Chapter 3

Communications Technologies

INTRODUCTION

The U.S. electronic communication infrastructure is a mixture of five media: 1) terrestrial radiofrequency transmissions; 2) satellite radiofrequency transmissions; 3) paired copper wires; 4) coaxial cables; and 5) optical fibers.[1] Each plays a role in providing efficient communication services for the United States (table 3-l). Rapid technological and economic changes are reshaping the roles these media play in our communication system.

Terrestrial broadcasting and coaxial cables distribute the major share of television to consumers today. Satellite transmission has filled the need of those not served by cable TV (CATV) or who are too far from broadcast stations to receive a reliable signal. HDTV could change the competitive balance between these various media and may stimulate the delivery of television services by other means, including direct broadcast satellite and, in the long-term, switched optical fibers through the telephone system. HDTV may also allow significant improvements in the efficiency of spectrum use. This might enable services now constrained by a lack of spectrum to be expanded.

The shift towards a digital operating environment is making the media perform more alike. Digitization can provide a common format that allows

Table 3-l—The U.S. Communications Infrastructure

Technology	Businesses	Year began	Current capacity			Approximate number of nodes	Available audience	Service industry revenues
Copper pairs	Telephone, data communication (LANs, WANs, MANs)	1876	From 3 kHz for single analog voice channel 144 kbps for basic ISDN			23,000 exchanges 240,000 PBXS	93% w/phones 20% w/PCs 8% w/modems	$140 billion
Coaxial cable	Cable TV	1948	Up to 550 MHz or 80 video channels			11,000 headends	81% of homes passed; 56% subscribe	$14 billion
Optical fiber	Voice, data, and video communication	1978	1.76 Gbps common and higher rates rapidly becoming available			Overlaps with copper pair and coaxial cable systems		
			Total* spectrum;	Spectrum /channel;	Channels /market			
Terrestrial communication	AM radio	1920s	1070 kHz;	10 kHz;	27	5,000 AM stations	98% population	$2 billion
	FM radio	1920s	20 MHz;	200 kHz;	50	5,600 FM stations	98% population	$4.5 billion
	VHF TV	1946	72 MHz;	6 MHz;	7	700 [+300 LPTV] stns	98% population	$24 billion
	UHFTV	1952	330 MHz;	6 MHz;	10	Same	Same	
	ITFS & OFS TV	1963	138 MHz;	6 MHz;	N/A	800 stations	N/A	
	MMDS TV	1962/83	60 MHz;	6 MHz;	N/A	24 stations	0.1% population	
	Cellular telephone	1983	50 MHz;	30 kHz;	varies	700 systems	1% population	$3 billion
Satellite communication	Voice, data, video	1962				530 civ. transponders		
L band	Radio RDSS paging	1989	16 MHz;			1 sat/7 slots		
C band	Broadcast/cable	1976	1 GHz;	40 MHz;		19** sats/35 slots	1% direct	
Ku band	Medium-powerDBS	1983	1 GHz;	40 MHz;		14 sats/35 slots		
Ku Band	High-power DBS	1987	1 GHz;	15 MHz;		O sats/8 slots		

* Note that the total spectrum available and the spectrum per channel are set by regulation. The channels usable per market are also set by regulation in order to control interference between stations in the same geographic location.

** Four satellites serve both C-band and medium-power DBS Ku-band; slots are orbital slots where satellites might be placed, with varying numbers of transponders per satellite.

SOURCE: Adapted from U.S. Department of Commerce, National Telecommunications and Information Administration, *Telecom* 2000, NTIA Special Publication 88-21, October 1988.

[1] U.S. Congress, Office of Technology Assessment, *Critical Connections: Communication for the Future*, OTA-CIT-407 (Washington, DC; U.S. Government PrintingOffice, January 1990). More detail of the technologies and analyses of communication issues maybe found in this report.

signals to be easily moved among media-terrestrial broadcast, microwave, satellite, cable, optical fiber—without distortion.

TERRESTRIAL RADIO COMMUNICATIONS

Terrestrial radio frequency communication includes mass media such as AM and FM radio and television; mobile radio links such as cellular telephone and police radio; and special services—amateur radio and aeronautical and marine navigation. Ground-based microwave links are also used for long-distance telephone, data and video transmissions. (Fundamentals of communication technologies are listed in box 3-l.)

Each service using the radio frequency spectrum is assigned a range of frequencies that matches the technical needs of the user and reduces interference from others sharing the spectrum (figure 3-4).[2]

The frequencies from about 30 MHz to 1 GHz are well suited for terrestrial, short-distance communication. As the frequencies increase above 30 MHz, radio transmissions become limited to direct line-of-sight (reflections from the ionosphere decrease), with less interference between stations. Below 1 GHz, the strength of radio waves are not significantly reduced by rainfall or other atmospheric effects. Above 10 GHz, attenuation from rainfall and other atmospheric factors increases rapidly and limit the use of these higher frequencies to short-haul links or for satellite communications where the signal must pass through only a few miles of atmosphere to the receiver.[3]

Competition for spectrum space is often keen. As technology develops new and better communications systems, user demand can cause crowding and overuse of some bands. Cellular telephone and other mobile services are assigned frequencies adjacent to the UHF TV bands. These services have experienced phenomenal growth in several urban areas, where they now suffer from congestion.

The Federal Communications Commission was considering the reallocation of the upper parts of the underutilized UHF TV spectrum to these other services when the potential needs of broadcasters for additional frequencies to broadcast HDTV led the regulatory agency to stay its action.[4]

Microwave systems are important links in the national telephone network and are also used in private nets. Modern digital microwave systems can achieve data rates of hundreds of megabits per second. Microwave provides line-of-sight communication, and repeaters are spaced at different intervals (commonly 20 to 30 miles) depending on terrain, weather conditions, obstructions, and frequencies.

Microwave systems operating in the 2-, 6-, and 11-GHz bands are typically used for long-distance transmission, while 18- and 23-GHz systems are better suited to short hauls due to the greater attenuation by rain at higher frequencies.

Sufficient bandwidth is available in the microwave bands to carry high-resolution, fill-motion television. Microwave-based multichannel multipoint distribution systems (MMDS) have been licensed to deliver video services in some metropolitan areas. In general, these ventures have had difficulty competing with conventional CATV service.

Cellular telephone is perhaps the best example of the tremendous changes taking place in the use of the radio spectrum as a result of technological advances. Conventional radio telephone service-the predecessor of cellular-has a capacity of about 25 channels, each able to carry one call. Radio telephone required a high-power transmitter and a receiver capable of communication up to 50 miles.

Cellular telephone technology dramatically increased the capacity for mobile telephone communication by breaking the service area into many ‘‘cells, ’ each served by its own transmitter and receiver coupled to a computer-controlled system (figure 3-5). Each cell operates at low power and short range. Neighboring cells use different frequencies to avoid interference, but cells far enough apart to avoid interference may share the same frequency. If a customer moves into the range of another cell during a call, the frequency is automatically switched to that cell without the caller knowing. These techniques greatly increase the carrying capacity of the limited spectrum available for

[2]For details of these services, see FCC Rules, 47 CFR 90 to 100.

[3]Where the satellite is near the horizon, the distance through the lower atmosphere could be much longer, perhaps 50 miles Or more.

[4]Further Sharing of the UHF Land Mobile Radio Service, Order, 2 FCC 6441 (1987).

Box 3-1—Fundamentals

Information can be electronically communicated in an analog or digital format. Other characteristics that must be considered include: how frequently the signal must be amplified to make up for losses in the medium; how to carry several independent signals in a medium without interference; and how much information can be carried.

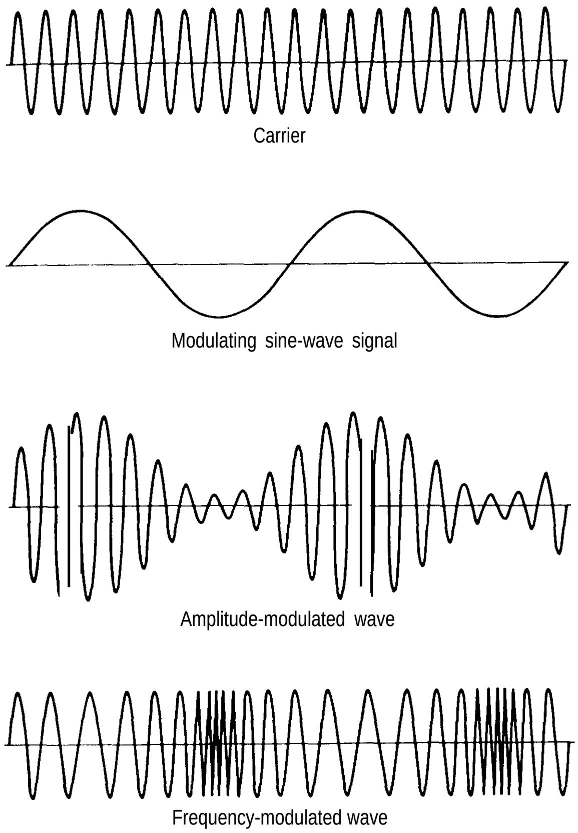
Analog—The analog format sends a continuously varying electronic signal proportional to the information. For example, a microphone generates a signal with a voltage proportional to the loudness of the speaker's voice. For applications such as radio and TV broadcasting, this signal modulates a carrier wave, most commonly by varying the amplitude (AM) or frequency (FM), figure 3-1.

Digital—For digital communications, the continuously varying signals of the real world—sound, light, etc.—are first converted to numbers (usually in a binary format, that is, as a string of “0s” and “1s”[1] proportional to their loudness or brightness. (See box 4-2.) These binary digits, orbits, can then be sent as a series of “on' or ''off pulses (figure 3-2) or can be modulated onto a carrier wave. Typical modulation techniques vary the frequency, amplitude, and/or phase of the carrier wave according to whether the signal is” 1“ or “O.” Examples of these techniques are shown in figure 3-3.[2]

Amplifiers (Analog Repeaters)—Transmitted over long distances, signals are inevitably attenuated. To boost their strength, analog signals are electronically amplified by repeaters at points along the way. With each amplification, there is a tiny amount of distortion because the electronics are not perfect. In turn, because the analog signal is continuously varying, it is extremely difficult to detect or correct the distortions that creep in.

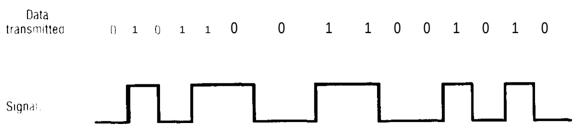
Digital or Regenerative Repeaters-digital signals are also attenuated over long distances, but digital signals are either “l” or “O.” Therefore, instead of simply amplifying the digital signal along the way and introducing more distortion each time, the data in the signal—''1s” or ''0s''—are recovered and anew digital signal is generated. As long as the signal is not so severely attenuated or distorted that a “1“ appears like a “O” or vice versa, there is no degradation of the data. Of course, digital signals can also be transmitted over analog systems and their signal simply amplified. Digital repeaters are also known as “regenerative repeaters. ”

Figure 3-l—Amplitude and Frequency Modulation of a Carrier



SOURCE: William Stallings, *Data and Computer Communications (New York, NY:* MacMillan Publishing Co., 1985). Used with permission.

Figure 3-2—A Digital Signal With Its Corresponding Numerical Equivalent



SOURCE: William Stallings, *Data and Computer Communications (New York, NY:* MacMillan Publishing Co., 1985). Used with permission.

[1]Thus, to count from 0 to 15 in binary gives the following series: 0000; 0001; 0010; 0011; 0100; 0101; 0110; 0111; 1000; 1001; 1010; 1011; 1100; 1101; 1110; 1111. Each position from the right corresponds to a power of 2 just as in the decimal system we commonly use, each position from the right corresponds to a power of 10.

[2]L. Brett Glass, ''Modern Modem Methods,'' *Byte*, June 1989; William Stallings, Data *and Computer Communications* (New York, NY: MacMillan Publishing, 1985).

Continued on next page

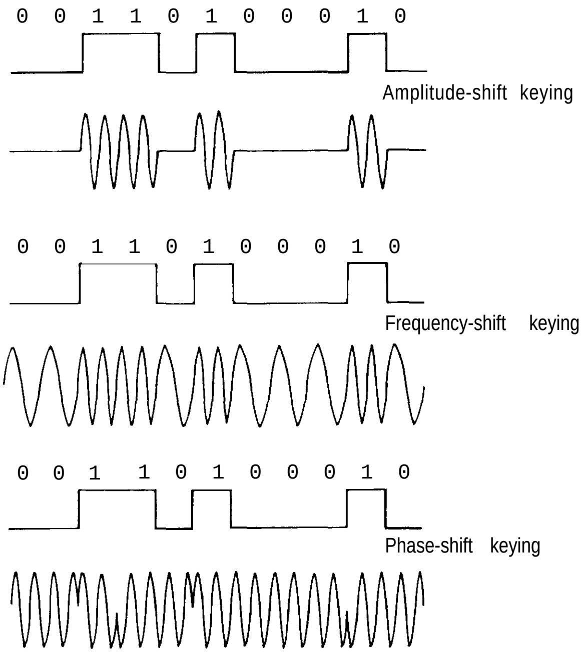
Box 3-1—Fundamentals—Contin ued

Repeater Spacing—High frequencies are attenuated more rapidly than lower frequencies-whether over copper pair, coaxial cable, optical fiber, or terrestrial or satellite broadcasting through the atmosphere—and this limits the range of carrier frequencies that can be used or else requires analog or digital repeaters to be spaced more closely.

Multiplexing—To carry more than one stream of information in a medium at a time, signals are multiplexed. Frequency division multiplexing (FDM) uses carrier waves of different frequencies so that a number of signals can share the same medium without interfering with one another. FDM is used in radio and TV broadcasting, and the frequency of the carrier wave corresponds to the channel. Time division multiplexing breaks the data into smaller packets and intersperses them. (See box 4-2.)

Bandwidth—Modulating a signal onto a carrier wave-whether by AM or FM-causes the frequency of the signal to vary from that of the carrier and creates ''sidebands' with the signal occupying a range of frequencies about the carrier frequency. This can be most easily seen in figure 4-3 for frequency modulation. To prevent interference between radio or TV stations, the range of frequencies of a signal are not allowed to overlap. This range is known as the bandwidth, and is about 3 kHz[3] for a telephone conversation; 10 kHz for an AM radio station; 200 kHz for an FM radio station; and 6 MHz for a TV station.[4]

Figure 3-3-Techniques for Modulating an Analog Carrier in Order To Send Data in a Digital Format



SOURCE: William Stallings, *Data and Computer Communications (New York, NY:* MacMillan Publishing Co., 1985). Used with permission.

The maximum potential information content or carrying capacity of an analog signal is given by its bandwidth (but is limited by the noise present). The higher information content of HDTV requires either wider bandwidths than today's allotted 6 MHz or much more efficient use of that available.

Data Rates-The information content of a digital signal, or data rate, is measured by the number of bits per second (bps) that are transmitted. When digital signals modulate a carrier[5], the data rate is determined by how efficient the encoding process is and the available bandwidth of the carrier. Today, data rates of as high as 7.5 bps per Hz of bandwidth are achievable with electronic signals, although at these very high rates transmission errors are more likely.[6] Due to technical limitations in the semiconductor lasers that drive light through optical fibers and the sensors that detect this light, encoding efficiencies (bps/Hz) for optical transmissions are not as great as for electronic signals. Optical fibers are nevertheless able to carry much more information than twisted pairs or coaxial cables because of the greater range of frequencies they can carry without excessive attenuation.

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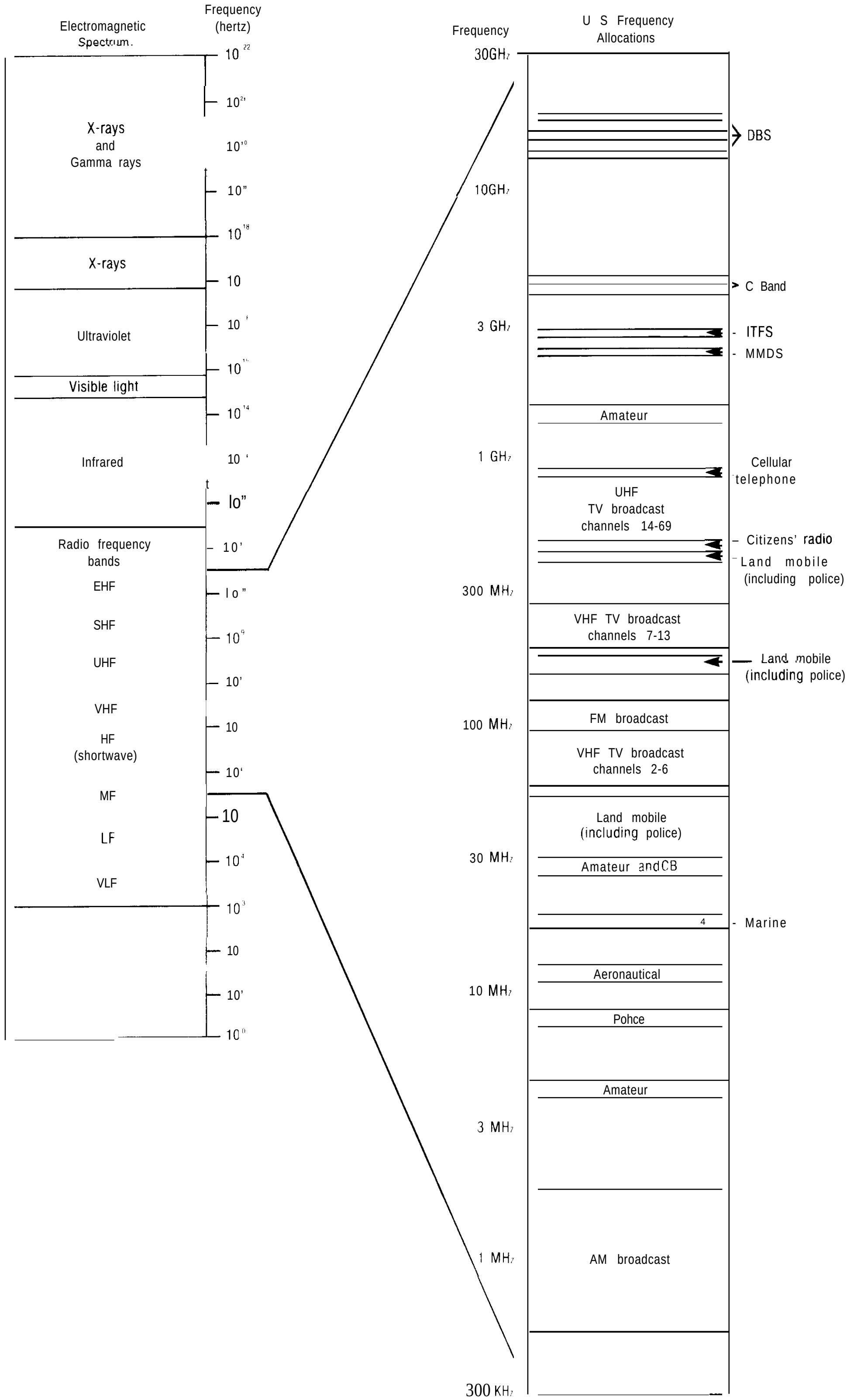
[3]One kHz is 1,000 cycles per second; 1 MHz is 1 million cycles per second; 1 GHz is 1 billion cycles per -rid.

[4]For AM and FM these include guardbands; for TV, adjacent channels cannot be assigned in the same geographic region and are known as taboo channels.

[5]Note that all carriers are analog.

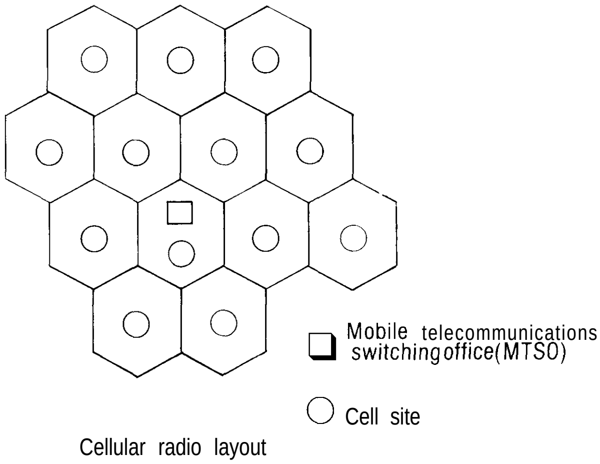
[6]Dale Hatfield, "Report on the Potential for Extreme Bandwidth Compression of Digitalized HDTV Signals," Hearings before the Committee on Science, Space, and Technology, U.S. House of Representatives, Mar. 22, 1989.

Figure 3-4-Selected Allocations of the Radio Frequency Spectrum



SOURCE: Adapted from: *Encyclopedia Americana, vol. 23, 1986,* p. 160; and FCC Rules, 47 CFR 90 to 100.

Figure 3-5—Map of a Cellular Radio System



SOURCE: William Stallings, *Data and Computer Communications (New York, NY: MacMillan Publishing Co., 1985).* Used with permission.

cellular phones. Digital cellular, now coming on the scene, promises to improve spectrum utilization even more.

A cellular system can grow to meet demand. Initial service to a metropolitan area might require a few large cells. As demand grows, cells can be subdivided and distant cells can use the same frequency. The system is quite flexible, but there are limitations.[5]

The FCC has allocated 50 MHz in the UHFregion of the spectrum to the mobile telephone service. This spectrum is subdivided into 832 pairs of 30 kHz bands (two-way conversations require one pair). Overall, this is sufficient capacity to handle the roughly 3 million users in the United States today, but there is significant congestion in some areas. In Los Angeles, New York, and Washington, DC, the cellular channels are overloaded during peak times.[6] Faced with an explosion in demand for cellular service and little prospect for acquiring additional frequencies, the industry is focusing on technologies that will use the assigned frequencies more efficiently. The most promising is end-to-end digital transmission, which is being adopted as an industry standard.

Digitization will increase the capacity of the assigned spectrum by as much as three to eight times or 9 to 24 million calls. The cost of conversion could be more than $4 billion.[7] Trends toward miniaturization leading to pocket-size cellular phones could boost demand even further.[8] Some industry analysts believe that cordless, mobile telephones may be the trend of the future, and that if provided sufficient spectrum for expansion, they could be substantial competition for the local telephone companies.[9]

With the prospect of advanced TV (ATV)services looming in the future, competition between ATV and cellular for the UHF TV bands will heighten. Both services may suffer spectrum compaction at that point unless technology can improve the efficiency of spectrum use or new transmission schemes are devised.

SATELLITE COMMUNICATIONS

Satellite systems are long-distance links for telephone, data, and television transmissions to distant ground-based stations. Although currently used primarily for feeds to broadcast stations and cable systems in the United States, another generation of satellites called Direct Broadcast Satellites (DBS) could be used to beam HDTV signals directly to home viewers in the future. Japan and European countries are planning to use DBS to deliver HDTV. The Japanese are introducing HDTV via DBS as a new service, and not as a replacement for NTSC, which will continue to be broadcast terrestrially.

Satellites are ‘‘parked’ in geostationary orbits 22,000 miles above the Earth-about one-tenth the distance to the Moon. By staying in the same position, their “footprint” (area of coverage) remains the same. Time delays for signals to and from Earth at that altitude disturb voice communications, but have no practical effect on video signals.

[5]Dale N. Hatfield and GeneG.@‘‘The opportunity CoStSof Spectrum Allocated to High Definition Television,” paper presented at The Sixteenth Annual Telecommunications Policy Research Conference, Airlie House, Airlie, VA, Oct. 30 to Nov. 1, 1988; William Stallings, *Data & Computer Communications (New* York, NY: MacMillan, 1985).

[6]Industry analysts forecast that b, 1995 there will be about 20 million cellular phones compared to 2.6 million in service today. See ‘‘Cellular phone Industry’s Numbers,” *Washington Post*, June 8, 1989, p. El, E6.

[7]Calvin Sims, ‘’Meeting Mobile Phone Demand,” New *York Times,* July 19, 1989, p. D1.

[8]Frank James, ‘‘Battle of Miniature Cellular Telephones Heat Up with Launch of Motorola Model,” *Wall Street Journal, May 5, 1989,* p. B1.

[9]Hatfield and Ax, op. cit., footnote 5.

Fixed Satellite Services (FSS)[10] are assigned orbital positions in space with separation between satellites arranged to minimize interference according to power levels and frequencies.[11] Spacing requirements limit the number of satellites in orbit for each band to about 40 for FSS or 8 for DBS.[12]

Satellite transponders receive signals at one frequency and relay them to Earth on a second frequency. The FCC has allocated 1 GHz of bandwidth in the spectrum (500 MHz for the uplink (ground to satellite) and 500 MHz for the downlink (satellite to ground). C-band satellites were the first domestic satellites in operation and carry the majority of satellite voice, data, and video communication. The Ku-band and the Ka-band (when operational) will carry increasingly more traffic.

The FCC regulates the broadcast power of C-band transponders to reduce the potential of interference with terrestrial communications, e.g., point-to-point microwave links.[13] Low power requires the use of large receiving dishes (C-band antennas are 10 to 12 feet in diameter). Antenna efficiency is improving through new technology, and 4-foot diameter antennas are now used for TV terminals.[14]

Ku-band transponders operate at higher frequencies than are commonly used for terrestrial communication, so the FCC allows them to operate at higher power. Higher power allows the use of smaller receiving dishes (3 feet in diameter), but the higher frequencies are subject to interference from rain and other atmospheric conditions.

There are currently no high-powered DBS TV services in the United States. The FCC promulgated regulations for DBS in 1982, but the medium has faced economic uncertainties that have slowed development.[15] This situation dramatically changed recently with the announcement of a partnership to establish a DBS system for the United States by as early as 1993.[16]

DBS can be received on antennas of 1 foot in diameter. This scale-down could overcome some of the objections and limitations imposed by some municipalities on Television Receive-Only (TVRO) home satellite dishes that receive low-power signals from the C-band satellites. Others argue that cable companies installed plant and equipment in urban areas minimizes the incremental cost of adding new customers or HDTV programming and limits DBSS advantage to largely rural areas.[17]

COAXIAL CABLES

Coaxial cables are widely used for distributing television to subscribers.[18] About 80 percent of American homes have access to cable TV, and 55 to 60 percent currently subscribe.

Cable TV systems generally use a cable trunk that carries up to 80 frequency division multiplexed analog video signals. Taps from the coaxial trunk are fed to each subscriber. Signal strength in the trunk diminishes with distance. Therefore, analog amplifiers are placed at regular intervals within the system to boost the signal strength; but each amplifier adds noise to the signal. To avoid excessive loss of picture quality, cable operators limit the length of the trunk system. Improvements in amplifiers and their closer spacing might increase coaxial cable bandwidths up to 1 GHz.[19]

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10 There are several classes of FSS satellites operating at different frequencies and different power levels, e.g., C-band (4/6 GHz), Ku-band (11-12/14 GHz), and in the future, Ka-band (20/30 GHz).

11 Assignment of Orbital Locations to Space StatiOnS in the Domestic Fixed-Satellite Service, 50 Fed. Reg. 35228 (1985).

12 This represents the number of satellites that can cover between about 60 to 140 degrees longitude across the United States. Fewer satellites would fit into the range of 85 to 130 degrees longitude that provides full useful coverage.

13 Timothy Pratt and Charles W. Bostian, *Satellite Communications* (New York, NY: John Wiley & Sons, 1986); and Charles W. Bostian, Virginia Polytechnic Institute, personal communication, Sept. 29, 1989.

14 Harry Jessell and Peter Lambert, "The Uncertain Future of DBS," *Broadcasting, Mar. 13, 1989,* p. 42.

15 *See* "DBS Viability Questioned," *TV Digest,* July 31, 1989, p. 8; David Rosen, "The Market for Broadband Services via Fiber to the Home," *Telematics, May* 1989, vol. 6, No. 5.

16 John Burgess, "Satellite Partnership Plans Pay-TV System," *Washington Post,* Feb. 22, 1990, p. El.

17 John Sic, TeleCommunications, Inc., personal commmunication, Oct. 12, 1989.

18 Coaxial cables have a central copper wire surrounded by an insulator with a finely braided copper shield around the outside of the insulator. The unit is encased in plastic or rubber armor. The concentric geometry allows higher frequencies to be carried than can pairs of copper wire. Most coaxial cable systems now in use have bandwidths of about 300 to 400 MHz, and some go as high as 550 MHz. Tbis is sufficient to carry 35 to 80video channels. See, Trudy E. Bell, "The New Television: Looking Behind the Tube," *IEEE Spectrum,* September 1984, p. 53.

19 Dale Hatfield, Hatfield Associates, he., personal Communication% Oct.12,1989.

Many cable operators are considering replacing the “backbone” of their cable system with optical fiber.[20] This would greatly reduce the number of existing amplifiers between the cable headend and any customer and correspondingly improve signal quality and channel capacity.[21] This could, by some estimates, be achieved for as little as $50 to $75 per subscriber.[22] This comparatively inexpensive upgrade of the system by the addition of an optical fiber backbone might provide today’s cable TV operators a significant performance and cost advantage over potential competitors (such as the telephone companies) in distributing HDTV in the near- to mid-term.[23] Such a system might not easily evolve into a two-way broadband system supporting interactive services as a fully fiber-based telephone system would.

A broadband telephone network is not likely to be widely available for 20 or more years, however, and some believe that an integrated cable TV-telephone network may provide some of the advantages of an interactive broadband system in the interim.[24] Today’s telephone network using N-ISDN can provide sufficient capacity for many information services (but not high-quality video) and the coaxial cable network can provide one-way distribution of high-quality video entertainent, possibly even called up over the telephone network. Whether such a cable/telco system is an evolutionary dead-end that slows or prevents the development of a fully switched broadband network by skimming off the most lucrative services or is an important interim step in the development of such a broadband network must be carefully considered.

COPPER TELEPHONE LINES

Often referred to as “twisted pairs,” the telephone lines leading into nearly every residence and business are the backbone of the telephone system. A number of twisted pairs are combined into a “cable system,” and these cables may be bundled into several rope-like “binder groups” (screened cables). These are currently being replaced by optical fibers between large central telephone switches and in high-traffic sections of the long-distance network. The economies resulting from the immense carrying capacity of optical fiber are driving the substitution of fiber for copper. Fiber is on the threshold of being cheap enough to replace copper to the home in new, high-density residential developments. As many as 250,000 homes are projected to be connected by fiber by the year 1992.[25] Its penetration into existing residences and low-density areas will be slower because of its higher cost in these applications.

The information carrying capacity of a twisted pair is limited to typically just a few hundred kHz to a few MHz, depending on the distance between analog or digital repeaters along the line. The bandwidth for an analog (voice) signal on a telephone is much more limited still. It is normally specified to range from about 0.3 to 3.1 kHz. This range is restricted so as to limit the amount of information transmitted by the many calls being carried at any one time in certain portions of the telephone network, such as the microwave links used for long-distance calls. This increases the number of calls that can be handled.

The capacity of a twisted pair for transmitting digital data varies considerably according to the efficiency of the encoding, modulation, and multiplexing processes, and to the amount of noise and interference on the line. Telephone line modems for today’s analog system with transmission rates of 9.6 thousand bits per second (kbps) are now common

[20] A recent poll of cable television MSO and system managers found tbat two-thirds expect fiber to replace coaxial cable in their networks. “Fiber Optics Handbook,” *Cablevision*, Apr. 24,1989.

[21] Robert Pepper, “Through the Looking Glass: Integrated Broadband Networks, Regulatory Policies and Institutional Change,” 4 FCC Rcd 1306, 1307 (November 1988); U.S. Department of Commerce, National Telecommunications and Information Administration, *Telecom 2000*, NTIA *Special* Publication 88-21, October 1988, p. 268.

[22] Hatfield, op. cit., footnote 19; David P. Reed and Marvin A. Sirbu, “Integrated Broadband Networks: The Role of the Cable Companies,” 1989 Telecommunications Policy Research Conference, Airlie House, Airlie, VA, Oct. 1-3, 1989; “Fiber Optic: Backbone for CATV,” *IEEE Spectrum*, September 1988, p. 26. Note that the various estimates of cost correspond only to within a factor of 2.

[23] Bruce L. Egan and Douglas A. Conn, “Capital Budgeting Alternatives for Residential Broadband Networks,” Center for Telecommunications and Information Studies, Graduate School of Business, Columbia University, October 1989.

[24] John Sic, Telecommunications, Inc., “Proposal for Telco/Cable Interface,” paper presented at the Telecommunications Reports’ Conference on Telco-Cable, Washington, DC, Sept. 22, 1989.

[25] John Markoff, “Here Comes the Fiber-Optic Home,” *New York Times, Nov. 5*, 1989, sec. *3*.

and rates twice this are becoming available.[26] Analog transmission over twisted pairs will continue to be the principal technology for the midterm, although Integrated Services Digital Network (ISDN) are gradually being installed in some areas, primarily for business service.

ISDN can carry voice, data, and video information over switched telephone networks in a digital format. It is a set of transmission, switching, and signaling technologies that support advanced digital services.[27] ISDN was designed to use existing subscriber loops consisting of copper pairs for digital transmission. The Basic Rate Interface (BRI) of 144 kbps specifies two 64 kbps channels for subscriber use and a 16 kbps channel for signaling and some slow-speed digital subscriber service.

Most homes today are wired with two pairs of twisted copper lines. When using the full capacity of N-ISDN, these two pairs will be able to carry data rates of 1.544 Mbps.[28] This rate is sufficient for a variety of interactive digital computer information services, but is not able to deliver real-time, high-resolution video services. By "compressing' the digital signal (see box 4-2), it is possible to transmit a modest quality video signal for teleconferencing.[29] For conventional TV, ATV, or HDTV, higher capacity transmission media are required, e.g., coaxial cable or optical cable.

The public telephone network could bean important medium for delivering HDTV to the home. The goal of "universal service' set forth in the Communications Act of 1934 is nearly a reality. It permits point-to-point routing for voice services through a switched network[30] to nearly all residences and businesses in the United States. It provides two-way communication, which could bean important attribute should HDTV evolve into an information ''appliance' for the interactive exchange of information.

Large investments will be needed if the telephone network is to provide the bandwidth and switching necessary for carrying real-time, high-resolution, full-motion video. If this is to happen, optical fiber technology and optoelectronic switching devices will hold the key.

OPTICAL FIBER CABLES

Fiber optics technology enables information—voice, data, and video—to be transmitted as light pulses through glass fibers. Optical fibers have many advantages over cables and wires. These include wider bandwidth and longer spacings between repeaters, lower weight, immunity to electrical interference, higher reliability, and lower maintenance costs.[31] Because of this, shielding is not required for fiber to meet FCC requirements. Glass fibers do not conduct electricity, thus a lightning strike cannot send a pulse down a fiber to cripple equipment on the network.

Because optical fibers do not conduct electricity, providing power to the system on the customer's premises may require using the customers' power source. This would likely not be as reliable as today's conventional system where backup power is provided by the central telephone exchange. Using rechargeable batteries on the customer premises could provide backup power in the event of an outage, but might lead to significant maintenance problems. Fiber systems are still more expensive than copper pair systems,[32] but costs are coming down rapidly.

An optical fiber transmission system includes one or more optical fibers housed in a protective cable, and devices for converting electrical signals into light pulses and back again. Repeaters are used to

[26] L. Brett Glass, "Modern Modem Methods, " *Byte,* June 1989; Eli Noam, "The Political Economy of ISDN: European Network Integration vs. American System Fragmentation%" Apr. 23, 1986, p.5; ''V.32 Modems,' *High Technology Business,* November-December 1989, p. 45.

[27] There are two generic forms of ISDN: Narrow band ISDN (N-ISDN) that can carry voice or data within its bandwidth, and broadband ISDN (B-ISDN) with sufficient bandwidth to carry high-resolution full-motion video but requires coaxial cable or optical fiber in addition to a wide-band switching network. See David Hack, *Telecommunications and information-Systernx Standardization—Is America Ready 87-458* (Washington, DC: Congressional Research Service, 1987).

[28] The T1 rate of 1.544 Mbps was chosen based on the typical distance between manhole covers—where analog or digital repeaters $113 Or can be placed-in the current telephone system. Bob Mercer, Hatfield Associates, Inc., personal communication Nov. 13, 1989.

[29] Richard Doherty, ''System Puts Real-time Squeeze on Color Video," *Electronic Engineering Times,* Feb. 27, 1989.

[30] Only circuit-switched systems will be discussed here. Packet-switched systems and others are also possible.

[31] Pepper, op. cit., footnote 21.

[32] J.E. Dulfer, ''When Does Fiber Make Sense?'' Business *Communications Review,* February 1989.

regenerate the signal over long distances, and multiplexing can be used to increase the carrying capacity of fiber links (see box 4-2). Data rates of 565 Mbps (8,064 voice channels) on optical fibers are common; rates of 1.76 Gbps are available;[33] and experimental systems have reached 16 Gbps.[34] Technologies to achieve much higher rates are being researched.

The versatility and technological capacity of optical fiber makes it superior to copper in many ways. Its bandwidth suits it to the transmission of HDTV signals as well as high-volume telephone trunk circuits. Many long-distance lines have been converted to optical fibers, but little fiber has been installed in the local telephone loops. A number of optical fiber demonstrations to residential subscribers have been undertaken in selected municipalities by the Bell Operating Companies and others, including: Heathrow, Florida (BellSouth); Perryopolis, Pennsylvania (Bell Atlantic); and Cerritos, California (GTE).[35]

The cost of broadband switching equipment and rewiring the local loop to existing buildings will delay widespread installation of fiber to residences. It may take 20 years or more before fiber becomes common in households. There are currently few services that demand broadband telephone service to residential subscribers. Telephone companies view the delivery of video dial-tone services and the potential delivery of HDTV to the home as an important driving force for the installation of fiber over the "last mile."

[33] Jonathan Kraushaar, "Fiber Deployment Update," FCC, Common Carrier Bureau, Industry Analysis Division, Feb. 17, 1989, p. 3.

[34] Miyoko Sakurai, "Semi 'Trailblazer'," *Electronic Engineering Times*, Feb. 20, 1989.

[35] Paul W. Shumate, Jr., "Optical Fibers Reach Into Homes," *IEEE Spectrum*, February 1989; Herb Brody, "The Rewiring of America," *High Technology Business*, February 1988; Michael Warr, "Southern Bell Switched-video Plans on Track," *Telephony*, *May 15, 1989*, p. 11.