

# Fundamentals of Telecommunications

## Overview

Sometimes, when attending a class, it is okay to miss the first half-hour. After all, we do know something about the subject, and that first half-hour is likely to carry little more than introductory information. The same holds true when picking up a textbook on a particular subject. Maybe the first chapter can be skipped; again, it contains introductory material that we already know.

But often this is not the case. We do not know as much as we thought we knew, and that first half-hour, or that first chapter, contains material that may well be prerequisite material. That is what this Web ProForum tutorial is all about. It provides the equivalent of that first half-hour or that first chapter and may well be valuable in understanding the other tutorials in this series. The tutorial will cover the fundamentals of telephony, from its inception in Alexander Graham Bell's laboratory to today's emerging technologies.

## Topics

1. History and Regulation of the Telephone Industry
  2. Network
  3. Switching Technology
  4. Transmission Media
  5. Transmission Technology
  6. Broadband Access and Service
  7. Wireless
- Self-Test  
Correct Answers  
Glossary

# 1. History and Regulation of the Telephone Industry

"Mr. Watson, come here, I want you." With these historic words Alexander Graham Bell called to his assistant Thomas Augustus Watson over the so-called "telephone," and an industry was born.

The place: 5 Exeter Place, Boston, Massachusetts

The time: evening, March 10, 1876

As with all inventions, the road had not been smooth. For years, Graham Bell (as he liked to be called) had been experimenting with a harmonic telegraph. It should be possible, he reasoned, to send six tones over the same wire at the same time and cause six reeds attached to the receiving end to be operated. Furthermore, if all worked well, varied combinations of these six pitches could reproduce human speech.

Simultaneously he was working on a scheme that utilized the varying resistance of a wire. A diaphragm, which would be vibrated by the human voice, was attached to a wire that was dipped into a mixture of acid and water. In theory, as the diaphragm moved downward, forcing more wire into the acid, the resistance of the wire would be decreased. As the diaphragm moved upward, the wire would be withdrawn from the conducting liquid, and its resistance would be increased. It was this device that was ultimately successful and that formed the basis for the telephone industry for many years.

A year later, on July 9, 1877, the Bell Telephone Company was formed, and Alexander Graham Bell became the company's electrician, at a salary of \$3,000, and Watson became superintendent in charge of research and manufacturing. Unfortunately for Bell, the basic patents were due to run out in 1893 and 1894. But by this time, Theodore Newton Vail had been brought in as general manager, and he immediately set about establishing an organization strong enough to survive without a monopoly. "What we wanted to do was get possession of the field in such a way that, patent or no patent, we could control it," Vail said. The first step was to obtain a captive manufacturing facility, and this was accomplished in 1881 with the purchase of Western Electric Company.

Vail also sent his salesmen into the field to set up telephone exchanges in virgin territory. Generally, local promoters were encouraged to organize a local telephone company and sell stock. Thus, by 1885 Vail had established a vertically integrated supply division, a network of companies licensed by the parent, and a strong research and development arm. The expiration of Bell's basic patents in 1893 and 1894 was the starting signal for open competition. Independent telephone operating companies sprang up throughout the country; by the turn of the century there were approximately 6,000 of them, and these 6,000 provided

service to some 600,000 subscribers. Through the years, mergers and acquisitions took their toll; at the present time there are approximately 1,300 local exchange carriers.

Unfortunately for the general public, all of these telephones were not interconnected. Therefore, it was necessary for a subscriber to have two or three instruments to communicate with the total population of the city. However, the great asset of AT&T, which became the official name of the company at the end of 1899, was the control of all the long-distance circuits and its steadfast refusal to interconnect any other company to it.

This would never do, and the Justice Department filed suit in 1912. The world was angry with AT&T, and an AT&T vice president—Nathan C. Kingsbury—realized it. He recognized that the best demonstration of AT&T not being in a monopoly position was to point to thousands of independents apparently operating in harmony. To this end, AT&T agreed to provide interconnection arrangements to all independents. This 1913 agreement was henceforth called the Kingsbury Commitment.

By 1934 telecommunications had become so important to the country that Congress passed a Communications Act and, simultaneously, created the Federal Communications Commission (FCC). The section of this Act that has turned out to be most important has to do with what we now call universal service. It said: "For the purpose of regulating interstate and foreign commerce in communication by wire and radio so as to make available, so far as possible, to all the people of the United States a rapid, efficient, nationwide, and worldwide wire and radio communication service with adequate facilities at reasonable charges."

As a result of this principle, a support structure has been established whereby certain groups of subscribers (e.g., long-distance users, business subscribers, subscribers in locations where telephone service can be provided with relative ease, etc.) will pay more than true costs, and other groups of subscribers (e.g., subscribers in rural and other high-cost locations) will pay less than true costs.

In 1949 the Justice Department again filed suit against AT&T, claiming that Western Electric charged inordinately high prices from their customers (i.e., the operating telephone companies owned by AT&T), thus making it possible for the operating telephone companies to charge their subscribers inappropriately high rates. The suit dragged on, and a consent decree was reached in 1956. AT&T won; Western Electric need not be divested from AT&T, the Bell System would engage only in telecommunications business, and nonexclusive licenses would be granted to any applicant on fair terms. This was the final judgment. The eventual breakup of the Bell System in 1984 was accomplished through a modification of this final judgment, hence the modification of final judgment (MFJ).

Although the Bell System appeared to be the winner in this 1956 suit, over the next two decades it would lose battles, one at a time. There was the Hush-A-Phone case in 1955; the Carterfone case in 1968; MCI's "above 890" case in 1959, and the MCI case dealing with a long-distance route from Chicago to St. Louis in 1969. In November, 1974, the Justice Department once again filed suit to break up the Bell System. The case trudged on until 1978, when Judge Harold Greene took over. He moved things quickly, and on January 4, 1982, a terse announcement was issued by the Justice Department and AT&T saying that negotiations had been reopened. Then, on January 8, 1982, the news broke; AT&T had agreed to break up its \$136.8 billion empire. It was agreed that AT&T would divest the local parts of the Bell operating telephone companies. It would keep its manufacturing facilities and its long-distance network. The agreement would take effect on January 1, 1984.

The 22 regional Bell operating companies (RBOCs) agreed to form 7 regional holding companies (Bell Atlantic, NYNEX, BellSouth, Ameritech, U S WEST, Pacific Telesis, and Southwestern Bell). The agreement also said that the Bell operating companies would not be allowed to manufacture nor would they be allowed to get in the long-distance business within their territories. AT&T would not be allowed to get in the local-exchange business nor to acquire the stock or assets of any RBOC.

That remained the state of affairs until the passage of the 1996 Telecommunications Act. This Act threw most of the rules established in 1984 out the window and left the implementation of the Act to the FCC. There have been problems ever since. What did the Congress mean by "promote competition?" Should AT&T be allowed to get in the local-exchange business? (Answer: yes.) Should the RBOCs be allowed to get in the long-distance business? (Answer: yes, but only after passing a 14-point checklist.) What did "expanded universal service" mean? Should the RBOCs be allowed to merge? (Answer: yes. Bell Atlantic has merged with NYNEX; Southwestern Bell [SBC] has merged with Pacific Telesis and is planning to merge with Ameritech. Bell Atlantic intends to merge with GTE. If all of these are ultimately approved, there will remain four RBOCs). To date, many questions remain, and there is no assurance that they will be answered in the foreseeable future.

## 2. Network

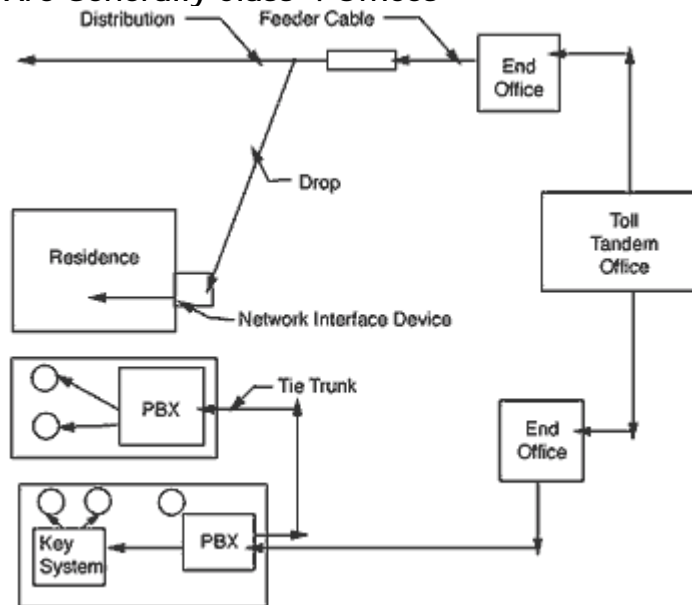
If there were only three or four telephones in a locale, it would make sense to connect each phone to all other phones and find a simple method of selecting the desired one. However, if there are three or four thousand phones in a locale, such a method is out of the question. Then it is appropriate to connect each phone to some centrally located office and perform switching there. This switching could be a simple manual operation using plugs and sockets or could be done with

electromechanical devices or with electronics. In any case, this central-office (CO) solution is the one that has been chosen by the telecommunications industry.

As we connect each of these thousands of telephones to the central office, we have what is a star configuration; all lines are particular to one and only one station, and all terminate on the nucleus of this star—the CO.

These connections are called the local exchange plant, and the telephone company handling this function is called the local exchange carrier (LEC). The connections themselves are often called the "local loop;" at other times we refer to them as "the last mile." In more technical terms, the section closest to the customer's premises is called the distribution plant and that section closest to the CO, the feeder plant (see *Figure 1*).

**Figure 1. Particular Names Are Applied to the Various Parts of the PSTN; End Offices Are Class-5 Offices; Toll Tandem Offices Are Generally Class-4 Offices**

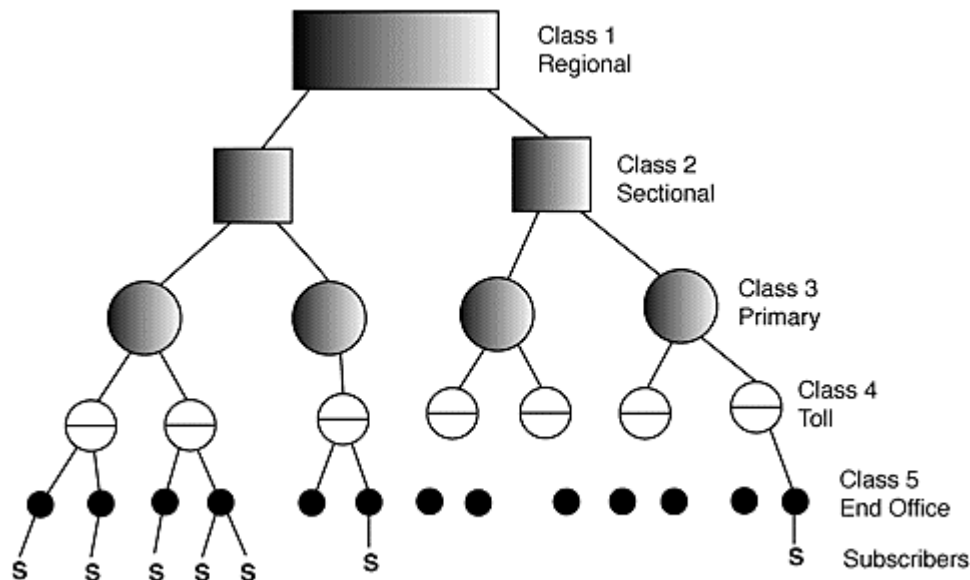


(Note: This is certainly a generalization, as will be much that follows. Although the feeder plant usually consists of one or more cables leading to some point of demarcation [a terminal box or an enclosure] after which the lines are spread out going in many smaller cables to the customer premises [the distribution plant], there are cases where there is no need for a point of demarcation. Then what do we call the plant? We will not struggle with such semantic difficulties here.)

But what if a particular telephone call is not originated and terminated within the particular CO's geographic coverage? How do we get to another city or another state or even another country?

The answer, of course, is to connect these COs to a higher-echelon CO (see *Figure 2*). We apply numbers to these levels of offices; the local office, also called the end office, is called a Class-5 office. The office to which it connects is called the Class-4 office. The top level, the Class-1 office, appears in only a few places in the country. Please note that the only office that has *people* as its subscribers is the Class-5 office. The other offices in this hierarchy have lower-level COs as their subscribers. Those lines connecting switching offices to switching offices, rather than to subscribers, are called trunks.

Figure 2. The Hierarchy of Switching Systems in its Most Basic Form Consists of Five Classes of Offices



This section of the telephone infrastructure—the section leading upward from the Class-5 offices—is handled not by the LECs but by the interexchange carriers (IXCs), the long-distance carriers. This entire structure has been titled the "hierarchy of switching systems." The total network is called the public switched telephone network (PSTN).

In days of old there was only one long-distance carrier—AT&T. Hence, any time a telephone number was dialed with an area code up-front, the LEC knew that it must be handed off to AT&T. But then came MCI, Sprint, and hundreds of other long-distance carriers. What was an LEC to do with a particular long-distance call? To whom should it be handed off? This was and is a technical challenge. In political terms, it was called "equal access," which means that a requesting long-distance carrier could require that the LEC examine the number and hand off the call to the proper long-distance carrier. This handoff was from the CO of the LEC to the point of presence (PoP) of the IXC. This PoP could be in a building adjacent to the telco's CO, or it could be in some convenient site in the suburbs where it could serve several of the telco's COs. The pure hierarchy of switching

systems was becoming somewhat corrupted; new hierarchies in the long-distance part of the network were being applied on top of the old one.

Although it is not pertinent to the topology of this network, it should be recognized that the interconnections between these various COs can be twisted copper-pair carrier systems utilizing copper pairs (e.g., T1), microwave, satellites, and certainly fiber.

However, this hierarchical network is not the only network in the telephone system of today. There are many others including the following:

- A local-area network (LAN) is a limited-distance network connecting a defined set of terminals. It could connect workstations in an office, offices in a building, or buildings on a campus.
- A wide-area network (WAN) links metropolitan or local networks, usually over common carrier facilities.
- The intelligent network is a concept that centralizes a significant amount of intelligence rather than installing this intelligence in individual COs. For instance, how does a particular CO know which long-distance carrier is to receive a particular call?
- The synchronous optical network (SONET) is a particular set of standards that allows the interworking of products from different vendors. It usually embodies a fiber-optic ring that will permit transmission in both directions.
- The Internet is really quite different from the network we have been describing. It is a packet network (rather than a circuit-switched network), but, as has been discussed, it is an overlay network.
- The common channel signaling network is especially important; it works closely with the PSTN. We also apply the term *out-of-band signaling*. In the original PSTN, signaling (e.g., call setup) and talking utilized the same common trunk from the originating switching system to the terminating switching system. This process seized the trunks in all of the switching systems involved. Hence, if the terminating end was busy, all of the trunks were set up unnecessarily. In the mid-1970s, the common channel signaling network was established; it utilizes the protocol called signaling system 7 (SS7). With this system, a talking path was not assigned until all signaling had been satisfactorily completed. This network, incidentally, was and is a packet network rather than a circuit-switched network.

The PSTN we have been describing utilizes a star configuration. However, this is not the only configuration being applied in today's telecommunications world. The cable-television (CATV) companies, for instance, use a tree-and-branch technology. In this case, the head end (equivalent to the CO) receives programming from satellites and sends all signals downstream, out on the trunk. At various points along the way, branches extend outward, toward various neighborhoods. These branches are split several more times before the coaxial cable (the media of choice in past CATV systems) reaches the customer's premises. Frequently the signals must be amplified along the way, and therefore power must be sent along with the TV signal. In any case, because the intent of the CATV system is broadcast—that is, send the signal to everyone—there is no need to send an individual and distinct wire to each and every subscriber, as was the case with the telephone system.

However, this methodology has proven to be disadvantageous to the CATV companies, because it is extremely difficult to send signals upstream. Of course, in a telephone system, signals (voices) must be sent in both directions. CATV companies are spending billions of dollars to upgrade their systems not only by utilizing fiber instead of the coax but by adding electronics to the many nodes that permit both upstream and downstream transmission.

### 3. Switching Technology

The PSTN we have been describing has a star configuration. Local loops (usually one per subscriber) terminate in a CO. This CO completes connections from one local loop to another local loop, or from one local loop to a trunk that terminates on some other CO. This CO has gone through a number of fundamental technological changes (see *Table 1*).

Table 1. Types of End-Office Switching and Their Evolution

| Switching System           | Operation         | Method of Switching | Type of Control               | Type of Network       |
|----------------------------|-------------------|---------------------|-------------------------------|-----------------------|
| 1878 manual operator       | manual            | space/analog        | human                         | plug/cord/jack        |
| 1892 step-by-step          | electromechanical | space/analog        | distributed stage-by-stage    | stepping switch train |
| 1918 cross-bar             | electromechanical | space/analog        | common control                | X-bar switch          |
| 1960 ESS—first generation  | semielectronic    | space/analog        | common control                | reed switch           |
| 1972 ESS—second generation | semielectronic    | space/analog        | stored program control        | reed switch           |
| 1976 ESS—third generation  | electronic        | time/digital        | stored program common control | pulse code modulation |



The manual system required, of course, constant attention from operators (see *Figure 3*). In the late 1800s, telephone calls were connected manually at the CO. When a call came in, an attendant would plug into a horizontal bar line. He then would yell to the operator who handled the customer being called, and that second operator would connect to the bar and finish setting up the call. When the call was completed, another operator would yell to all in the room that the line was clear again. The step-by-step system, which is still in operation in many parts of the country, utilized what is known as the Strowger switch. The intelligence in the system was located in relays mounted on each switch. The switch itself responded to the dial pulses of the rotary dial.

Figure 3. A Depiction of an Early CO



The crossbar system was still electromechanical in nature, but the intelligence of the system was separated from the actual switch. Thus, this common control could be used repeatedly to set up and tear down calls and never sit idle.

When electronics came along, the electromechanical control of the common control system was replaced with electronics, and the network, or matrix, was usually replaced with tiny glass-encapsulated reed switches. Hence, only a part of the switch was electronic. In the next generation, the stored program operation of a digital computer was applied to the switch, although the network remained a complex of reed switches. In the final generation, called a digital switch, the talking path was no longer an electrically continuous circuit; rather the speech being carried was digitized into a stream of "1s" and "0s." Notice that this final generation depicted a significant change from the previous generations in that there was no longer an electrical talking path through the switch. We were, in fact, operating in a digital (rather than analog) domain.

However, whether the system was analog or digital, one thing must be recognized: there was an actual talking path—a circuit—from the calling party to the called party. This talking path was established at the beginning of a call and held for the duration of a call. We call it circuit switching. This system is not actually efficient. When I am talking, you are listening, and the circuit is being used in only one direction—that is, 50 percent. When you are talking and I am listening, it is still 50 percent. When neither of us is talking, or when there is silence between words, the efficiency is 0 percent.

There is, however, a different kind of connection, and we see it today in a number of applications:

- credit-card verification
- automated teller machine
- SS7
- Internet and the World Wide Web

This system is called packet switching (as opposed to circuit switching). In a packet-switching system, the information being transmitted (be it data or digitized voice) is not sent in real time over a dedicated circuit; rather it is stored in a nearby computer until a sufficiently sized packet is on hand. Then a very smart computer seizes a channel heading in the general direction of the destination, and that packet of data is transmitted at very high speeds. Then the channel is released. So, except for some necessary supervisory information (destination, error checking codes, etc.) the channel is 100 percent efficient. When the distant station gets that message no more than a few milliseconds later, it responds with the necessary handshaking information—again, by accumulating a packet of data, seizing a channel, and bursting the information out over that channel. Again, 100 percent efficient.

As mentioned earlier, the packet networks in the world (actually overlay networks to the PSTN) are being used extensively for data; only recently are we seeing them being used for voice. As systems are perfected, this also will change.

## 4. Transmission Media

There are four types of media that can be used in transmitting information in the telecommunications world:

- copper wire
- coaxial cable (actually an adaptation of copper wire)

- fiber
- wireless

In days of old, copper wire was the only means of transmitting information. Technically known as unshielded twisted pair (UTP), this consisted of a large number of pairs of copper wire of varying size in a cable. The cable did not have a shield and therefore the signal—primarily the high-frequency part of the signal—was able to leak out. Also, the twisting on the copper pair was very casual, designed as much to identify which wires belonged to a pair as to handle transmission problems. However, this is the way it was done, and for voice communications it was quite satisfactory. Consequently, there are millions of miles of copper in the PSTN—miles that must be used.

Not only did the copper cable itself have limitations, but things were done to this cable to make it even more unsuitable for high-speed data transmission. These actions primarily took two forms:

- **loading**—Load coils were frequently added to loops longer than 18,000 feet. These load coils were essentially low-pass filters. That is, they passed without attenuation all voice frequencies but effectively blocked frequencies above the voiceband. This is disastrous for data communications, which depend on high frequencies to achieve the desired speed of transmission.
- **bridge taps**—A bridge tap is any unterminated portion of a loop not in the direct talking path. A bridge tap may be a used cable pair connected at an intermediate point or an extension beyond the customer. For example, a drop wire that provided a second line to a home is left in place even after the second set of customer premises equipment (CPE) is removed. Records of this were not always kept and assigning a particular copper pair to a high-speed data circuit is far from a sure thing. Bridge taps do nasty things to data transmission.

Coaxial cable consists of a single strand of copper running down the axis of the cable. This strand is separated from the outer shielding by an insulator made of foam or other dielectrics. A conductive shield covers the cable. Usually an outer insulating cover is applied to the overall cable—this has nothing to do with the carrying capacity of the cable. Because of the construction of the cable, obviously coaxial in nature, very high frequencies can be carried without leaking out. In fact, dozens of TV channels, each 6 MHz wide, can be carried on a single cable.

The fact that a coaxial cable—or coax—can support a tremendous bandwidth has not been lost on the CATV folk. A leader of the CATV industry said, some years ago, "We have more bandwidth by accident than the telephone people have on

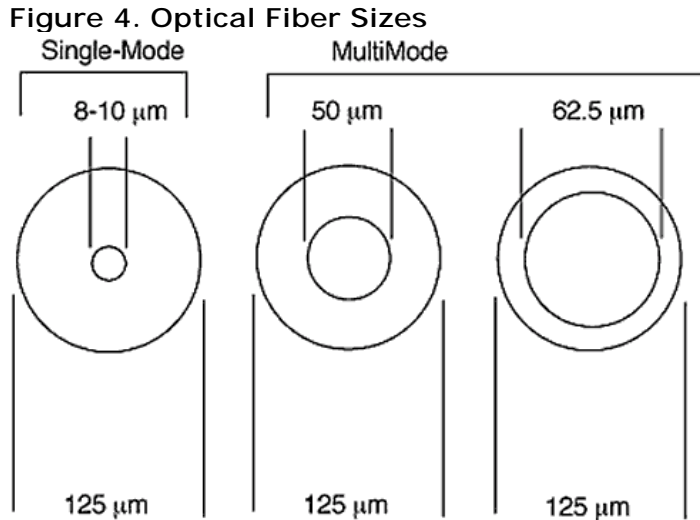
purpose." Indeed, that is correct; piggybacking a telephone channel on a coax cable is no challenge at all.

Fiber is the third transmission media, and it is unquestionably the transmission medium of choice. Whereas transmission over copper utilizes frequencies in the megahertz range, transmission over fiber utilizes frequencies a million times higher. This is another way of saying that the predominant difference between electromagnetic waves and light waves is the frequency. This difference, in turn, permits transmission speeds of immense magnitudes. Transmission speeds of as high as 9.9 Gbps have become commonplace in the industry today. At this speed, the entire fifteen-volume set of Encyclopedia Britannica can be transmitted in well under one second.

Laying fiber, on a per-mile basis, still costs somewhat more than laying copper. However, on a per-circuit basis there is no contest; fiber wins hands down. However, if a local loop is being laid to a residence, there is little justification to installing fiber—there will never be a need for more than one or two or three circuits. This realization has led to a transition in our thinking. Shortly after the commercialization of fiber, we talked about fiber-to-the-home (FTTH). It was then realized that there was little need to install fiber for a final several hundred yards, so the industry shied away from fiber-to-the-curb (FTTC). In such a system, fiber would carry a plurality of channels to the "curb," whereupon they would be broken down and applied to the copper drop leading to the home. In many cases even this was overkill, and fiber-to-the-neighborhood (FTTN) is now being used. The message is clear: apply fiber when it is economical to do so, and otherwise rely on copper.

One final approach is being used in many areas, and it often proves workable. This is a combination of fiber and coax or, as it is known, hybrid fiber/coax (HFC). As we have seen, coax has a greater bandwidth than copper but a smaller one than fiber. Also, in some 60 percent of the homes in the United States, coax in the form of CATV goes to the home; tying fiber to coax for the final several hundred yards makes technological sense.

Fiber comes in several forms; the two predominant ones are multimode and single-mode (see *Figure 4*). As can be seen, the total strand diameter for both is about 125 microns (a micron is a millionth of a meter). However, the ultrapure glass that forms the core transmission medium is between 50 and 62.5 microns for the multimode fiber and about 8 to 10 microns for the singlemode fiber. One would think that the multimode fiber would have a greater carrying capacity; however, just the opposite is true. With single-mode fiber, only one ray or mode can travel down the strand, and this makes for a simpler job in regenerating the signal at points along the span. In fact, single-mode fiber makes up the majority of today's long-distance network.



The tremendous capacity of fiber certainly makes for more efficient communications; however, placing so much traffic on a single strand makes for greater vulnerability. Most of the disruptions in the long-distance network are a result of physical interruption of a fiber run. It is called backhoe fade.

Wireless communications is the final option as a transmission medium. This can take several forms: microwave, synchronous satellites, low-earth-orbit satellites, cellular, personal communications service (PCS), etc. Some of these will be described in more detail later. In every case, however, a wireless system obviates the need for a complex wired infrastructure. In the case of synchronous satellites, transmission can take place across oceans or deserts. With microwave there is no need to plant cable, and in mountainous territories this is a significant advantage. Cellular and PCS afford mobility. There are advantages and disadvantages to each.

## 5. Transmission Technology

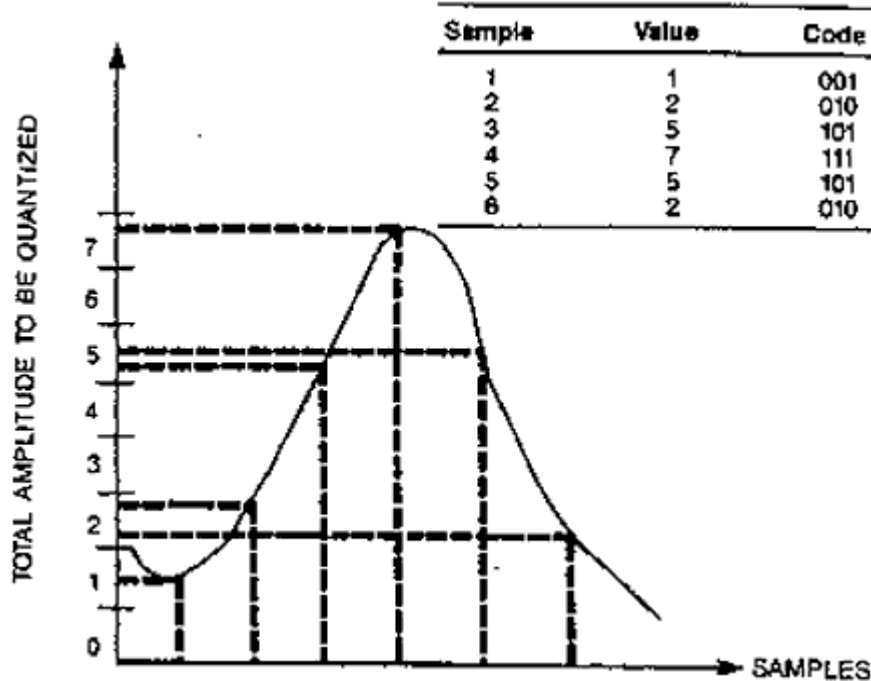
Most transmission—at least most transmission in the local exchange plant—is analog in nature. That is, the signal being transmitted varies continuously, both in frequency and in amplitude. A high-pitched voice mostly contains high frequencies; a low-pitched voice contains low frequencies. A loud voice contains a high-amplitude signal; a soft voice contains a low-amplitude signal.

In the long-distance network, and more and more in the local exchange plant, digital transmission is being used. A digital signal is comprised of a stream of 1s and 0s that portray the analog voice signal by means of a code.

Analog signals can be combined (i.e., multiplexed) by combining them with a carrier frequency. When there is more than one channel, this is called frequency division multiplexing (FDM). FDM was used extensively in the past but now has

generally been replaced with the digital equivalent: time division multiplexing (TDM). The most popular TDM system is known as tier 1 (T1). In a T1 system, an analog voice channel is sampled 8,000 times per second, and each sample is encoded into a 7-bit byte. Twenty-four such channels are mixed on these two copper pairs and transmitted at a bit rate of 1.544 megabits per second. T1 remains an important method of transmitting voice and data in the PSTN (see *Figure 5*).

Figure 5. Pulse Code Modulation (PCM) Sampling, Quantizing, and Encoding Process: In This Example, a 3-Bit Encoding Scheme Is Used for Quantizing the Total Amplitude



Such a digital transmission scheme (and certainly there are modifications of it that improve efficiency, capacity, or quality, etc.) works hand in glove with the digital-switching schemes we talked about previously. Those 1s and 0s need not be transmitted through an actual circuit in that switch; rather, one can simply turn on and off the various electronic devices that make up that switch.

Thus a talking path (i.e., a switched circuit) in the PSTN can be either analog or digital or a combination thereof. In fact, a digital signal can be transmitted over a packet-switched network as easily as a circuit-switched network. Now if we consider the next step, we see that digitized voice is not very different from data, and if data can be transmitted over a packet network, then so can digitized voice. This, of course, is now known as voice over the Internet. The challenge, of course, is to get the transmitted signal to the destination fast enough. After all, this may well be a time-sensitive voice conversation. A second challenge is to get each packet, which is a small piece of a voice conversation, to the destination in the

proper order. Progress is being made, and we can well believe that packet switching will play an important role in the PSTN of tomorrow.

## 6. Broadband Access and Service

Transmission in the telecommunications networks of today is, more and more, digital in nature, and the transmission medium of choice is fiber. "Digital," however, does no more than imply a string of 1s and 0s racing through the network. But how are these 1s and 0s to be arranged? At what speed are they to travel? What route should they take? Answers to questions such as these have taken many forms and have made for the most complicated aspect of the telecommunications business.

There has never been a scarcity of coding schemes in the industry. Starting with Morse code, going to the Baudot code, then the ASCII code, we have seen each providing for better transmission and higher quality. In this section we will discuss the most popular and important three codes.

### SONET

SONET is a standard for optical telecommunications transport. The SONET standard is expected to provide the transport infrastructure for worldwide telecommunications for at least the next two or three decades. It defines a technology for carrying many signals of different capacities through a synchronous optical hierarchy. The standard specifies a byte-interleaved multiplexing scheme. The synchronous optical hierarchy mentioned is shown in *Table 2*.

Table 2. SONET Hierarchy

| Signal | Bit Rate      | Capacity   |
|--------|---------------|------------|
| OC-192 | 9953.280 Mbps | 5376 DS-1s |
| OC-48  | 2488.32 Mbps  | 1344 DS-1s |
| OC-12  | 622.080 Mbps  | 336 DS-1s  |
| OC-3   | 155.520 Mbps  | 84 DS-1s   |
| OC-1   | 51.840 Mbps   | 28 DS-1s   |

OC = optical carrier

The DS-1 channel can carry twenty-four voice circuits, each called a DS-0

The SONET standards govern not only rates, but also interface parameters; formats; multiplexing methods; and operations, administration, maintenance, and provisioning (OAM&P) for high-speed transmission. We most often hear of SONET rings in which fiber strands are strung around a metropolitan area in a

ring configuration. The system is designed so that transmission can take place in either direction; should there be a fault at any one location, transmission will immediately take place in the opposite direction. That is, the system is self-healing.

## ATM

Asynchronous transfer mode (ATM) is a high-performance switching and multiplexing technology that utilizes fixed-length packets to carry different types of traffic. Information is formatted into fixed-length cells consisting of 48 bytes (8 bits per byte) of payload and 5 bytes of cell header. The fixed cell size guarantees that time-critical information (e.g., voice or video) is not adversely affected by long data frames or packets. Of course, if the cells were longer in length the system would be more efficient, because the header would take up a smaller percentage of the total cell.

Multiple streams of traffic can be multiplexed on each physical facility and can be managed so as to send the streams to many different destinations. This enables cost savings through a reduction in the number of interfaces and facilities required to construct a network.

## ADSL

Asymmetric digital subscriber line (ADSL) is, essentially, a modem that employs a sophisticated coding scheme. This coding scheme permits transmission over copper pairs at rates as high as 6 Mbps for distances of 9,000 to 12,000 feet. Speeds of this magnitude bring to mind television signals; a 6-Mbps channel can easily handle a television movie.

ADSL succeeds because it takes advantage of the fact that most of its target applications (video-on-demand, home shopping, Internet access, etc.) function perfectly well with a relatively low upstream data rate—hence the word *asymmetric*. LECs are now using ADSL as an access technology for their television businesses and for Internet access.

## 7. Wireless

The first commercially available radio and telephone system, known as improved mobile telephone service (IMTS), was put into service in 1946. This system was quite unsophisticated—but then there was no solid state electronics available.

With IMTS, a tall transmitter tower was erected near the center of a metropolitan area. Several assigned channels were transmitted and received from the antenna atop this tower. Any vehicle within range could attempt to seize one of those

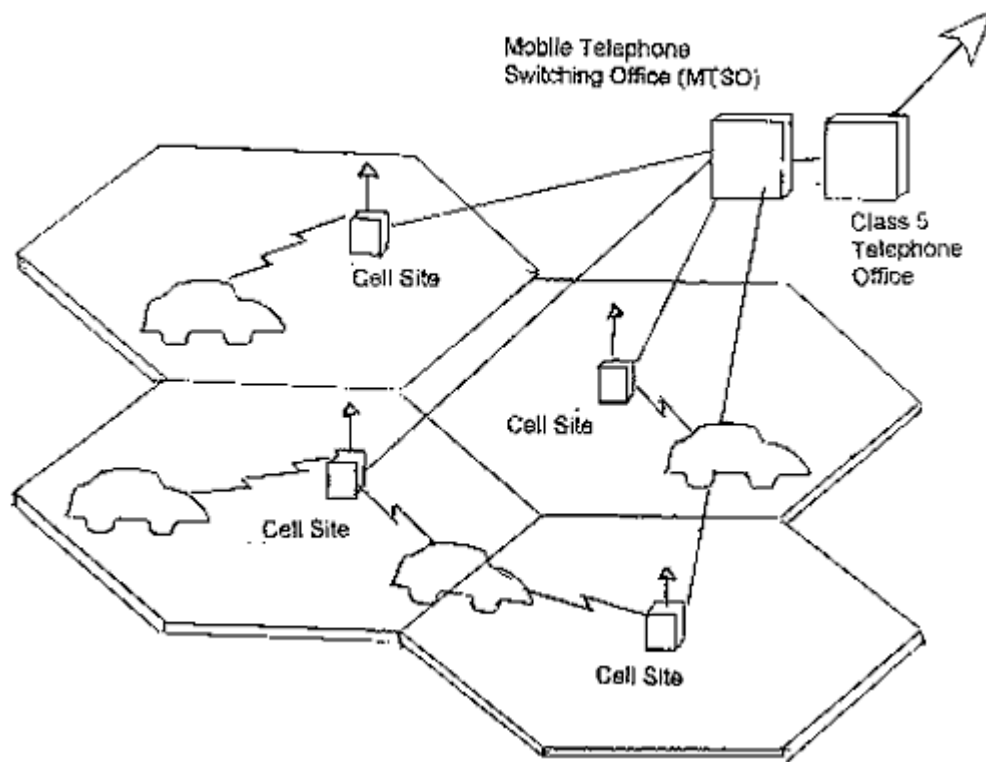


channels and complete a call. Unfortunately, the number of channels made available did not come even close to satisfying the need. To make matters worse, as the metropolitan area grew, more power was applied to the transmitter or receiver, the reach was made greater, and still more erstwhile subscribers were unable to get dial tone.

The solution to this problem was cellular radio. Metropolitan areas were divided into cells of no more than a few miles in diameter, each cell operating on a set of frequencies (send and receive) that differed from the frequencies of the adjacent cells. Because the power of the transmitter in a particular cell was kept at a level just high enough to serve that cell, these same sets of frequencies could be used at several places within the metropolitan area. Beginning in 1983, two companies, one called a wireline company and the other called a nonwireline carrier, were given a franchise to operate in each major territory.

Two characteristics of cellular systems were important to their usefulness. First, the systems controlled handoff. As subscribers drove out of one cell and into another, their automobile radios, in conjunction with sophisticated electronic equipment at the cell sites (also known as base stations) and the telephone switching offices (also known as mobile telephone switching office [MTSO] ), transferred from one frequency set to another with no audible pause. Second, systems were also designed to locate particular subscribers by paging them in each of the cells. When the vehicle in which a paged subscriber was riding was located, the equipment assigned sets of frequencies to it, and conversation could begin (see *Figure 6*).

Figure 6. In a Cellular System, Vehicle-to-Cell-Site Communications Take Place Using FDMA, TDMA, CDMA, GSM, etc.; Communications between the Cell Site and the MTSO Utilize Conventional Techniques



The initial transmission technology used between the vehicle and the cell site was analog in nature. It is known as advanced mobile phone service (AMPS). The analog scheme used was called frequency division multiple access (FDMA).

But the age of digital transmission was upon us, and many companies operating in this arena concluded that a digital transmission scheme would be preferred. The result was time division multiple access (TDMA). In Europe, the selected scheme was an adaptation of the TDMA used in the United States, and it was called *groupe special mobile*. Since then, the name has been changed to global system for mobile communications (GSM).

As if that was not enough, a third group of companies determined that a special spread-spectrum or frequency-hopping scheme would be even better, and this also was developed and trialed. This is called code division multiple access (CDMA). Thus, there are at least four schemes that may be used for communications between a vehicle and the cell site. Communications between the cell site and the MTSO utilized more conventional techniques, such as microwave, copper pairs, or fiber optics.

The continuing growth of cellular communications (there are presently about 20,000 new subscribers signing on each day), led government and industry in the United States to search for additional ways to satisfy the obvious need not only for ordinary telephone service but also for special services and features, smaller telephones, and cellular phone use. This search led to the PCS industry. Additional frequency bands were allocated for their use, and rather than assign them to the first comers or by way of a lottery, the FCC auctioned them off through a sophisticated bidding contest that brought the U.S. treasury billions of dollars.

Geosynchronous satellites represent yet another way of providing wireless communications. These satellites, located 22,300 miles above the earth, revolve around the earth once each twenty-four hours—the same as the earth itself. Consequently they appear to be stationary. Communications between two places on earth can take place by using these satellites; one frequency band is used for the uplink, and another for the downlink. Such satellite systems are excellent for the transmission of data, but they leave something to be desired for voice communications. This is a result of the vast distance and the time it takes for an electrical signal to make an earth-satellite-earth round trip. That time amounts to one quarter of a second. A reply from the called subscriber takes another quarter of a second, and the resultant half a second is definitely noticeable. Consequently, voice communications is seldom carried via geosynchronous satellites.

Yet another wireless telecommunications technology is the low earth orbit (LEO) satellite system. LEOs are satellites that communicate directly with handheld telephones on earth. Because these satellites are relatively low—less than 900 miles—they move across the sky quite rapidly.

In a LEO system the communications equipment on a satellite acts much like the cell site of a cellular system. It catches the call from earth and usually passes it to an earth-based switching system. Because of the speed of the satellite, it is frequently necessary to hand off a particular call to a second satellite just rising over the horizon. This is akin to a cellular system, except that in this case it is the cell site that is moving rather than the subscriber.

Several systems are now in the planning stage, and in fact many satellites have already been launched. The most noted is Iridium, created by Motorola, which would utilize sixty-six satellites. A second system, called Globalstar, would employ forty-eight satellites. There are at least two or three others that are well advanced in terms of preparations to launch.

# Self-Test

1. Alexander Graham Bell called his first telephone a synchronous telegraph.
  - a. true
  - b. false
2. The expiration of Bell's basic patents in 1893 and 1894 was the starting signal for open competition.
  - a. true
  - b. false
3. In 1946, Congress passed a Communications Act and established the Federal Communications Commission.
  - a. true
  - b. false
4. Each telephone subscriber is connected to several central offices (COs).
  - a. true
  - b. false
5. The local loop, or the connections between individual subscribers and central offices, is also known as the last mile.
  - a. true
  - b. false
6. The \_\_\_\_\_ is a particular set of standards that allows the interworking of products from different vendors. It usually embodies a fiber-optic ring that will permit transmission in both directions.
  - a. local-area network (LAN)
  - b. wide-area network (WAN)
  - c. synchronous optical network (SONET)
  - d. common channel signaling network

7. Packet switching is used for which of the following?
- a. credit-card verification
  - b. automated teller machines
  - c. SS7
  - d. the Internet and the World Wide Web
  - e. all of the above
8. The types of media that can transmit information in the telecommunications world are the following \_\_\_\_\_.
- a. copper wire, coaxial cable, fiber, and wireless
  - b. hybrid fiber/coax and copper wire
  - c. wireless and copper wire
  - d. copper wire, coaxial cable, fiber, and hybrid fiber/coax
9. Analog signals can be \_\_\_\_\_ by combining them with a carrier frequency.
- a. carried
  - b. transported
  - c. multiplexed
  - d. mixed
10. \_\_\_\_\_ is a high-performance switching and multiplexing technology that utilizes fixed-length packets to carry different types of traffic.
- a. asynchronous transfer mode (ATM)
  - b. asymmetric digital subscriber line (ADSL)
  - c. synchronous optical network (SONET)
  - d. none of the above

# Correct Answers

1. Alexander Graham Bell called his first telephone a synchronous telegraph.
  - a. true
  - b. false**See Topic 1.
2. The expiration of Bell's basic patents in 1893 and 1894 was the starting signal for open competition.
  - a. true**
  - b. falseSee Topic 1.
3. In 1946, Congress passed a Communications Act and established the Federal Communications Commission.
  - a. true
  - b. false**See Topic 1.
4. Each telephone subscriber is connected to several central offices (COs).
  - a. true
  - b. false**See Topic 2.
5. The local loop, or the connections between individual subscribers and central offices, is also known as the last mile.
  - a. true**
  - b. falseSee Topic 2.

6. The \_\_\_\_\_ is a particular set of standards that allows the interworking of products from different vendors. It usually embodies a fiber-optic ring that will permit transmission in both directions.
- a. local-area network (LAN)
  - b. wide-area network (WAN)
  - c. synchronous optical network (SONET)**
  - d. common channel signaling network

See Topic 2.

7. Packet switching is used for which of the following?
- a. credit-card verification
  - b. automated teller machines
  - c. SS7
  - d. the Internet and the World Wide Web
  - e. all of the above**

See Topic 3.

8. The types of media that can transmit information in the telecommunications world are the following \_\_\_\_\_.
- a. copper wire, coaxial cable, fiber, and wireless**
  - b. hybrid fiber/coax and copper wire
  - c. wireless and copper wire
  - d. copper wire, coaxial cable, fiber, and hybrid fiber/coax

See Topic 4.

9. Analog signals can be \_\_\_\_\_ by combining them with a carrier frequency.
- a. carried
  - b. transported

**c. multiplexed**

d. mixed

See Topic 5.

10. \_\_\_\_\_ is a high-performance switching and multiplexing technology that utilizes fixed-length packets to carry different types of traffic.

**a. asynchronous transfer mode (ATM)**

b. asymmetric digital subscriber line (ADSL)

c. synchronous optical network (SONET)

d. none of the above

See Topic 6.

## Glossary

### **ADSL**

asymmetric digital subscriber line

### **AMPS**

advanced mobile phone service

### **ATM**

asynchronous transfer mode

### **CDMA**

code division multiple access

### **CPE**

customer premises equipment

### **CO**

central office

### **FCC**

Federal Communications Commission

### **FDM**

frequency division multiplexing

### **FDMA**

frequency division multiple access



**FTTC**

fiber-to-the-curb

**FTTH**

fiber-to-the-home

**FTTN**

fiber-to-the-neighborhood

**GSM**

Global System for Mobile Communications

**HFC**

hybrid fiber/coax

**IMTS**

improved mobile telephone service

**IXC**

interexchange carrier

**LAN**

local-area network

**LEC**

local exchange carrier

**LEO**

low earth orbit

**MFJ**

modification of final judgment

**MTSO**

mobile telephone switching office

**OC**

optical carrier

**PCM**

pulse code modulation

**PCS**

personal communications service

**PoP**

point of presence

**PSTN**

public switched telephone network

**RBOC**

regional Bell operating company

**SONET**

synchronous optical network

**SS7**

signaling system 7

**TDM**

time division multiplexing

**TDMA**

time division multiple access

**UTP**

unshielded twisted pair

**WAN**

wide-area network