

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28: [TelecomWriting.com: Private Line Newsletter No. 4](#)

300 ms has nothing to do with why you don't hear the SAT. In fact you can hear tones/signals of less than 300 ms. Perhaps you should say 'You don't hear it since ...

<http://www.privateline.com/Newsletters/PLNews4b.html>

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one after another. Since calls are separated by time TDMA can put several calls on one channel. In code division multiple access we separate calls by code, putting ...

<http://www.privateline.com/Cellbasics/Cellbasics09.html>

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30: [TelecomWriting.com: Digital Wireless Basics: Radio Principles, Cellular defined](#)

York city area. To cover the 63,000-square-mile service area, Ericsson says Omnipoint installed over 500 cell sites, with their attendant base stations and antennas, ...

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span the country, enabling a nationwide telephone system, fulfilling Alexander Graham Bell's 1878 vision. Recalling those years in an important interview with the ...

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32: [TelecomWriting.com: Cellular Telephone Basics by Tom Farley](#)84% 

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824.04 MHz to 893. 97 MHz. In particular, cell phones or mobiles use the frequencies from 824.04 MHz to 848.97 and the base stations operate on 869.04 MHz to 893.97 ...

<http://www.privateline.com/Cellbasics/Cellbasics03.html>

33: [TelecomWriting.com: Digital Wireless Basics: Mobile Phone History Page Seven](#)84% 

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in detail how it might be implemented." [SRI2] Although the two papers cited above were chiefly limited to Bell System employees, it seems they were substantially ...

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is used mainly as a CODEC, or video and audio compressor. In landline service the videophone could communicate with a unit like it on the end of a normal phone line. ...

<http://www.privateline.com/war/videophone.html>

35: [TelecomWriting.com: Telephone History by Tom Farley, Page Two: 1830 to 1876](#)84% 

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(external link) Joseph Henry's "telegraph" From the December, 1963 American Heritage magazine, "a sketch of Henry's primitive telegraph, a dozen years before Morse, ...

<http://www.privateline.com/TelephoneHistory/History1A.htm>

36: [TelecomWriting.com: Digital Wireless Basics: Mobile Phone History Page Four](#)84% 

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Marconi did indeed establish the first successful and practical radio system. Starting in 1894 with his first electrical experiments, and continuing until 1901 when ...

<http://www.privateline.com/PCS/history4.htm>

37: [TelecomWriting.com: Digital Wireless Basics: Mobile Phone History](#)
[Page Eight](#)

granted on September 16,1975. In a 1999 interview with Dr. Cooper, Marc Ferranti, writing for the IDG News Service, describes the competitiveness of that era, "While ...

<http://www.privateline.com/PCS/history8.htm>

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38: [TelecomWriting.com: Cellular Telephone Basics: Cell Phones and](#)
[airliners](#)

cellular network can handle all the calls made from airliners, placing calls haphazardly in one system, then the next, well fine. But I doubt they will approve. While ...

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39: [TelecomWriting.com: Daily Notes](#)

in the economy and what that means to information technology. My comments are fairly obvious but you should read the article for what other respondents think. Here's ...

<http://www.privateline.com/dailynotes/>

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40: [TelecomWriting.com: Text of private line magazine. Volume 2, Number](#)
[2A \(Issue 5\)](#)

list of private line. This is an update to the list that first appeared in issue Number 5. I think it is the best magazine list on the Internet. I hope to update ...

<http://www.privateline.com/issues/p.l.No.5A.html>

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type and frequency have the best reception - I'm not talking about coverage, but a more local reception issue - which can be quite variable from between two locations ...

<http://www.privateline.com/Newsletters/PLNews5.htm>

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Most competitors disappeared as soon as the Bell Company filed suit against them for patent infringement, but many remained. They either disagreed with Bell's right ...

<http://www.privateline.com/...oneHistory2A/Telehistory2A.htm>

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British Columbia V6B 4A1 Or contact VOTW at beeman@mindlink.bc.ca C. GTE's most excellent demarcation points I wrote a little about the demarcation point in _private ...

<http://www.privateline.com/issues/p.l.No11.html>

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Depth: 1

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most information. One translator mechanism might hold 1200 cards in a single stack. A particular card was selected by shooting a light beam through the stack and ...

<http://www.privateline.com/issues/p.l.No.7.html>

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carrier shall submit to the Attorney General a statement identifying any of its systems or services that do not have the capacity to simultaneously the number of ...

<http://www.privateline.com/issues/p.l.No.6A.html>

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Telephone International, Inc. 27. Thanks for the sub. I don't understand this publication myself. It's not a hacker zine or a corporate telecom magazine. Even my ...

<http://www.privateline.com/issues/p.l.No.6.html>

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