Chapter 2

Radiocommunication Technologies and Services: Problem and Solution

As the velocity of change in telecommunications technology increases, so too does the political significance of international telecommunication regulation.[1]

Introduction

In the last decade, the pace of technology development in radiocommunications has dramatically quickened. Many new radio-based technologies and services have been developed and implemented, and yet more systems and services are waiting for spectrum allocations in order to begin delivering innovative services. These new technologies and services put increasing pressure on both domestic and international spectrum management structures and practices, making the process of allocating and assigning radio frequencies more complicated at all levels. Pekka Tarjanne, Secretary General of the International Telecommunication Union (ITU), recently commented,

> This entire subject has become increasingly complex because of the dramatically increased use of digital transmission, signal processing, and dynamic spectrum management techniques that both blur the distinctions between the old notions of radio services, and afford remarkable new opportunities for a more intensive use of the spectrum.[2]

These technology pressures are one of the most significant forces driving the 1992 World Administrative Radio Conference (WARC-92) and the changes envisioned for the ITU.

The relationship of technology/services and spectrum requirements, and the impact of new technologies and services on spectrum management is actually twofold. On one hand, new technologies make innovative services possible, increasing the demand for radio frequencies and contributing to spectrum congestion and 'crowding. For example, the advent of relatively low-power, limited-range transmitters, combined with new frequency reuse techniques and small portable phones, created the now-booming market for cellular telephony. In addition, existing services are also demanding more spectrum. The demand for high frequency broadcasting spectrum, for example, consistently exceeds the amount allocated for such services. On the other hand, new technologies can help ease spectrum congestion by enabling more efficient use of the spectrum, and by squeezing more users into existing bands. Digital compression and mixing techniques, for example, allow more information (charnels) to be transmitted.

Spectrum Basics[3]

Radio Waves

Radio waves are the basic unit of wireless communication.[4] By varying the characteristics of a radio wave—frequency, amplitude, or phase-these waves can be made to communicate information of many types, including audio, video, and data (see box 2-A). Radio waves that carry information are called radio signals, and the process of encoding intelligence onto a radio wave so that it can be transmitted over the air is called modulation.[5] In the process of modulation, the information or message to be transmitted-a human voice, recorded music, or a television signal-is impressed onto (modulates) a' 'carrier' radio wave that is then transmitted over the air. When a radio signal is received, the information is converted back into its original form (demodulated) by a receiver and output as sound, images, or data.

[1] James G. Savage, *The Politics of International Telecommunications Regulation* (Boulder, CO: Westview Press, 1989), P. 11.

[2] Pekka Tarjanne, "An Unusual Event," *Telecommunications Journal, vol. 58, No. HI,* March 1991, p. 123.

[3] Much of the material in this section comes from Richard Gould, ''Allocation of the Radio Frequency Spectrum," contractor report prepared fOr the Office of Technology Assessment Aug. 10, 1990.

[4] Although the term ''radio'' is most commonly associated with commercial radio broadcasting services (AM and FM radio), the term also properly encompasses the entire range of wireless communications technologies and services, including television microwave, radar, shortwave radio, mobile, and satellite communications.

[5] Two of the most familiar modulation techniques are amplitude modulation (AM) and frequency modulation (FM).

Box 2-A—Basic Definitions of Radiocommunication Terms

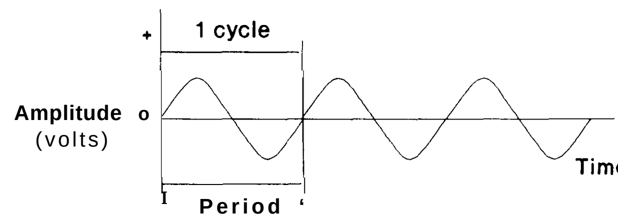
Radio communication depends on a number of basic characteristics and processes.

Amplitude: A measure of the value of a radio wave, measured in volts (see figure 2-A-l).

Analog: In analog radiocommunication, the message or information to be transmitted is impressed onto (modulates) a radio carrier wave, causing some property of the carrier-the amplitude, frequency, or phase-to vary in proportion to the information being sent. Amplitude modulation (AM) and frequency modulation (FM) are two common formats for analog transmission. In order to send analog signals, such as voice and video, over digital transmission media, such as fiber optics or digital radio, they must first be converted into a digital format. See modulation, digital.

Bandwidth: The process of modulating (see below) a radio wave to transmit information produces a radio signal, but also generates additional frequencies called ‘sidebands” on either side of the carrier (see figure 2-A-2). The total width of frequencies, including the sidebands, occupied by a radio signal is its bandwidth. In practical terms, however, the bandwidth of a signal refers to the amount of spectrum needed to transmit a signal without excessive loss or distortion. It is measured in hertz. In figure 2-A-2, the bandwidth of the signal is 4 kHz. The bandwidth of a radio signal is determined by the amount of information in the signal being sent. More complex signals contain more information, and hence require wider bandwidths. An AM radio broadcasting signal, for example, takes 10 kHz, while an FM stereo signal requires 200 kHz, and a color television signal takes up 6 MHz. The bandwidth required by a television channel is 600 times greater than that of an AM radio channel.

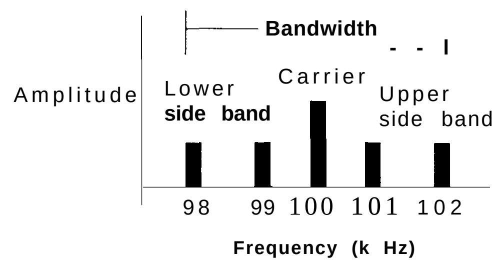
Figure 2-A-l—Basic Radio Wave



Each cycle of a pure radio wave is identical to every other cycle.

SOURCE: Office of Technology Assessment, based on Harry Mileaf (cd.), *Electronics One,* revised 2d ed. (Rochelle Park, NJ: Hayden Book Co., 1976) p. 1-10.

Figure 2-A-2-Side-Band Frequencies and Bandwidth



NOTE: This figure represents a 100-kHz earner wave modulated by 1- and 2-kHz frequencies.

SOURCE: Harry Mileaf (cd.), *Electronics One,* revised 2d ed. (Rochelle Park, NJ: Hayden Book Co., 1976), p. 1-31.

Radio waves are distinguished from each other by their frequency or their wavelength (see box 2-A). Frequency represents the number of cycles a radio wave completes in 1 second, and is the most common description of a radiocommunication signal. The international unit of frequency measurement is the hertz (Hz), which represents 1 cycle per second.[6] Radio signals can also be identified by their wavelength. Signals with long wavelengths have lower frequencies, while those at higher frequencies have shorter wavelengths. Commercial AM radio signals, for example, consist of very long waves (approximately 100 to 300 meters), that may complete a million cycles per second (1 megahertz (MHz)). Microwave signals, on the other hand, are very short (as little as 0.3 centimeters) and may complete hundreds of billions of cycles per second (100 gigahertz (GHz)). The relative nature of radio wavelengths is the origin of terms such as “short wave, ’ which was given to radio frequencies around

[6] Multiples of the hertz are indicated by prefixes (see box 2-A): “kilo” for one thousand, “mega” for one million, and ‘giga” for one billion. Thus, a million hertz-a million cycles per second—is expressed as one megahertz (abbreviated “MHz”).

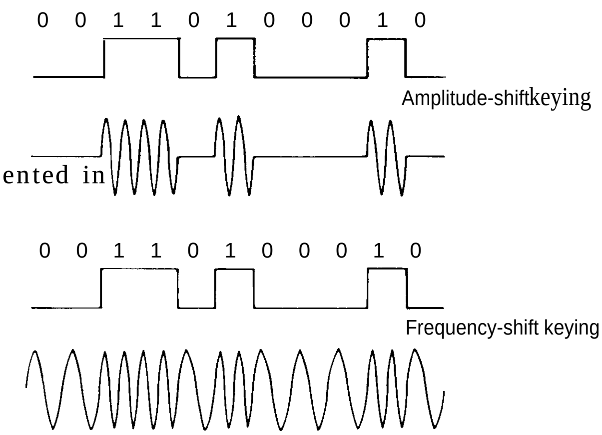
Carrier: A radio wave that is used to transmit information. Information to be sent is impressed onto the carrier, which then carries the signal to its destination. At the receiver the carrier is filtered out, allowing the original message to be recovered.

Digital: Digital transmission formats can be used to transmit images and voice as well as data. For continuously varying signals such as voice or images, an analog/digital converter changes the analog signal into discrete numbers (represented in binary form by O's and l's). These binary digits, or bits, can then be sent as a series of "on" /"off' pulses or can be modulated onto a carrier wave by varying the phase, frequency, or amplitude according to whether the signal is a "l" or a "O." Data is sent in a similar fashion although it does not have to be converted into digital form first. (See figure 2-A-3,)

Frequency: The number of cycles a radio wave completes in 1 second (see figure 2-A-4). Frequency is measured in hertz (1 cycle per second equals 1 hertz). Radio frequencies are described as multiples of hertz: kHz, kilohertz: thousand cycles per second; MHz, megahertz: million cycles per second; GHz, gigahertz: billion cycles per second.

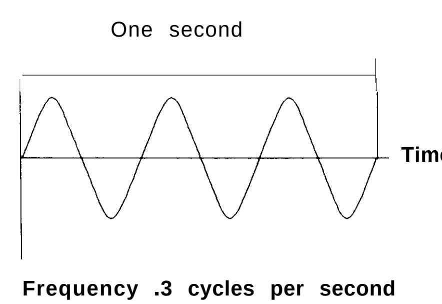
The frequency of a radio wave is the inverse/reciprocal of its period. For example, if a wave had a period of 0.1 seconds, its frequency would be 10 hertz.

Figure 2-A-3-Techniques for Modulating an Analog Carrier To Send information in a Digital Format



SOURCE: U.S. Congress, Office of Technology Assessment, *The Big Picture: HDTV & High-Resolution Systems,* OTA-BP-CIT-64 (Washington, DC: U.S. Government Printing Office, June 1990), figure 3-3, p. 41.

Figure 2-A-4-Frequency of a Continuous Wave



SOURCE: Harry Mileaf (cd.), *Electronics One,* revised 2d ed. (Rochelle Park, NJ: Hayden Book Co., 1976), p. 1-10.

(continued on next page)

2.8 MHz in the 1920s because the wavelengths in that frequency range were shorter than the wavelengths that had previously been used.

The radio spectrum is divided into "bands" that correspond to various groups of radio frequencies. These bands are identified by their frequencies or wavelengths (as above), or by descriptive terms that have been adopted over time. Several types of descriptive names have been attached to various portions of the spectrum (see figure 2-l). One method denotes relative position in the spectrum: very low frequency (VLF), high frequency (HF), very high frequency (VHF), superhigh frequency (SHF), etc. Another method derives from usage developed in World War II to keep secret the actual frequencies employed by radar and other electronic devices: L-band, S-band, and K-band.[7] The ITU classifies frequencies according to band numbers—Band 1, Band 2, etc. Frequency bands are also

[7] These letter designations are not precise measures of frequency because the band limits are defined differently by different segments of the electronics and telecommunications industries.

Box 2-A—Basic Definitions of Radiocommunication Terms-Continued

Modulation: The process of encoding information onto a radio wave by varying one of its basic Characteristics-am plitude, frequency, or phase-in relation to an input signal such as speech, data, music, or television The input signal, which contains the information to be transmitted, is called the modulating or baseband signal. The radio wave that carries the information is called the carrier wave. The radio wave that results from the combination of these two waves is called a modulated carrier. Two of the most common types of modulation are amplitude **modulation (AM) and frequency modulation (FM) (see figure** 2-A-5).

Period: The length of time it takes a radio wave to complete one full cycle (see figure 2-A-l). The inverse of the period is a radio wave's frequency.

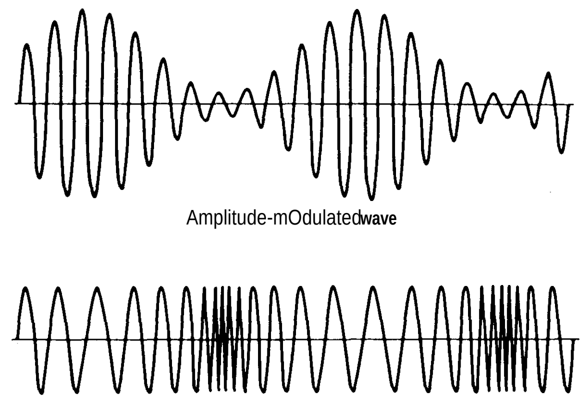
Phase: A measure of the shift in position of a radio wave in relation to time (see figure 2-A-6). Phase is often measured in degrees.

Spectrum: Each radio signal is actually made up of a number of different radio waves at different frequencies. The spectrum of a radio signal refers to the range of frequencies it contains. In **figure 2-A-2,** the spectrum of the signal extends from 98 to 102 kHz. The width of the spectrum is called the bandwidth of the signal More broadly, the radio frequency spectrum consists of all the radio frequencies that are used for radio communications.

Wavelength: The distance between successive peaks of a continuous radio wave.

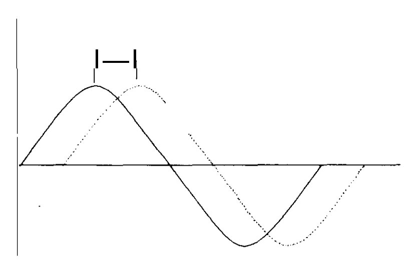
SOURCES: Harry Mileaf (ed.), Electronics One, revised 2d ed. (RochellePark, NJ: Hayden Book Co.,Inc., 1976); U.S. Congress Office of Technology Assessment, *The Big Picture: HDTV & High-Resolution Systems,* OTA-BP-CIT-64 (Washington, DC: Us. Government Printing Office, 1990); William Stallings, *Data and Computer* Communications (New York, **NY:** MacMillan **Publish**ing CO., 1985).

Figure 2-A-5--Amplitude and Frequency Modulation



SOURCE: U.S. **Congress, Office of Technology Assessment, The *Big Future: HDTV & High-Resolution Systems,* OTA-BP-CIT-64 (Washington, DC: U.S. Government Printing Office, June 1990), figure 3-1, p. 41.**

Figure 2-A-6-Phase of a Continuous Wave



SOURCE: Harry Mileaf (cd.), *Electronics One,* revised 2d ed. (Rochelle Park, NJ: Hayden Book Co., 1976), p. 1-10.

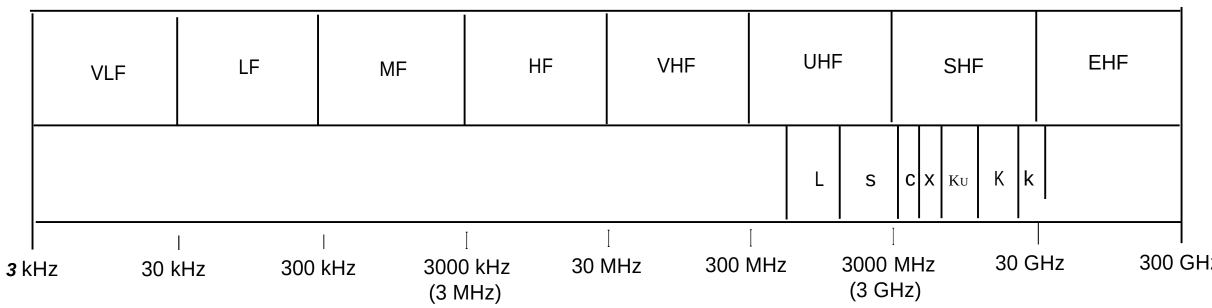
known by the services which use them-the AM radio broadcast band, for example, occupies the range (band) of frequencies 535-1605 kHz.

Transmission Characteristics

Several factors affect the transmission of radio signals, and at different frequencies, some factors will affect radiocommunication more than others. Attenuation refers to the weakening of a radio signal as it passes through the atmosphere. All radio signals are attenuated as they pass through rain or any kind of water in the air (clouds, snow, sleet), but radio signals at higher frequencies will be attenuated more than those at lower frequencies. For instance, the attenuation of a radio signal passing through a rain storm will be 10 times as great if the frequency of the signal is doubled from 5 GHz to 10 GHz. This makes radiocommunication, especially over long distances, extremely difficult in the upper (above 10 GHz) frequencies.

Radio waves are also bent and/or reflected as they pass through the atmosphere. Because of changes in

Figure 2-l—Frequency Band Designations



SOURCE: **Office of Technology Assessment, 1991, based on Richard G. Gould, "Allocation of the Radio Frequency Spectrum," OTA contractor report, Aug. 10, 1990.**

the density of the atmosphere with height, radio signals bend as they pass from one atmospheric layer to the next. This bending is called refraction (see figure 2-2). In addition to refraction, if atmospheric conditions are right, radio waves are also reflected by the ionosphere, the top layer of the Earth's atmosphere. Ionospheric reflection enables some radio signals to travel thousands of miles, and accounts for the long-distance communication that is possible in the frequency range between about 3 and 30 MHz (the HF band-see below).

Although refraction and reflection are conceptually distinct, and refraction can occur without reflection, it is possible to think of reflection as an extreme case of refraction in the ionosphere.[8] The amount of refraction, or bending, experienced by a radio signal is related to its frequency. Lower frequencies bend (are refracted) easily and are readily reflected back to Earth. Higher frequency signals experience less refraction than those at lower frequencies, and at progressively higher frequencies, there will be less and less bending. At a certain frequency, atmospheric conditions will be such that there is so little refraction that the signal will not be reflected back to Earth. The point at which this occurs is called the maximum usable frequency (MUF), and is generally in the range of 10-15 MHz, although it can be as high as 30 or 40 MHz or as low as 6 MHz, depending on time of day, season, and atmospheric conditions. Below the MUF, radio signals can be used for long-distance communication by reflecting the signal off the ionosphere. Above the MUF, the signal travels straight through the atmosphere and into space.

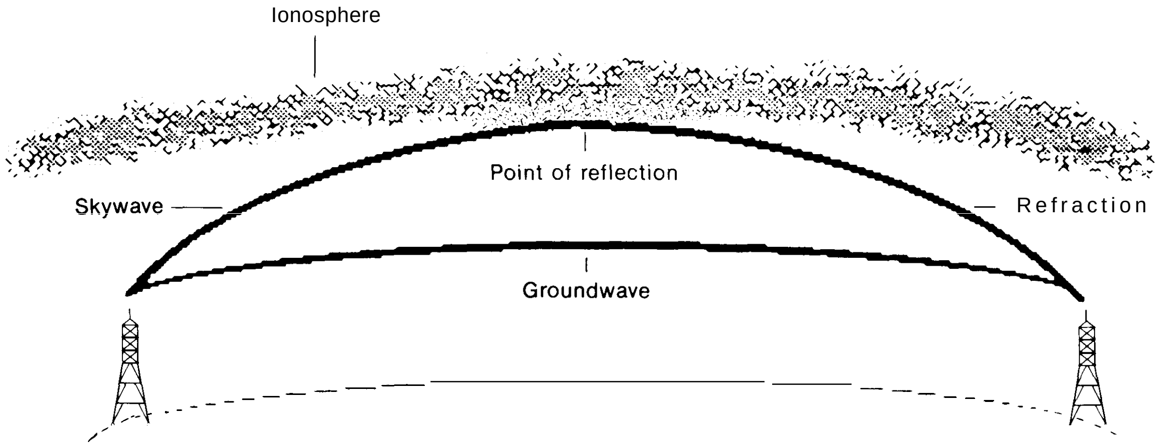
At higher frequencies, above the MUF, radio signals travel in almost straight lines from the transmitter to receiver, a transmission characteristic referred to as "line-of-sight."[9] Line-of-sight conditions affect radiocommunication above the MUF, but especially affect frequencies above 1 GHz. The distance a line-of-sight signal can travel is usually limited to the horizon or a little beyond. However, because the Earth is curved, the transmission distance will also be limited depending on the height of the transmitting antenna-the higher the antenna, the farther the signal can travel. For example, if the transmitting antenna is mounted on top of a mountain or a tall tower, the line-of-sight distance will be greater. Satellites, in simple terms, extend line-of-sight to the maximum distance (see figure 2-3). Line-of-sight transmission requires that there be no obstacles between the transmitter and receiver—anything standing between the transmitter and receiver, e.g., a building or mountain will block the signal.

Atmospheric conditions have substantial impacts on line-of-sight radiocommunications. Differences in atmospheric temperature or the amount of water vapor in the air, for example, can cause radio signals to travel far beyond the "normal" line-of-sight

[8] All radio waves are bent as they pass from a region of the atmosphere having a certain number of free electrons to a region with a different number of electrons. During the day, energy from the Sun splits the molecules of the gasses far above the surface of the Earth (in the troposphere and the ionosphere), producing many free electrons and creating layers of ionized particles. A radio wave from Earth entering one of these layers will be refracted, and if there are enough free electrons, the bending will be so great that the signal will be reflected back to Earth

[9] It is important to note that refraction does not cease to affect radio waves above the MUF. Even at frequencies in the VHF and UHF bands, radio waves bend slightly as they move through the atmosphere.

Figure 2-2—Radio Wave Transmission



SOURCE: Office of Technology Assessment, 1991.

distance. This condition is called ducting or superrefraction. At such times, signals travel for many miles beyond the horizon as though the Earth were flat. This condition is much more common over large bodies of water than over land. Atmospheric conditions can also bend the signal away from the Earth, shortening the practical transmission distance. The occurrence of these rare conditions complicates radio system design and spectrum management. For line-of-sight systems, too large a radius cannot be assumed for the service area because of the possibility that "subrefraction" or "negative' refraction may keep the signal from reaching the periphery of the service area. On the other hand, the same frequency cannot be used again many miles beyond the horizon because of the possibility that superrefraction may carry an interfering signal far beyond its accustomed limits. One of the basic functions of international spectrum management is to prevent or reduce such interference.

Characteristics of Radio Frequency Bands

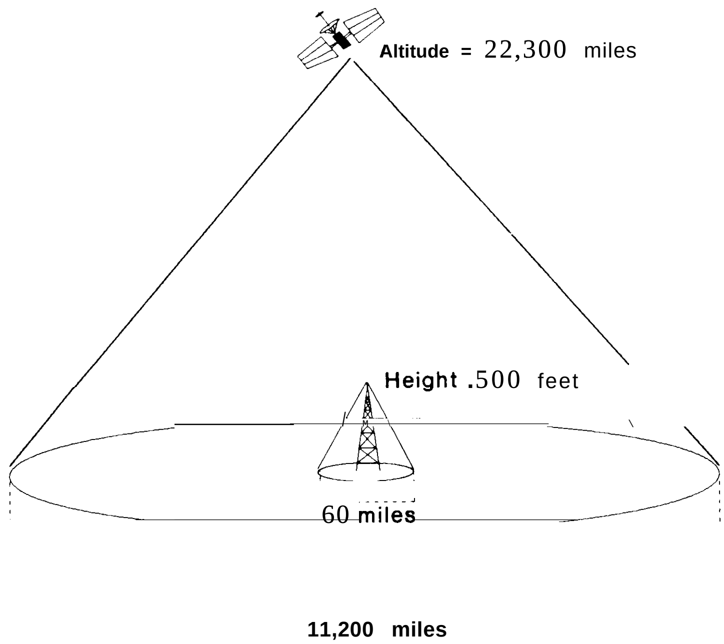
The physical properties of radio waves, combined with the various transmission characteristics discussed above, determine how far and where radio signals can travel, and make different radio frequencies better suited to certain kinds of communications services. The following is a brief description of the various radio bands, some of their uses, and the factors affecting transmission of radio signals in them.

Very Low, Low, and Medium Frequencies: 3 to 3000 kHz

In this portion of the spectrum, encompassing the bands denoted as VLF, low frequency (LF), and medium frequency (MF), radio signals are transmitted in the form of "groundwaves' that travel along the surface of the Earth, following its curvature. Groundwaves lose much of their energy to the Earth as they travel along its surface, and high power is required for long-distance communication throughout this portion of the spectrum. Groundwaves travel farther over water than over land.

At the lower end of this region, transmissions are used for low data rate communications with submarines and for navigation. The maritime mobile service, for example, has allocations in this band for communication with ships at sea. Conventional AM radio broadcasting stations also operate in a part of this band, at MF, typically between 540 and 1605 kHz. Attenuation during daylight hours limits the range of these AM stations, but at night, when attenuation is lower, AM radio signals can travel very long distances, sometimes even hundreds of miles. To prevent interference at these times to distant radio stations using the same frequency, some stations may be required to reduce the power of transmissions in the direction of those distant stations.

Figure 2-3-Terrestrial and Satellite Transmission Ranges



NOTE: This figure is not drawn to scale.

SOURCE: Office of Technology Assessment, 1991, based on Richard G. Gould, "Allocation of the Radio Frequency Spectrum," OTA contractor report, Aug. 10, 1990.

High Frequencies: 3 to 30 MHz

In this frequency range, denoted as HF, propagation of a "skywave" supplements the groundwave (see figure 2-2). While the groundwave dies out at about 100 miles, the skywave can be bent back to Earth from layers of ionized particles in the atmosphere (the ionosphere). When the signal returns to Earth, it may be reflected again, back toward the ionized layers to be returned to Earth a second time. The signal can make several 'bounces' as it travels around the Earth. It is this reflection that makes long-distance communication possible. However, there are occasional-and largely unpredictable— disturbances of the ionosphere, including sunspots, that interfere with HF communications. Overall, the reliability of HF communications is low, and the quality is often poor.

The HF 'shortwave' bands are used primarily by amateur radio operators, governmental agencies for international broadcasting (Voice of America, Radio Moscow), citizens' band radio users, religious broadcasters, and for international aviation and maritime communications. Overseas telephone links using HF radio have, for the most part, been replaced by satellites, and Inmarsat satellites have taken over a major portion of the maritime communications previously provided by HF systems. Likewise, future aeronautical mobile-satellite service (AMSS) systems may also supplement or replace the HF channels now used by airplanes when they are out of range of the VHF stations they communicate with when over or near land.

While little use is made of HF radio systems for domestic communications in industrialized countries like the United States, developing countries still find HF cost-effective for some of their domestic radiocommunication needs. This has led to a conflict over allocating the HF band internationally: the developed world wants to use the band for international broadcasting and long-distance mobile communication, while the developing countries want to retain it for their domestic point-to-point systems.

Very High, Ultrahigh, and Superhigh Frequencies: 30 MHz to 30 GHz

The groundwave, which permits communication beyond the horizon at lower frequencies (VLF, LF, MF), dies out after a short distance in this frequency range. Moreover, the skywave--which is reflected from the ionospheric layers at lower frequencies—tends to pass through the atmosphere at these higher frequencies. Communication in this band is thus limited to little more than line-of-sight distances. For short transmitting antennas, the maximum distance a radio signal can travel may be no more than 25 miles, but this distance can be increased by raising the height of the antenna.

This limitation can also bean advantage: the same frequencies can be reused by stations beyond the normal transmission range. Unfortunately, the distances that these line-of-sight signals can sometimes travel can be quite large, especially if the path is over water. At times, atmospheric conditions may establish a' 'duct" over a large body of water (see above). As it travels down the length of the duct a signal will be reflected back and forth between the water and the top of the duct, which can be hundreds of feet above the Earth's surface. These trapped signals can travel hundreds of miles. To minimize interference from a ducted signal, stations on the same frequency must be spaced far apart. This requirement limits the frequency reuse that can be achieved.

This part of the spectrum is used by many important communication and entertainment services, including television broadcast signals, FM radio, and land mobile communications. These frequencies are also used by the radiolocation service for long-range radars (1350 MHz to about 2900 MHz), aircraft landing radar (around 9000 MHz), and for point-to-point radio relay systems (various bands between 2000 and 8000 MHz). In recent years, communication satellites have made increasing use of frequencies in this band.[10]

The portion of this band between approximately 1 and 10 GHz is particularly valuable. It is bounded by increasing cosmic and other background noise at its lower end, and by precipitation attenuation at its upper end, but in between, communications can be carried out very well. Today, because of its favorable transmission characteristics, the 1-3 GHz band is especially sought after for mobile communications, including personal communication services (PCS), and for new broadcasting technologies such as digital audio broadcasting (DAB).

Above **10 GHz**

At 10 GHz and above, radio transmissions become increasingly difficult. Greater attenuation of the radio signal takes place because of rain, snow, fog, clouds, and other forms of water in the signal's path. Nevertheless, crowding in the bands below 10 GHz is forcing development of the region above 10 GHz. One desirable feature of the frequencies above 10 GHz, beside the fact that they are relatively unused, is the extremely wide bandwidths that are available. The 3-30 MHz, HF band, for example, is 27 MHz wide. That is enough bandwidth for about 9,000 voice charnels (at 3 kHz each). However, the frequency range 3-30 GHz is 27,000 MHz wide. That bandwidth could accommodate about 9 million voice channels.

Technologies and Services Create Congestion

The radio frequency spectrum has been more or less crowded almost since its first use for communication—technology (and the regulations and procedures to support it) must continually advance to enable the supply of spectrum to meet demand. Today, however, as the number of users and applications booms and more of the usable communication spectrum is filled, congestion has once again become a serious problem. Virtually all of the radio frequencies below 3 GHz are allocated and in use, and innovative technologies such as PCS, DAB, and air-to-ground communications systems must compete with existing services and technologies for a crucial slice of the spectrum pie. Spectrum managers are faced with a classic battle of old versus new—trying to accommodate existing technologies while simultaneously promoting innovation and technological advancement.

In the early days of radiocommunication, there were fewer services compared to today, and relatively few users. Nevertheless, the spectrum was still congested. The range of frequencies that could be

[10]Satellites operating in the C-band, e.g., use frequencies around 4 and 6 GHz, and are heavily used for transmitting television programming to cable television operators. Ku-band satellites, which generally operate at frequencies around 12 and 14 GHz, are increasingly being used for private communication networks and the delivery of entertainment programming.

used was limited by available technology, and equipment capabilities-transmitter power, antenna gain, receiver sensitivity-and, most important, by the cost of the equipment itself.[11] The government and commercial broadcasting concerns quickly filled the airwaves. As technology advanced, the range of frequencies that could be used for communication expanded, but the number of users and applications grew as well. And as increasing numbers of users began taking advantage of new services, the amount of unused spectrum shrank.

Over the past two decades, many new radiocommunication technologies have been developed, leading to the introduction and rapid dissemination of many innovative radio-based services. Satellites became a staple of long-distance communication in the 1970s and 1980s; in the 1980s first citizens' band radios and then cellular telephones put two-way radios in many of America's cars, trucks, and boats; and today, baby monitors, cordless phones, and garage-door openers are in many of America's homes. **All** of these technologies, and the services and industries they generated, depend on radio frequencies for their operation. The use of almost all these wireless systems and services will continue to increase as people come to depend on them more and more. The use of mobile radio communications systems, for example, has exploded in the last decade, and today there are over 10 million two-way radios being used by industry, transportation, and public safety (police and fire) organizations. This dramatic growth in the use of existing radiocommunication technologies, exacerbated by the rapid development of new radio-based technologies, has led to increasing crowding and congestion in many of the most valuable frequency bands.

Reallocating spectrum is difficult because the spectrum is finite-almost any allocation that is made to a new service (or for the expansion of an existing service) will have to be taken away from an existing service. The process is never easy—reallocation of spectrum is based on social and political factors as well as on technical and economic considerations. At the international level, the process of reallocation takes place at the WARCs, and WARC-92 is faced with resolving the competing demands of existing service providers who want to protect their spectrum or even expand it, and a variety of new services that are demanding access to spectrum. This is the technological context facing the United States as it approaches WARC-92. This section will examine some of the old and new technologies vying for spectrum both domestically and internationally.

Broadcasting

The demand for AM, FM, and TV broadcasting stations has been increasing, particularly in major market areas. Prospective operators of these stations see a need for more specialization in programming (narrowcasting) and for improved signal quality (e.g., high definition television (HDTV) for television stations and digital modulation for compact disc quality radio broadcasting). HF broadcasters such as the Voice of America and many religious groups also are making increasing use of radio broadcasting to reach audiences overseas (see ch. 1).

HDTV, which promises picture and sound quality far superior to today's television, has been in development for many years, but only recently have definitive steps been taken to promote its widespread adoption around the world.[12] Originally, an allocation was made for ITU Region 2 (the Americas) in the 12.2-12.7 GHz band to the broadcasting-satellite service (BSS) that would allow satellites to deliver conventional television programming directly to home receivers.[13] Since a plan was developed for this service in 1983, however, HDTV has developed rapidly, and HDTV proponents are now seeking to use the BSS allocations for this new kind of television, preferably in the same frequency band all over the world (see ch. 1). Experimental or quasi-operational HDTV service is currently being planned or implemented in Japan, the United Kingdom, France, and Germany.

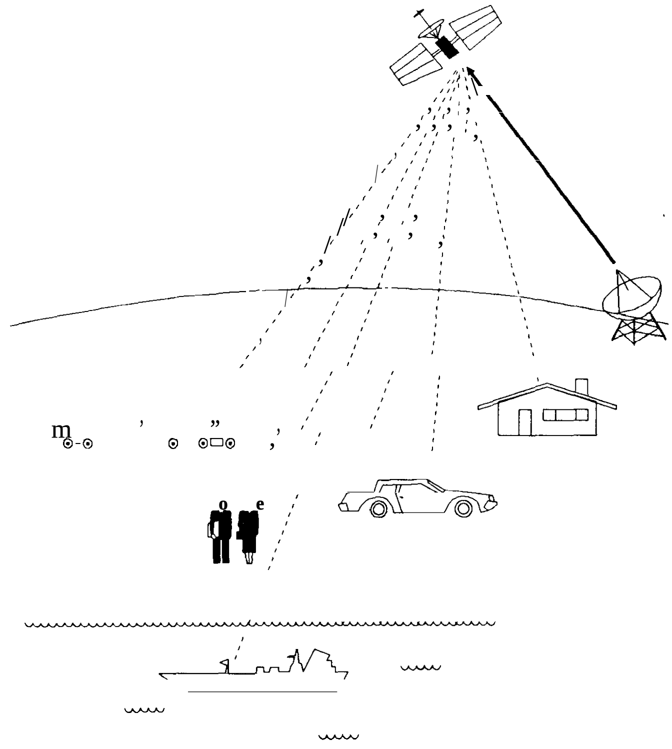
[11] When transmitters cost thousands of dollars, radio was used primarily for those commercial and governmental applications that could Justify the expense. Now, however, cellular mobile telephones are available for under $100, and remote garage-door openers, wireless microphones, and cordless telephones are within the budgets of millions of individuals and families.

[12] See U.S. Congress, Office of Technology Assessment *The Big Picture: HDTV & High-Resolution Systems,* OTA-BP-CIT-64 (Washington, DC: U.S. Government Printing Office, June 1990).

[13] The satellite transmission of programming directly to homes is also known as direct broadcast satellite service, or DBS. There are no DBS systems operating in the United States, although several are planned (see app. C). Only a few DBS systems are operating in other countries.

Another technology that is being aggressively developed is BSS-Sound.[14] BSS-Sound, while not yet in operation, will use satellites (supplemented in some cases by terrestrial transmitters) to deliver high-quality audio services directly to home and car radio receivers throughout the country (see figure 2-4). Such services will not be compatible with existing analog radio receivers, and will require consumers to buy new radios. Some operators plan to offer BSS-Sound services in conjunction with other mobile services such as paging and location services, and several companies have filed applications at the Federal Communications Commission (FCC) to provide such service. However, as of early July 1991, only one experimental application had been granted (see app. C). The primary hurdle to introduction of such services both domestically and internationally is a lack of agreement on the radio frequencies to be used (see ch. 1).

Figure 2-4--Broadcasting-Satellite Service-Sound



SOURCE: Office of Technology Assessment, 1991.

Mobile Services

Mobile communications is one of the fastest growing segments of telecommunications services. In the past 10 years, there has been a phenomenal growth of personalized radio services for general-purpose communications: cellular mobile telephone, specialized business mobile telephone services, local and nationwide paging, and the newest personal telephone services just on the horizon, PCS. Estimated yearly growth rates for mobile services are as high as 25 percent and up to 80 percent for cellular services worldwide, and demand shows little signs of slacking.[15] Nearly 15 percent of the telephone lines installed in this decade are expected to be wireless.[16] Mobile services delivered by satellite, including data transfer, voice services and position determination for individuals, cars, trucks, ships, and aircraft, are also experiencing rapid growth. WARC-92 will address increasing the allocations for both Mobile and Mobile Satellite Services.

Cellular

Since its inauguration in 1983, cellular telephone service has grown at an explosive rate (see figure 2-5), and is predicted to serve over 20 million subscribers by the year 2000.[17] Today, cellular service is available in all major urban areas of the country, and rural cellular licensing is in progress. In recent years, many cellular systems, especially in urban areas, have become increasingly congested—calls often cannot be completed because the system is overcapacity. The cellular industry has developed a number of innovative solutions to address this problem. Cell sizes have shrunk, allowing frequencies to be reused more often and more users to be served. Recently, the industry has begun moving toward the next generation of cellular systems using

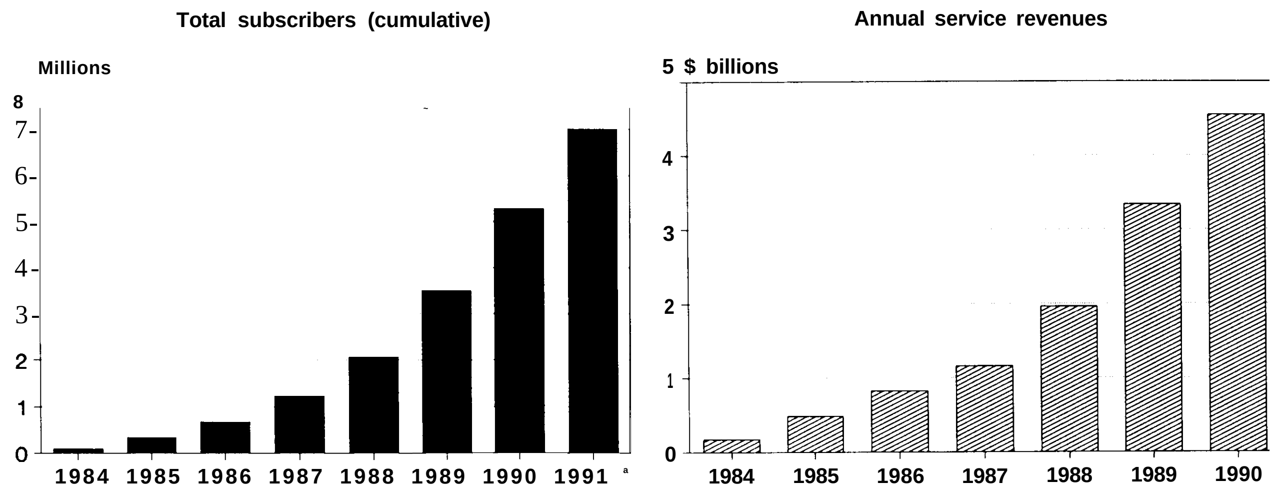
[14] The term digital audio broadcasting (DAB) is often used in the United States in place of BSS-Sound, reflecting continuing U.S. concern for terrestrial broadcasting systems and operators.

[15] Pekka Tarjanne, op. cit., footnote 2, p. 123. One conference brochure touts a 530-percent expansion of mobile communications markets (cellular, personal communication networks, cordless, mobile radio, and paging) by the year 2000.

[16] Pekka Tarjanne, "Simpler Radio Regulations?" editorial in *Telecommunications Journal,* vol. 58, No, II, February 1991, p. 65.

[17] John Keller, "Cellular Phones Dial Digital for Growth," *Wall Street Journal,* May 5, 1990, p. B1.

Figure 2-5-Growth in Cellular Phone Service, 1984-91



[a]The 1991 subscriber figure is an estimate.

SOURCES: U.S. Department of Commerce. International Trade Administration. 1991 *U.S. Industria/lOutlook* (Washington, DC: U.S. Government Printing Office, January 1991); and U.S. Department of Commerce, unpublished data, 1991.

digital technology. Digital compression technology, which can pack more phone calls into a given portion of spectrum, promises to increase cellular system capacity from 6 to 20 times (see below). Such advances will take time to implement, however, and some urban cellular systems may remain congested for many years.

In addition to traditional cellular voice applications, new data services are being developed. GTE Mobilnet, for example, is planning a field trial of a cellular packet data system (using existing cellular equipment) that could give rise to new services and expand the market potential for cellular networks .18 The system could be used for credit card verification, remote monitoring of vending machines, and connecting field service personnel to customer's records stored in a remote computer.

Personal Communications Services

PCS is emerging as an umbrella term encompassing a wide range of personal communications systems and applications now being developed.[19] Basically, PCS is wireless phone service that lets users communicate wherever they are-walking outside; in a car, ship, or plane; or even at work. PCS systems are usually considered terrestrially based, but satellite-delivered systems are also being developed. The use of small, lightweight and (eventually) inexpensive handsets is one common factor of all these systems.

PCS takes many different forms. The most basic type of PCS service is often called Telepoint. Telepoint allows users with portable phones to make calls (but not receive them) as long as they are close enough (within approximately 100 yards) to the Telepoint receiver that is connected to the public telephone network. Most advanced are the full-featured two-way voice and data services commonly known as Personal Communications Networks (PCN) (see box 2-B). PCNs will operate similarly to cellular telephone systems, but will use many more, much smaller cells (called microcells) that allow more people to use the system and enable smaller, more portable phones. These types of networks, which are being developed by telephone companies, cable television companies, and small telecommunications companies, allow users to place and receive phone calls or even exchange data with remote computers—all with radio technology that frees them from a wire connection. Eventually, users may also be able to send and receive video signals.

Many companies have begun PCS trials around the country, but none are operational yet (see app.

[18]"GTE Mobilnet Announces *a Field* Trial of a Cellular Packet-Data Network,"*Telcom Highlights International*, vol.13, *No*- 3, Jan. 16, 1991, p. 5.

[19]The February 1991 issue of *IEEE Communications* Magazine is devoted to personal communications and contains articles 011 technology, regulatory, and service issues. *IEEE Communications Magazine*, vol. 29, No. 2, February 1991.

Box 2-B—Future Phone? The PCN Is a Wireless To Watch

Pity the mail handlers at the Federal Communications Commission. When the agency asked for ideas last year on how to promote and regulate new wireless phone services, more than 3,000 pages of comments poured in from everywhere from Silicon Valley to Sweden. The intense interest reflected the huge potential of new wireless technologies, especially one called the personal communications network (PCN). Impulse Telecommunications Corp., a Dallas-based market researcher, estimates that by the year 2000, PCNs will bring in $2.78 billion annually-about what cellular phone systems bring in today.

Even though PCNs are at the experimental stage, proponents say they could eventually render the wired local phone monopolies passe. At minimum, they'll be one of many forces acting to loosen the grip of local phone companies on their customers. But before they take on the establishment, the upstart PCN systems must overcome technical, financial, and regulatory hurdles.

As envisioned by their proponents, PCNs would have light, inexpensive handsets that would communicate via low-power antennas. Subscribers would be able to make and receive calls while traveling, as they can with cellular phone systems, but at a lower price. Eventually, so many people would use PCNs that most calls would never have to travel over the wires of the local phone company.

Cable Assist. That's a costly vision. To carry as much traffic as their business plans call for, PCN startups may need to erect a dozen antennas to cover the same area that a cellular system now serves with one. That means an enormous up-front investment. Indeed, companies experimenting with PCNs are already seeking ways to hold down expenses-perhaps by piggybacking on cable TV networks or creating networks only in certain areas, such as within large office buildings.

Finding a market niche for PCNs will be a challenge, too. Cellular is already well entrenched. And a cordless phone service known as CT-2 does some of what PCNs promise, but at a substantially lower cost. Already used in England, CT-2 lets customers make-but not receive-calls while in the vicinity of special transmitters.

And regulation is yet another hurdle. The FCC hasn't decided how-or whether-to make room on the precious airwaves for a service that overlaps existing ones. To ease its way with the commission, New York-based Millicom Inc. is testing a PCN setup in Houston and Orlando that works on part of the spectrum already used by microwave communications.

Even PCN entrepreneurs concede that they have a long struggle ahead. "It's not a shoo-in, and we're going to have to learn things about it," says Millicom CEO J. Shelby Bryan. Still, even if they don't match the cellular-phone revolution, PCNs are likely to be one more factor in the demise of the local phone monopolies.

SOURCE: Reprinted from the Mar. 25, 1991 issue of *Business Week* by special permission.

C). Great Britain has experimented extensively with the more limited second-generation cordless telephone (CT2) and Telepoint systems. WARC-92 will address the issue of finding spectrum dedicated to PCS as part of discussions on Future Public Land Mobile Telecommunication Systems (see ch. 1).

Paging

The use of radio paging has also increased markedly in the last decade. From 6.5 million customers in 1987, paging services are expected to be used by 15 million customers by 1995.[20] Like many telecommunications applications, paging started out as a local service (for repair people, technicians, doctors), but now serves customers from all segments of the business community, including executives and sales personnel. In recent years, pagers have also gained popularity with illegal-drug dealers, who use them to keep in contact with their buyers.

Paging systems primarily use terrestrial radio signals to reach local subscribers, but several companies have developed national terrestrially based paging systems and still others plan to use satellites to deliver national paging. Paging companies would like to offer their services in foreign countries ("international roaming"), but equipment incompatibility is a limiting factor. Many different frequencies are used in other countries, and none of the larger developed countries use the same frequencies for their national paging service as those used in the United States. This means that a U.S. traveler

[20] U.S. Department of Commerce, National Telecommunications and Information Administration, "Telecom 2000: Charting the Course for a New Century," NTIA Special Publication 88-21 (Washington, DC: U.S. Government Printing Office, October 1988), p. 286.

cannot be served by his or her pager in a foreign country. New frequencies are being sought to permit paging anywhere in the world using the same paging unit.

Specialized Mobile Radio

Specialized Mobile Radio (SMR) services were created by the FCC in 1974 to provide land mobile communications on a commercial basis to businesses, government agencies, and individuals.[21] SMRs operate in two bands (around 800 and 900 MHz), and provide dispatch services and service similar to cellular telephony .22 Construction companies with many trucks at different job sites or limosine services are typical SMR users. Since the first service began operation in 1977, SMR service has grown to over 7,000 SMR systems serving over 1 million users. The annual growth rate for 800-MHz SMRs has been about 15 percent, but the growth rate of the newly introduced 900-MHz SMRs between 1988 and 1990 was over 240 percent. The FCC expects the growth rate for SMR services to remain in double digits for some years.

Radiodetermination-Satellite Service

The Radiodetermination-Satellite Service (RDSS) uses satellites to provide location information (primarily for vehicles, ships at sea and airplanes) and the transmission of brief data messages. RDSS systems, using new allocations around 1600 MHz for uplinks to the satellite, and around 2500 MHz for downlinks, are expected to be widely used by the transportation industry, among others, for locating vehicles and also will serve vital safety and rescue functions by helping to locate lost hikers, boats, and downed airplanes. Currently, the future of dedicated RDSS systems is in doubt with the recent bankruptcy filling of Geostar Corp., a leading proponent of RDSS. Some claim that RDSS will not survive as a service by itself, and that RDSS spectrum and services should be considered as part of a more generic Mobile Satellite Service (MSS) that would provide voice and data services in addition to RDSS.[23] Several companies, including those developing low-Earth orbiting satellite (LEOS) systems, plan to offer RDSS services bundled with more advanced messaging services (see app. C).[24]

Aeronautical Services

Another relatively new mobile radiocommunication service is air-to-ground telephone service for airline passengers. The FCC has expanded the number of service providers in the nascent field of phone service from airplanes (none transmits to airplanes yet). Currently, six providers are licensed to provide service from airplanes, up from only one a year ago.[25] Data services for airplanes are also being developed and implemented. COMSAT and ARINC, for example, have begun offering satellite-based low-speed data services to airlines with eventual services expected to include voice, electronic messaging, fax, and computer file transmissions.

Mobile Satellite Service

The increase in terrestrial mobile communication services is mirrored in space. Several developments have recently widened the provision of MSS. A portion of the spectrum previously set aside for aeronautical mobile-satellite service (AMSS) was recently reallocated by the ITU to land mobile-satellite service (LMSS). In the United States, the FCC approved a domestic mobile-satellite system which is scheduled for operation in the mid- 1990s.[26] Proponents of mobile-satellite services are already requesting that more spectrum be allocated for such systems, and WARC-92 will address how and where to provide more spectrum for future expansion of MSS (see ch. 1).

In the United States, interest is also growing in LEOS systems (see ch. 1). In contrast to the more

21For a description of SMRs, their history, and their regulations, see Doron Fertig, "Specialized Mobile Radio," background PaPer, Federal Communications Commission, Private Radio Bureau, Land Mobile and Microwave Division, Policy and Plarming Branch, March 1991.

22SMRs are generally smaller, less complex, and less costly to construct and maintain than cellular systems.

23"TRW, Loral/Qualcomm Venture," *Telecommunications Reports*, vol. 57, No. 24, June 17, 1991, p. 28.

24Qualcomm, Inc. already operates an extensive (16,000 terminals) two-way messaging service, and Orbital Communications Corp. and Starsys, Inc. plan to use LEOS to provide similar services (see below). Daniel Marcus, "Messaging Market Evolves," *Space News*, vol. 2, No. 24, July 8-14, 1991.

25The six are: Airfone, Inc., the first company t. receive an experimental license from the FCC; Clairtel Communications Group; Mobile Telecommunications Technologies Corp.; American Skycell Corp.; Jet Tel; and the In-Flight Phone Corp.

26The future of this system, t. be operated by the American Mobile Satellite Consortium (AMSC), was in doubt after a court struck down key portions of the FCC's ruling requiring a consortium approach. The FCC subsequently has issued a tentative decision reaffinning AMSC'S status as the U.S. MSS licensee. AMSC is proceeding with its plans.

common 'conventional" satellites, which circle the Earth in a geosynchronous orbit 22,300 miles above the equator, LEOS systems will use a network of smaller, lighter, and cheaper satellites to maintain constant contact with users on the ground.[27] Nine companies have applied with the FCC to offer LEOS services, basically divided into two groups-those planning to operate at frequencies below 1 GHz and those planning to operate above 1 GHz (see app. C). The frost LEOS systems proposed to the FCC plan to use frequencies below 1 GHz to deliver data services. Of this original group, none has been granted an operational license, but Orbcomm and VITA have received experimental licenses.[28] The other group of applications, including Motorola's Iridium system, propose systems that would use frequencies in the L-band (1.5- 1.6 GHz). They plan to offer both voice and data services. None of these applications has yet been acted on.

Part 15 Devices

Part 15 of the FCC Rules regulate radio-operated devices that, in theory, use such low power that they will not cause interference to other services and systems in the same band, and therefore do not need to be licensed. However, the number and variety of these devices has increased sharply in recent years, bringing about interference between the devices themselves, and between them and other services. Part 15 devices include: cordless telephones, wireless or cordless microphones (for stage performers, and for baby monitors), garage-door openers, control and security alarm devices (for fire, and intrusion detection), automatic vehicle identification systems (e.g., at toll plazas), auditory assistance devices (headsets used by hearing impaired patrons in theaters), and devices that permit the simultaneous viewing of a VCR on several TV sets throughout a house.

Part 15 devices operate under the restrictions that they must not cause interference to other users, nor claim protection from interference. However, the consumers who buy these devices are often unaware of their tenuous regulatory status. Not unreasonably, consumers think that the devices they have bought should perform their advertised function throughout their useful lifetime.

Point-to-Point Microwave Radio Relay Systems

The general growth in telephone usage, data communications, and information services and in the distribution of video materials such as TV programming and teleconferencing has brought about a commensurate increase in the need for long-distance, wideband, point-to-point systems for transmitting this information. Even though some of this demand has been absorbed by communications satellites and by the use of coaxial and fiber-optic cable systems, the number, extent, and capacity of terrestrial microwave systems have been growing. As the lower bands have become congested, particularly in and around major metropolitan areas, higher frequencies have been employed around 11 GHz, and 18-23 GHz. Some systems in the higher bands are designed for relatively short distances, with close spacing of the relay stations. These relays are small and self-contained, and can be mounted on existing telephone poles.

Radio in the Local Loop

A larger trend that may have an impact on the demand for radiocommunication services is the opening of portions of the public telephone network to competition.[29] Bypass of the public network 's increasing as large companies build their own networks or subscribe to private fiber networks and satellite teleports. Cable companies have begun to examine how their existing wire networks can carry telephone calls as well as video entertainment. Radio technologies, including microwave, cellular, and eventually microcell/PCN and satellite communications systems are increasingly seen as viable alternatives to the traditional wireline network—either replacing it completely or serving as an alternative way to connect to the public telephone network. These technologies provide potential competitors to the phone companies a way to build a

[27] While the individual satellites used in LEOS systems may be inexpensive compared to traditional geosynchronous satellites, this does not mean that the LEOS systems are any less expensive. Since they require many more (anywhere from 24 to 77 in current plans) satellites to cover the Earth, initial system costs still remain high. Motorola's Iridium, e.g., is expected to cost well over $2 billion.

[28] Andrew Jenks, "Flurry of Low Earth Orbit Filings Flood the FCC," *Washington Technology,* vol. 6, No. 6, June 131991.

[29] For a recent discussion of the technologies and politics of bypass and competition in the local loop, see Gary Slutsker, "Divestiture Revisited," *Forbes, Mar. 18, 1991,* pp. 118-124; Peter Coy and Mark Lewyn, "The Baby Bells Learn a Nasty New Word: Competition," *Business Week, Mar. 25, 1991,* pp. 96-101.

competing network and service without the major expense and time (and without having to acquire rights of way) for laying cable.

Many companies are now experimenting with wireless alternatives to the "last mile' or local loop connection of the phone companies, including the phone companies themselves. Several cable companies are investigating using their existing cable networks to supply PCN services (see app. C). There are several examples of how wireless local telephone service can be provided.[30] Cellular/PCS systems could supplement the existing wire network, but some advocates believe that with enough subscribers these systems could actually become a second phone system separate from the wire system. The second way in which radio technologies are coming into the local loop are through a new generation of digital radio services designed to bring local telephone service to rural areas not economically served by wire technologies. The primary advantage of such systems is their ability to bring 'plain old' and eventually advanced voice and data services to rural customers without the heavy expense of laying (copper or fiber optic) cable.[31] Such systems are currently serving more than 15,000 customers, with estimates that up to 900,000 more remote subscribers could be served.[32]

For the same reasons radio technology is attractive to rural applications in the United States, it also being deployed in developing countries and in countries with underdeveloped telecommunication infrastructures, such as Eastern Europe. The German Ministry of Posts and Telecommunications, for example, is considering radio technologies such as CT2 and PCN in order to improve telecommunications services in former East German states.[33]

Satellite Services[34]

Another fast growing telecommunication service vitally dependent on spectrum is the rapidly growing field of satellite communications. Satellite communication systems are used for a variety of purposes including delivering entertainment programming, transmitting long-distance telephone calls, and facilitating data transmission. For example, private users as well as government agencies are making increasing use of private satellite networks based on very small aperture terminals (VSATs). The decrease in size, cost, and ease of installation has made satellite receivers attractive to users with minimal communications requirements. Customer premises Earth stations are frequently located on the roof of a company headquarters or a warehouse. These stations are most commonly used for data communications, but can easily accommodate voice and video applications as well.

Networks of these satellite terminals allow businesses to communicate directly with hundreds or thousands of individual locations. Currently, an estimated 20,000 VSATs are operating in the United States, and estimates project use to increase severalfold by 2000.[35] Chevron, for example, has begun building a private network connecting approximately 4,000 service stations and corporate sites, primarily for interactive data, but also with some video services.[36] The FCC typically grants blanket licenses to hundreds or even thousands of VSATs at a time.[37]

Two of the most rapidly increasing uses of satellites are for videoconferencing and education. Interactive videoconferencing has increased dramatically in recent years as standards have been established and technology has improved the quality

[30] For a more detailed description of how radio technologies are being used to deliver local telephone service in rural areas, see U.S. Congress, Office of Technology Assessment *Rural America at the Crossroads: Networking for the Future,* OTA-TCT-471 (Washington DC: U.S. Government Printing office, April 1991), pp. 71-74.

[31] The average cost of providing access to rural customers can run as high as $10,000, while the average cost of digital radio is $3,000. Ibid., P. 73.

[32] Ibid.

[33] Local wireless access will be tested later this year with CT2 in order to get subscribers connected to the public network as quickly and cheaply as possible. In the future, PCN may either function as an alternative to the public network or as a supplement to it, as cellular. "Wireless Technology for Eastern GermanY," Telecommunications, International Edition, vol. 25, No. 4, April 1991, pp. 15-16.

[34] The services described in this section represent only one small portion of all the satellite-based systems. Other services, such as mobile satellite, are described elsewhere in this chapter depending on what type of service they deliver.

[35] "VSAT NOTES," *Telcom Highlights International,* vol. 13, No. 13, Mar. 27, 1991, P. 14.

[36] 'Hughes Installing Hybrid VSAT Network for Chevron Corp., " *Telcom Highlights International,* vol. 13, No. 1, Jan. 2, 1991, p. 16.

[37] Scientific Atlanta, e.g., was granted a license for 2,500 VSATs, while GTE Spacenet was granted a license for 101. "Actions of Interest at the FCC," *Telcom Highlights International,* vol. 12, No. 50, Dec. 12, 1990, p. 15.

of the transmission while simultaneously lowering the cost. During the recent war in the Persian Gulf, for example, videoconferencing increased dramatically as U.S. businesses restricted travel abroad. The educational use of satellites, distance education, has also increased dramatically in the last 5 years.[38] In most education uses, satellites are used to transmit a live, one-way video image of the teacher to subscribing schools around the country. Students at the schools can respond to the teacher in real-time through the use of telephones ("800" numbers) or computers. Such systems have proven to be a highly effective way to bring educational resources to isolated students.

During the 1980s, C-band satellites, operating in the 6/4-GHz bands, were the most commonly used satellites for commercial, education, and entertainment applications. However, the anticipated growth in smaller Earth stations has led to launching of many higher-power, Ku-band satellites for U.S. domestic service. The next frontier for satellite services is at 20 and 30 GHz, the Ka-band. This shift up in frequency is occurring not because the higher frequency bands are attractive technically (in fact, they are extremely sensitive to rain attenuation), but because lower frequency bands are at or near capacity. Italy and Japan have launched experimental Ka-band satellites, and the National Aeronautics and Space Administration's (NASA) Advanced Communications Technology Satellite (ACTS), expected to be launched in 1993, will operate in this band. Norris Satellite has filed an application for a commercial Ka-band system.

Other Specialized Services

Many other specialized radio services are being developed, some of which are already operating:

Stolen Vehicle Recovery Systems

Stolen Vehicle Recovery Systems (SVRS) are proliferating. Ire-jack, a service intended to aid in the radiolocation of stolen vehicles, is one example. A radio receiver/transmitter is mounted in an unobtrusive location on vehicles. If a vehicle so equipped is stolen, the owner calls the police and a coded transmission is broadcast which turns on the transmitter in that vehicle. Radio direction finders can then be used to home in on the stolen vehicle. Implementation of this new service required the reallocation of only one 25-kHz wide radio channel, but even that small "loss" of spectrum was strenuously opposed by many government agencies having large and growing mobile radio requirements. In addition to the original Ire-jack system, many other companies have entered the vehicle location and tracking market, including Teletrac, which plans to expand its services to 100 metropolitan areas in the next several years.[39]

Interactive Video Data Service

Interactive Video Data Service (IVDS) uses radio signals to allow television viewers with special home transmitters to interact with all forms of commercial, educational, and entertainment programming delivered by broadcast, cable, or direct broadcast satellite technologies.[40] Users are able to shop or bank from home, respond to polls, and receive information through their television sets. The system has been tested and is currently the subject of an FCC Notice of Proposed Rulemaking.[41]

Wireless Business Telephone

Wireless business telephone systems are being developed which provide the same features and capabilities of existing (wire-based) business telephone systems. These systems utilize digital radio signaling and intelligent transmission management techniques to eliminate many of the quality, noise and fading problems of cordless and cellular telephones. At the same time, they provide complete coverage anywhere within a building.[42]

[38] For a complete discussion of distance learning, see U.S. Congress, Office of Technology Assessment *Linking for Learning: A New Course for Education*, OTA-SET-430 (Washington, DC: U.S. Government Printing Office, November 1989).

[39] "Teletrac Launches Fleet Locator Service,' *Telcom Highlights International*, vol. 13, No. 3, Jan. 16, 1991. p. 16.

[40] "FCC Proposes Interactive Video Data Service in the 218-218.5 -Band d," *Telcom Highlights International*, vol. 13, No. 3, Jan. 16, 1991, p. 18; "FCC Proposes Spectrum Allocation for New TV-Based 'Interactive Video Data Service,' " *Telecommunications Reports*, vol. 57, No. 2, Jan. 14, 1991, p. 10,

[41] Gen Docket No. 91-2, Notice *of proposed Rule Making* "Amendment of Parts (),1,2 and 95 Of the Commission Rules to Provide for Interactive Video Data Services," 6 FCC Rcd 1368 (1991).

[42] "New Wireless Business Telephone Market To Reach $2.1 Billion," *Telcom Highlights International*, vol. 13, No. 6, Feb. 6, 1991, p. 5.

Wireless Data Applications

One of the "hottest" new wireless services involves the use of radiocommunications for data transmission. Many types of wireless data systems are being developed using infrared signals, spread spectrum (see below) signals below 1 GHz, and microwave signals.[43] Wireless data applications include both wireless local area networks (LANs) such as those marketed and proposed by Motorola and Apple, and wide-area data services such as Ardis (Motorola/IBM), Coverageplus (Motorola), Mobitex (Ericsson), and VISA's proposed radio-based authorization system for credit cards.[44] Ram Mobile Data has begun operating a digital mobile data service in several cities in the SMR band.[45] NEC has also introduced a wireless portable computer that combines the functions of a standard personal computer with cellular communications capabilities.[&]

Technology Solutions to Spectrum Crowding

Many solutions have been proposed to alleviate spectrum congestion. Some of these are technological, some economic, some legislative, and some administrative. The earliest technological advancements involved the development of inexpensive and widely available microprocessors, which allow radio signals to be easily manipulated. Recently, advances in digital technology have reduced required channel bandwidths, increased charnel capacities, and made it easier to combine and configure radiocommunications systems to make them more efficient.

Most of the technological solutions to spectrum crowding focus on opening up more of the spectrum-expanding the range of usable (higher) frequencies and making spectrum use more efficient. Improved efficiency generally means that more users can share the same spectrum bands and that different services can coexist using the same frequencies.[47] Certain technological solutions that have increased the efficiency of spectrum were developed specifically to solve a congestion or interference problem. Others, however, were developed to create new radiocommunication services, but did so in a way that made more efficient use of spectrum than the conventional systems they replaced or supplemented. This section will describe some of the technological solutions that may help ease spectrum crowding.[48]

Use of Higher Frequencies

As the lower frequency bands have become increasingly crowded, engineers have begun to develop technologies that would use higher, less crowded frequencies.[49] The use of higher frequencies does not mean that more efficient use is now being made of the spectrum-it is simply an escape to less crowded territory. As was the case in extending terrestrial frontiers, taming the wilderness is difficult and expensive. In addition to the cost of developing new devices that will operate at the higher frequencies, transmission problems typically worsen at higher frequencies. Some of those problems, such as increased attenuation due to rain, appear to be surmountable only by brute force-by increasing transmitter power. In satellite systems,

[43]For further discussion of wireless LANs, see Christopher Hallinan, "Cableless LANs: The Network of the Future?" *Telecommunications, International* Edition, vol. 25, No. 6, June 1991.

[44]Ira Brodsky, ''Wireless Data Networks and the Mobile Workforce, "Telecommunications, North American Edition, vol. 24, No. 12, December 1990; "VISA, Digital Radio Networks Have Pact To Roll Out 'Radio Wave Authorization Services,' " *Telecommunications Reports,* vol. 57, No. 7, Feb. 18, 1991, p. 36.

[45]''Ram Mobile Data Rolls Out Digital packet-switched Mobile Data Service in 10 Markets,'' *Telecommunications Reports,* vol. 57, No. 7, Feb. 18, 1991, p. 34.

[46]''Japan's NEC Corp. Unveils Its Wireless Notebook PC,' *Wall Street Journal,* Mar. 28, 1991, p. B1.

[47]Efficiency is not easily defined. While efficiency is often touted as a goal in and of itself, it is rarely pursued for its own sake, Rather, it is mOre properly conceived of as a means to an end—a way to extend or expand the use or availability of a resource, in this case spectrum. The ultimate goal of efficiency in this view of spectrum use, therefore, is not just being efficient, but permitting as many users and services to share the spectrum as possible. Other definitions of efficiency emphasize the social use of the resource—is one television channel or 600 AM radio stations or 1,500 telephone calls most efficient? If all use the same amount of spectrum, some type of social utility or market value approach may be used to define which is more efficient.

[48]For a discussion of the range of solutions t. spectrum crowding, see U.S. Department of Commerce, National Telecommunication and Information Administration, *U.S. Spectrum Management Policy: Agenda for the Future, NTIA* Special Publication 91-23 (Washington, DC: U.S. Government Printing Office, February 1991), p. 13; and Richard Gould, op. cit., footnote 3. See also Margaret E. Kriz, ''Supervising Scarcity,' *The National Journal,* July 7, 1990, and George Gilder, "What Spectrum Shortage?" *Forbes,* May 27, 1991, for a broader discussion of the issues involved in domestic spectrum allocation and management.

@For a recent discussion of the Upwind expansion of usable radio frequencies, see Edmund L. Andrews,''Seeking To Use More Of the Radio Spectrum,'' New *York Times,* Sept. 11, 1991, p. D7.

power must be increased at both the original transmission (uplink) site on Earth and on the satellite itself. Increased satellite power greatly increases costs.

Trunked Mobile Systems

In conventional (nontrunked) mobile radio systems, one or more users are assigned to the same charnel. If that channel is busy, the user must wait until the channel is free. This process is unnecessarily time-consuming to the user, and delays the handling of messages. Not infrequently, the same channel is assigned to different companies, some of which may even be competitors in the same field (e.g., taxi companies, pizza delivery services, cement suppliers). Such disparate users have no business incentive to accommodate the needs of others seeking use of the charnel. Moreover, all the information being sent on the charnel can be heard by all its users, including potential competitors. Trunking can increase the amount of traffic that can be handled by specialized mobile telephone systems while protecting the privacy of the user.

Trunked systems use many communication channels to serve a much larger number of users. A user seeking access to the system initiates a request for a communications charnel by lifting a microphone or handset (or pressing a button). The system automatically searches for an open pair of frequencies (one each for incoming and outgoing signals) and assigns it to the user. When the connection is ready both stations are signaled, and both the mobile unit and the base station are automatically tuned to the selected frequencies. Busy signals are sent if no channels are available, or if the base station is otherwise occupied. Requests for a specific base station can be stacked up and handled in order of receipt. In trunked systems, users do not 'inadvertently hear any other conversations. Scrambling or channel-hopping schemes can be built in to the system controller to increase the level of privacy.

Establishment of trunked systems has been somewhat easier for nongovernment users than for government agencies. The majority of SMR systems, for example, are trunked systems. A group of companies, or an individual entrepreneur, can establish a trunked system for common use based on its economic appeal: namely, better communications at lower cost than in separate, individual channel systems. However, it has been difficult for the government to use trunked systems since agencies generally do not like to share systems with each other.

Reuse of Frequencies in Mobile Cellular Radio Systems

Mobile cellular radio is an example of a technology that was developed to provide a new service, but that also makes more efficient use of spectrum than previously existing mobile systems. In cellular systems, a mobile user is switched automatically from one base station to another as the vehicle moves from one part of a city to another, or travels from city to city. This "cellular' feature, designed to provide geographic continuity of service, results in a significant reuse of frequencies, and the amount of frequency reuse can be increased as traffic in the system increases.

In order to visualize how a cellular system maximizes frequency reuse, imagine a large metropolitan area covered, at frost, by one base station with power high enough to cover the whole area. In that situation, the frequencies are used only once throughout that area. As the traffic volume within the service area grows, the one base station can no longer accommodate all users and is replaced by several, lower-power stations. While the same frequencies cannot be used by adjacent transmitters (i.e., by transmitters in adjoining cells), they can be reused two cells away. Within a geographic area encompassing many cells, the same frequencies might be used three or four times. Shrinking cell sizes and lower transmitter powers, however, are not a permanent solution. Growth will continue, and there are limits on how small a cell can be and how low power can go while still maintaining adequate quality. Eventually, new methods must be found to accommodate steadily increasing numbers of users.

Digital Compression

The trend toward digital processing and transmission in all forms of radiocommunication has significant potential to increase channel capacity and service quality and options. Ironically, converting and transmitting analog signals in a digital transmission format requires larger bandwidths than transmitting the analog signals in their original form. The benefits of digital radiocommunications come in its ability to compress and combine signals. Digital compression works by removing redundant or unnecessary information from the signal. In audio transmission, for example, sound frequencies that the human ear cannot hear are often removed. This allows less information to be sent, requires less bandwidth, and allows more channels (conversations, broadcasts) to be transmitted.

Applications using digital compression techniques are spreading rapidly in many radiocommunication services. In cellular telephony, for example, digital signal processing (DSP) promises improved quality and capacity eight times as great as existing analog cellular systems.[50] COMSAT has developed technology that digitizes, compresses, and combines up to three separate TV signals for transmission on a single satellite transponder.[51] Other technology is under development that will combine up to 16 video signals on a single charnel.

Combined with compression, digital transmission techniques also allow radio signals to be sent more efficiently. Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) are digital coding schemes that allow more charnels to be packed into any given bandwidth than analog technology could ever allow.[52] TDMA divides each conversation or data stream into discrete chunks and sends them at specified times coordinated with a receiver that then reassembles the chunks of data into the whole conversation. CDMA techniques assign each transmission a unique identification code that allows the receiver to pick out the desired signal from among many simultaneous signals. All signals share the same range of frequencies. CDMA is used in many spread spectrum applications (see below). The primary application of such techniques is in mobile communications such as cellular and PCS, where their impressive capacities promise to alleviate at least some of the near-term capacity shortages now being experienced in cellular systems around the country. TDMA, for example, is expected to increase current capacity by 3 to 5 times, while CDMA proponents claim that CDMA will boost capacity 10 “to 20 times.[53] Which technique will dominate is unclear. TDMA appears to be further developed than CDMA, and has already been endorsed by the Cellular Telecommunications Industry Association for use in second generation cordless systems. CDMA, on the other hand, maybe more spectrum efficient than TDMA, but will require new, and potentially expensive, transmission and receiving equipment. Many companies, however, are testing CDMA and some have announced plans to build CDMA systems.

Improved Transmission Techniques

Satellite Antennas

Advanced satellite antennas permit the use of smaller, less expensive Earth stations by making more efficient use of available satellite power. Such antennas direct the signal toward, and concentrate it in, areas where the intended users are located. Systems with such antennas, called spot beams, also make more efficient use of spectrum than those with large, circular beams which waste satellite power by transmitting beyond the limits of the desired service area. The reduction of signal levels outside the service area permits the same frequencies to be reused by other systems serving nearby areas, in the same way that cellular technology operates. Motorola’s Iridium and NASA’s ACTS satellite systems both plan to use spot beam techniques.

Spread Spectrum

Spread spectrum is a modulation technique first developed to hide military communications amid natural noise. More recently, spread spectrum has been used to permit low-level signals to share spectrum with other services. As the name implies, the original modulating signal is spread over a wide range of frequencies (bandwidth) for transmission. The spreading over the wider band of frequencies is done according to a pattern that is also known by the receiver. The receiver reconstructs the incoming signal using the same pattern as the one used for spreading it. Interference from conventional signals, or other spread spectrum signals using a different spreading pattern, appear as noise to spread spectrum signals, and can be faltered out.

There are several types of spread spectrum systems. One type, known as direct-sequence spread spectrum, divides a radio signal’s energy over a wide range of frequencies so that a little part of the signal

[50] Steve Cox and Bob Fine, “DSP May Spell Relief for Urban Cellular Congestion” *Telephony*, vol. 220, No. 9, Mar. 4, 1991, p. 18.

[51] “Compression News From COMSAT,” Satellite *Communications*, vol. 15, No. 1, January 1991, p. 9.

[52] For a discussion of CDMA and TDMA, see Donald L. Schilling, Raymond L. Pickholtz, and Laurence B. Milstein, “Spread Spectrum Goes Commercial,” *IEEE Spectrum*, vol. 27, No. 8, August 1990.

[53] Charles Mason, “Motorola, PacTel To Test CDMA,” *Telephony, vol. 220, No.* 17, Apr. 29, 1991.

appears on each frequency in the band. Frequency-hopping spread spectrum techniques spread a signal out over many frequencies by hopping from frequency to frequency in a sequence synchronized with the receiver. One frequency is not dedicated to one user, and all frequencies can be used more efficiently. Satellite CD Radio, for example, has proposed a digital frequency-hopping scheme for its BSS-Sound system that hops frequencies every 2,000th of a second and is thus better able to resist the fading of a particular frequency, resulting in improved quality.[54]

Frequency modulation or FM, is a crude form of spread spectrum. Terrestrial radio relay systems and satellite transponders compensate for their limited transmitter power by using FM, which spreads the signal over a much wider bandwidth. Thus, bandwidth can be "traded' for some of the power that would otherwise be required to send a usable signal from space to Earth. The price for this reduced power requirement is much less efficient use of spectrum. A TV signal that can be broadcast from a local station using only 6 MHz requires some 36 MHz when carried by satellite.

Because of spread spectrum's ability to coexist or overlay other types of radiocommunications signals, it is being aggressively developed as a way for many users to share spectrum. But while the spread spectrum technique permits many low power signals to share a band, each of the spread spectrum signals adds to the background noise level of the other signals in the band—including any other spread spectrum signals, lowering the signal-to-noise ratio of them all. As more signals are added, the noise will eventually become too great for good communications. New adaptations of spread spectrum techniques, including advanced forms of CDMA may help solve some of these problems.[55]

Single Sideband Transmission

In single sideband transmission (SSB), only one set of the sidebands (see figure 2-A-2) that makeup a radio signal is transmitted.[56] This is possible because all of the intelligence in a radio signal (e.g., music, video, speech) is contained and duplicated in both upper and lower sidebands. Eliminating one of the sidebands has no effect on the information being sent, and receivers can still reconstruct an accurate signal.

There are several advantages in SSB transmission, most importantly, the fact that SSB reduces by half the bandwidth required to send a signal, thereby allowing more signals to be sent or to reduce the interference between signals. Another advantage of SSB is its reduced susceptibility to noise and other forms of interference since there are fewer frequencies for noise to invade. The disadvantage of SSB is that it requires more sophisticated (and hence, more expensive) transmitters and receivers. Today's HF broadcast receivers will not work with SSB transmissions, and replacement will be necessary.[57] One of the U.S. positions for WARC-92 involves the expanded use of reduced carrier SSB transmission for HF broadcasting.

Alternatives and Competitors to Radio Systems

The remarkable advances in radio technology have been paralleled by equally remarkable advances in wire-based systems and devices.[58] In many cases, these technologies can provide an alternative to radio-based systems, thus relieving some of the pressure on crowded spectrum resources. The use of fiber optics for long-distance telephone service is one example. The majority of long-distance telephone calls used to be carried by microwave radio links and satellites. However, with the development of fiber-optic transmission technologies in the 1980s,

[54] *Satellite* communications, Op. cit., footnote 51, pp. 9-10.

[55] Synchronous CDMA, e.g., is being developed for use in future personal communications systems. Jack Taylor, Cylink, personal communication, Mar. 14, 1991.

[56] For a discussion of sidebands and single sideband transmission, see Harry Mileaf (cd.), *Electronics One* (Rochelle Park, NJ: Hayden Book Co., 1976).

[57] Currently, full-carrier double-sideband is used in the HF broadcasting bands. This is a major barrier, especially for developing countries, where the cost of radio receiver replacement becomes an issue. Broadcasters do not want SSB until listeners have receivers, but no one will manufacture or buy receivers until there is something to listen to. To address this problem, the United States submitted a proposal to the Inter-American Telecommunications Conference (CITEL) Interim Working Group for the WARC, "encouraging the manufacture, in developing CITEL countries, of inexpensive, HF-broadcast receivers compatible with the three classes of emission potentially involved in the conversion of HF broadcasting from the full-carrier double-sideband (DSB) presently in use, to reduced-carrier single-sideband (SSB)." Input document WARC-92/19 for CITEL PTC III 1992 WARC Interim Working Group.

[58] Wire-based is used here to refer to any of the so-called wireline media, including: twisted copper wire pairs, coaxial cable, digital T-1 lines, or fiber optics.

many long-distance telephone providers began to build extensive fiber-optic networks to take advantage of the huge capacity and high quality of optical transmission. Today, most domestic long-distance telephone service is routed over fiber-optic lines, leaving satellites and microwave to carry data and video services.[59]

Another alternative to radio transmission, primarily for the delivery of video programming to the home, is cable television. Broadband cables for cable television now pass 85 percent of homes in the United States, and cable penetration is above 60 percent. Most cable service is now transmitted over coaxial cables, but in new installations the trend is to use fiber optics. Such systems could supplant some radio-based systems to bring communications to homes and businesses at freed, and more or less permanent, locations. Such a shift would release spectrum to those services, such as broadcasting to mobile and portable receivers and the mobile services in general, that have no practical alternatives to radiocommunication.

In the long run, the division of communications services and resources between wired and radio services may need to be revisited. Many analysts believe that communication services now using radio spectrum could be easily (and in some cases better) supplied through wire media.[60] Radiocommunication systems would be used for applications or services not possible or practical with wired systems, such as mobile applications. If applications were switched from radiocommunication to wire delivery, a large amount of spectrum could potentially be freed for other (mobile) uses.

Barriers to such a fundamental reordering of the communications infrastructure in this country are formidable. Entrenched users will fight to keep their spectrum resources. The question of who would finance such a changeover is also difficult. In the case of long-distance providers, adequate market incentives existed to make the switch. Unfortunately, that may not be the case for all alternatives and incentives may have to be put in place to encourage users to move. Long-term U.S. telecommunications policy should examine the consequences of this shift in communication resources in order to maximize the efficient use of the spectrum. Consistent with these themes, the National Telecommunications and Information Administration (NTIA) makes the following recommendations:

> NTIA and the FCC should develop policies on the use of non-radio technologies as part of a coordinated program to foster spectrum efficiency, when consistent with other public policies. NTIA and the FCC should also develop additional regulatory or economic incentives for the use of alternative technologies in congested areas.[61]

Summary

Recent developments in radiocommunications technology have put increasing pressure on spectrum management structures and processes, but also offer opportunities for using spectrum resources more efficiently-allowing more users to have access to them. Structures, procedures, and philosophies that were adequate for dealing with technology developments in the past maybe inadequate to meet future planning and allocation needs. The rapid pace of technological development requires nations to adopt a flexible approach to wireless communication and spectrum management. Hardened approaches protected by entrenched interests, both within the government and the private sector, international and domestic, must give way to structures and processes that encourage innovation and flexibly combine the interests of all users.

[59] However, as illustrated by many of the distance learning projects being built around the country, fiberoptic is also being extensively used for private videoconferencing applications. See OTA, *Linking for Learning,* op. cit., footnote 38.

[60] See the discussion and comments in NTIA, *U.S. Spectrum Management Policy,* op. cit., footnote 48, p. 156.

[61] NTIA, *U.S. Spectrum Management Policy,* op. cit., footnote 48, p. 157.