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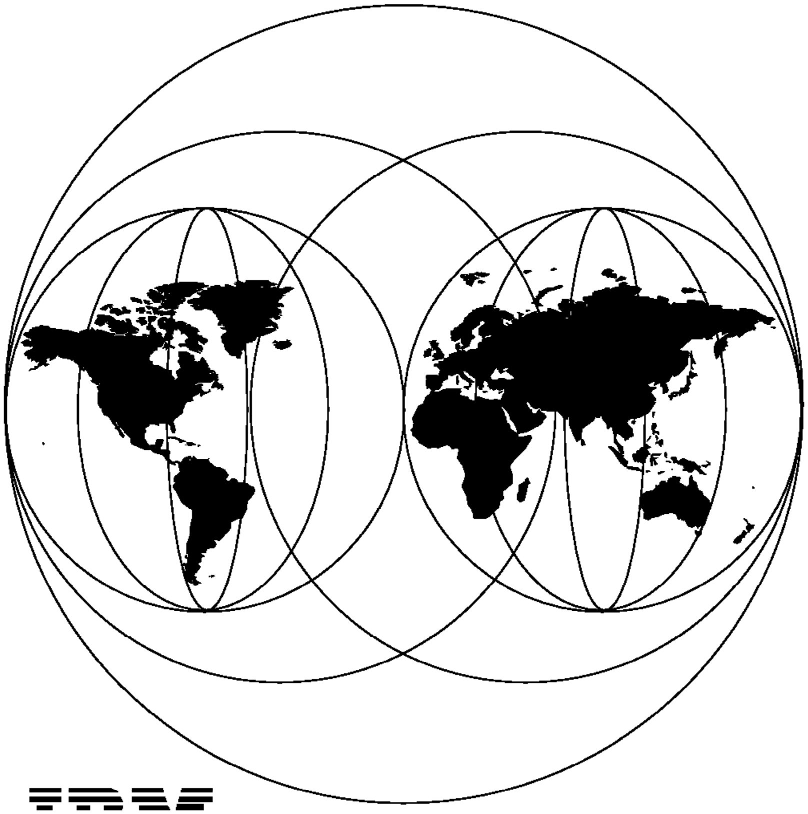
An Introduction to Wireless Technology

October 1995



International Technical Support Organization
Raleigh Center

International Technical Support Organization

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Second Edition (October 1995)

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Abstract

This is the Second Edition of this work. It expands the focus and subject treatments of the original work and includes information not found in other publications.

This book introduces the reader to wireless communication technologies and how they are used to implement new wireless connectivity solutions. It is focused on radio frequency and infrared technologies; emerging technologies such as spread-spectrum, digital cellular, mobile data networks, CDPD and LAN integration are presented.

This document was written for IBM customers, systems specialists, network planners and administrators who are involved with designing, implementing and maintaining data communications networks. A basic knowledge of data communications terminology and familiarity with its concepts is assumed.

(184 pages)

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Preface

This document is intended to provide the reader with background knowledge in wireless technology as well as make the technology more readily understood. A large part of this work is given over to a survey of the current technologies employed for wireless communications, including those used in IBM products, their design points and the issues involved with their mutual strengths and shortcomings. The book is technical in nature, but with a practical emphasis on the real-world translation of theory into product.

This document is intended for use by IBM customers, systems specialists, network planners and administrators who are involved with designing, implementing and maintaining networks. A basic knowledge of data communications terminology and familiarity with its concepts is assumed.

Preface to the Second Edition

The second edition of this book is intended to more fully develop some of the subject areas that have been covered previously. With the announcement of new IBM local and wide-area wireless products, a significant amount of additional detail is provided on how technology is translated into product. Two additional chapters are included and some restructuring of the book has provided details on new and emerging trends.

How This Document is Organized

The document is organized as follows:

- Chapter 1, “Introduction”

  This provides an overview of why wireless technology is becoming more important. A history of radio telephony leads up to a description of cellular telephones and the move to digital systems. A number of other wireless services are discussed.

- Chapter 2, “Wireless Methodologies”

  This describes the wireless methodologies in use today. An introduction to the physical principles of wireless communications, signal characteristics and frequencies is given. The use of wireless technology in local area networks and wide area networks is described.

- Chapter 3, “Radio Technology”

  This is a description of radio frequency technology. Many of the modulation and multiplexing methods used in radio communications are described. The access methods CSMA and TDMA are also discussed.

- Chapter 4, “Infrared Technology”

  This is a description of infrared technology. Laser diodes and light-emitting diodes are compared and the regulations controlling their use is discussed. The use of infrared technology in LANs is described as well as modulation and coding methods.

- Chapter 5, “Radio Communication in LANs”

This is a look at wireless LAN characteristics and issues. The effects of multi-path transmission, fading and inter-symbol interference in LANs are described. A comparison is made between common radio techniques using Spread Spectrum and Frequency Hopping and the topologies used in wireless LANs.

- Chapter 6, "Wireless Communication in WANS"

  This discusses the characteristics of RF wide area networks and some of the problems and solutions pertaining to them. The differences in technology between circuit-switched and packet-data networks are highlighted, and information on their suitability for differing applications included. Interconnection between RF wide area networks and traditional land-based networks is included.

- Chapter 7, "Emerging Technologies"

  This is a view of how today′s wireless technologies may develop in the future. The rapid spread of digital technology and the move towards standardization in wireless communications will drive the ability to provide personal communications and global intelligent networks.

- Chapter 8, "Operational Considerations"

  This is a look at the regulations, standards and environmental issues of wireless communications. The IEEE 802.11 WLAN standard is described for US products. Separate descriptions of worldwide, US, European and Japanese regulations are given. The wireless spectrum available and the ISM bands in particular are described. Security and health issues are also dealt with. Finally, some of the obvious and not-so-obvious benefits of using wireless communications are discussed.

Related Publications

The publications listed in this section are considered particularly suitable for a more detailed discussion of the topics covered in this document.

- *Wireless LAN Systems* by Santamaria and Lopez-Hernandez
  ISBN 0-89006-609-4
- *IBM Wireless LAN, Designing Your Network*, GA33-0189
- *IEEE 802 Plenary 802.11 Documents, Draft*
- *Simulation of Multipath Impulse Response for Indoor Diffuse Optical Channels, Proceedings IEEE Workshop on LANs, May 1991* by John R. Barry, J.M. Kahn, E.A. Lee and D.G. Messerschmitt
- *Wireless InHouse Data Communication via Diffuse Infrared Radiation, Proceedings IEEE, v67 n11, Nov. 1979* by F.R. Gfeller and U. Babst
- *Wireless LAN Design Alternatives*, by Bantz and Bauchot, IEEE Network, March/April 1994

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Chapter 1. Introduction

Since the earliest times, man has found it essential to communicate with others. Developments in communications technology have always been driven by the need for information to be distributed in the shortest possible time.

It may come as a surprise, but the earliest forms of communication were made by using wireless data technology. Long before the telephone was invented by Alexander Graham Bell in 1876, people were using wireless data communications. American Indians used smoke signals to communicate over long distances and messages could be passed along between a number of people spread over a considerable distance. Sailors were using semaphore with flags, or Morse code with signalling lanterns, to communicate between ships or to the shore. Long distance communications were accomplished by using carrier pigeons to deliver written messages. You can probably think of several other examples of wireless data which have been used in the past.

Communication using coded signals rather than voice was still the only method of sending information over long distance telegraph wires prior to the invention of the telephone. Morse code allowed normally written characters and symbols to be transmitted over copper wires for the first time. The first practical radio communication was demonstrated by Gugielmi Marconi when he made the first transatlantic wireless communication in 1901 using Morse code to transmit messages. Voice communication over wires had been around for many years, but Morse code was the only radio communication method until 1904 when a demonstration of voice broadcasting was made at the St. Louis World′s Fair. Morse code is still used occasionally for long distance communications to ships at sea and by amateur radio enthusiasts.

For the purposes of this book, we can define wireless communication as any form of communication without using wires (or fiber optic cable). Data communication means transmitting information that is not in the form of speech. Radio (or radio frequency) is the part of the electromagnetic spectrum that has a frequency lower than that of infrared light.

The advent of computer communications has changed our perception of data communications from thinking of Morse Code operating at one character per second over relatively short distances to the very high-speed data links of thousands or millions of bits of information per second over tremendous spans of geography. The data transmitted can represent many different types of information including multiple voice channels, full-motion video and computer data. The most common use of radio data communication today is the microwave link, which provides high-speed communications without underground or overhead cables and is a primary mechanism for carrying long-distance voice traffic.

Voice communications over radio has moved into the public domain with the rapid spread of cellular telephone technology in many countries of the world. Anyone with a cellular phone can now stay in touch with people while traveling, or even just away from their normal telephone.

Parallel to these developments in wireless technology, the power of personal computing has brought high-speed data processing ability to the desktop. New applications have made PC users more productive; new lightweight and inexpensive portable PCs allow users to take their information and tools with them. The need to share information and resources among personal computer users has spawned the spread of local area networks (LANs), which in turn have required wire-based connections. The use of copper wires limits user flexibility to move freely within the office environment. Growth in client/server applications has made unfettered connectivity between workstations and other network resources very attractive.

The marriage of wireless communications and mobile computing will transform the way we do business. The convergence of hardware, software, communications and wireless technologies will ensure that information and services will be available to computer users at all times, in all places. Many different wireless communication technologies currently support hundreds of services. Cellular and cordless phones, pagers, portable computers, mobile radio units, and vehicle tracking units all use a wide range of protocols and transport options. Future portable products such as Personal Digital Assistants (PDAs) or Personal Intelligent Communicators (PICs) will combine separate voice and data functions in compact portable packages. The communications technologies will provide a choice of communications methods with several wired and wireless options available in a single device, automatically selected for the most appropriate method according to the kind of information transfer required, the physical location of the device, and the needs of the user.

1.1 Why Is Wireless Technology Important?

Wireless communication is growing at an explosive rate around the world. In the United States alone, the number of cellular telephones grew ten-fold from one million in mid-1987 to 10 million in 1993; 180,000 cellular phones are being sold each month. The number of cellular subscribers worldwide in 1994 was 52 million. In Europe, the highest penetration of cellular phones is in Sweden. With a population of only 8 million people, more than one person in ten has a cellular phone. There are some 50 million cordless telephones in use; satellite paging systems (a small fraction of all paging systems) are projected to grow from $90 million in 1992 revenue to $500 million in 1995. Cellular phones have changed from heavy automobile-mounted devices to shirt pocket portables weighing the same as a pocket diary. The many emerging mobile end-user devices will become “information appliances”.

Wireless products and services in the 1990s are forecasted to be an even bigger revolution than the personal computer (PC) and local area network (LAN) were in the 1980s. The mobility offered by wireless technology will be used to allow businesses to optimize their use of employee time, become more competitive, make better business decisions and provide better customer service. As a result, many businesses will dramatically restructure their operations to more effectively take advantage of wireless benefits. Therefore, industry will truly be looking to install wireless solutions as a major step towards running businesses profitably.

Cutting-edge companies today are capitalizing on time as a critical component of competitive advantage. The way leading companies manage time in new product development, product introduction and production, as well as in sales, distribution and service, represent the most powerful new source of competitive advantage. By reducing the consumption of time in every aspect of business, companies reduce costs, improve quality and stay closer to their customers.

Some driving forces behind the interest in utilizing time as a source of competitive advantage are as follows:

- Quicker response time - through the use of remote input and access of data, fax or voice information.
- Increased customer contact and satisfaction - by contacting customers early, before they contact someone else.
- “Just In Time” manufacturing practices - maintaining leaner inventories.
- Accuracy of information - direct input of data without transcribing.
- Faster management information systems - information “as it happens”.

We are truly witnessing one of the most dramatic opportunities of our time Wireless communications will emerge as the major technology of the 21st century. With wireless communications access any time and any place, you will expect and get the delivery of information and services no matter where you are.

Wireless technologies make it possible to be logically present though remote connections: an increased level of responsiveness can be achieved from remote locations.

New wireless technologies offer convenience, providing value to general business and everyday use. Un-tethered operations are required for immediacy when moving about (for example, to contact a public safety officer on patrol, or a medical professional in case of a problem), to avoid wiring expenses for temporary communications or in an environment where wiring is impractical (for example, a national landmark building or a staging area where emergency response teams are mobilized), when wire lines are down (for example, in a natural disaster), or where an inadequate, unreliable, or obsolete wired infrastructure exists (for example, underdeveloped areas). *Why now?* Technology has advanced and it is now possible to communicate with small, reliable, energy-constrained mobile devices that are cheap enough for widespread use. These radical changes occurred at a surprisingly rapid pace, creating in a short time, mobile telephony systems used by millions. In the 1990s, other forms of information are being merged into more advanced digital wireless systems, a trend driven by portable computers and digital hand-held data devices. Metropolitan, national, and even international public and private networks with wireless capability are emerging today. All of these wireless “enablers” can be the basis of new devices and applications.

The most important issue for wireless communications in the 1990s is usage: who will use the technology when and how will they use it? Cost of service will also be a critical issue: how much will a user be willing to pay every month to connect a personal communicator to a network? What value will be perceived from such services? Cellular phone service has only been available for a few years, and at first it was considered to be too expensive for general use and only a few of the most senior people in large companies were able to justify the cost of ownership. In a few short years cellular phones became an affordable and sometimes essential device for all kinds of people in their working day. Today, cellular phones are becoming common in the domestic environment and very soon a mobile phone will be as essential as a TV receiver or VCR to an ordinary family.

New technology drives new uses and applications for the technology, which in turn creates demand for further technological advances. As more users purchase equipment and services, so the price becomes more affordable and the amount and diversity of uses increase.

Governmental regulation of the frequency spectrum is, and will continue to be, another key question; the answer to which will dictate technical strategy and tactical plans. Inconsistent worldwide frequency allocations and licensing will remain an issue and inhibit international roaming. It will take a very long time for all countries in the world to agree and implement a worldwide allocation of radio frequencies. Governments and commercial enterprises have invested very large sums of money in existing radio communication infrastructures and the frequencies allocated to these applications will only be freed up once new technology has been established and the very last user of the old service has agreed to change to the new service.

Wireless communication solutions that provide logical presence through physical roaming, or the ability to stay in touch on one′s own terms, will continue to be in great demand. Today, these requirements are requested by mobile professionals and other workers who want to download E-mail, update their calendars, send or receive a fax, check inventory, place an order, record route status, call a customer, talk to a peer in short a virtual office - anywhere, anytime. The Electronic Mail Association predicts a tripling of electronic mail users, to 27 million sending more than 14 billion messages annually in 1995 alone.

Advances in semiconductor technologies enable the use of higher frequencies and will achieve better reliability of wireless connections. This will accelerate wireless product development. Continued miniaturization of circuitry, of displays, of user interfaces (for example, gallium arsenide, flash memory), the “building blocks” of portable devices, along with advances in low-power electronics, battery (life, weight) and solar cell technologies, will also help the mobile product user achieve higher levels of efficiency. Affordable application solutions will be the key ingredient in the rapid acceptance of wireless technologies.

Traditional methods of interaction with computing devices will have to change when they become highly miniaturized and portable. For example, the technology exists to build a computing device that may be worn on the wrist, but it would be very difficult to interact with such a device using traditional methods. It would be impossible to produce an alphanumeric computer keyboard that could be used successfully and a screen could only display a few characters if it were to be used by a person with average eyesight.

1.1.1 Characteristics of the World of Wireless in the 1990s

In this changing world, technological leaders such as IBM will package mobile/wireless devices and other products in individualized ways, implementing seamless connectivity for vertical industry solutions to common business problems. IBM will be a wireless vendor and service provider due to a continued wireless communications focus that will be characterized by an environment of:

1. Ubiquity: People will want to be in touch from anywhere, at any time. This will force standards to emerge between carriers and between vendors for common devices and seamless roaming.
2. Spectrum Availability: Current frequency allocations are not sufficient for the wireless public world of the 1990s. Constrained frequency allocations are a

critical asset for competition, requiring competence on working through regulatory agencies and licensing bodies.

3. Mass Customization: Wireless devices must be easily tailored (that is, programmable) to individual roles and preferences.
4. Price discontinuities: A price threshold will be found which ignites explosive usage of cellular and RF data, fax, and voice usage.
5. Social/human/usability issues: The social acceptability of wireless devices will affect demand. For example, wireless technologies could enable people to have their personal whereabouts recorded, resulting in an undesirable invasion of privacy. People may not want to be able to be reached in circumstances where they are used to unwinding and being out of touch. Human-centric solutions will be required.
6. Key applications, total systems solutions: critical vertical and cross-industry applications will propel wireless technologies. Simply put, wireless applications are crucial and product vendors will have to align with application developers.
7. Merging industries: The computer, communications, networking, consumer electronics, and entertainment industries of the next five years will be much more integrated than they are today.
8. Wireless communities are emerging, especially in sparsely populated areas (for example, the telephone connections in the Australian outback are mostly wireless). The high cost of long cable runs in rural areas makes wireless communication a more cost-effective solution. Wireless technologies will be a credible and cost-effective alternative to upgrading some existing wired infrastructures or creating a spontaneous communication situation, such as in a disaster area.
9. Technological advances in batteries (life, weight), solar power, and circuit miniaturization will increasingly enable attractive, functional, affordable, and practical devices which will use wireless communications.
10. Incorporated intelligence will become more pervasive. Appliances, automobiles, or remote equipment will use wireless devices to alert central maintenance facilities when service is required. Intelligent vending machines will automatically place just-in-time wireless calls for restocking, cash removal, and service; allowing vendors to operate at enormously improved levels of efficiency.
11. Wireless networks will provide value added services both directly and by means of links into other services. Delivery of timely, accurate and relevant information such as weather warnings, traffic delays and emergency messages will become an essential part of any wireless network service.

1.2 Wireless Applications

The main driving force behind wireless and remote computing devices is the applications. The successful introduction of a new technology depends on the wide acceptance of those applications which use that technology. The applications must meet a real need.

1.2.1 Voice Communication

Early wireless communications used Morse code followed by simple voice communications. In the 1930s, radio equipment used valves (tubes) which needed high-wattage power supplies. Radio receivers were either electric main power source operated or needed large batteries for the high voltages required. Police mobile radio allowed one-way communication from central dispatch to cars who listened in on dedicated frequency bands. The police officer then called back from a pay phone. Amplitude Modulation (AM) was employed but was not very efficient in using the available bandwidth. In 1935 Frequency Modulation (FM) was invented. It was further developed by the military during World War II and in the 1940s all police radio systems were moved to FM. The need for two-way communications led to the establishment of the first Mobile Telephone Service in 1946 in St.Louis. This was based on one FM transmitter with a coverage area of 50 miles (80 km) diameter. Within a year this service was available in 25 US States. The system used a number of base stations, each with an FM transmitter. Each base station was connected into the wired telephone network using a controller.

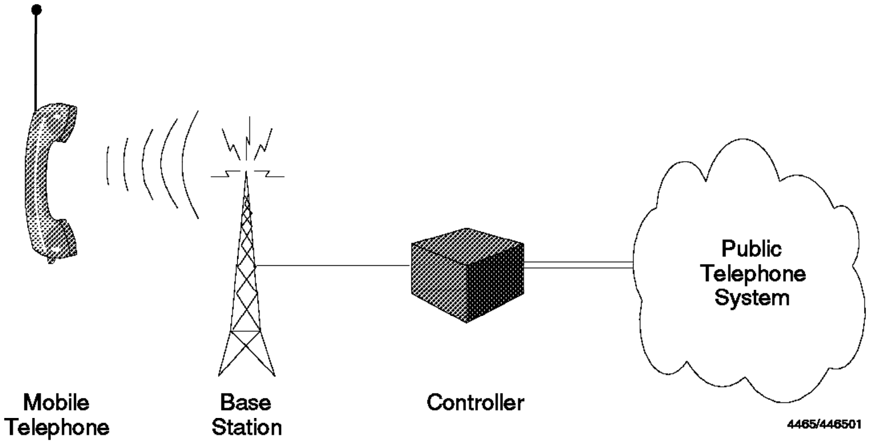


Figure 1. Mobile Telephone Service

A new and improved wireless system was introduced in the mid 1960s. This system was known as the Improved Mobile Telephone Service (IMTS) and was the forerunner of the present cellular service. The new features included:

- Automatic trunking (all users can access all channels - no dedicated channels)
- Direct dialing (no operator at the mobile network controller)
- Full-duplex (no “push to talk” required)
- FM channel of 25-30 kHz
- Each phone searches for a free channel (special tone used)

As the number of subscribers increased there were not enough channels available to allow access for everyone who wanted a connection. This led to the development of cellular radio. By reducing the area covered, the bandwidth could be reused and hence more users could be supported. Cities and rural districts were carved up into “cells” or areas, each with their own base transmitter. The same frequencies were used as before but with much lower transmitter power. Since the power is low, the signals remain within the cell, which has a diameter of between 1 mile (1.6 Km) and 20 miles (32 km) with little chance of interference in nearby cells. To further reduce the probability of interference between mobile stations on the same channel in adjacent cells, channel re-use was not allowed until a cell was skipped. The first cellular systems were developed by Bell Laboratories in the 1970s and experimental operation of the Advanced Mobile Telephone System (AMPS) began in 1979 in Chicago. Other countries followed with their own versions of cellular telephone systems, notably the Scandinavian countries in 1981 with the Nordic Mobile

Telephone on 450 MHz (NMT450), and the UK in 1985 with the Total Access Control System (TACS). Japan has its own unique analog cellular system developed by NTT, and Germany and France both have unique systems that are incompatible with other countries. A list of cellular phone networks can be found in Appendix A, "Cellular Networks Worldwide" on page 151.

1.2.2 Cellular Systems

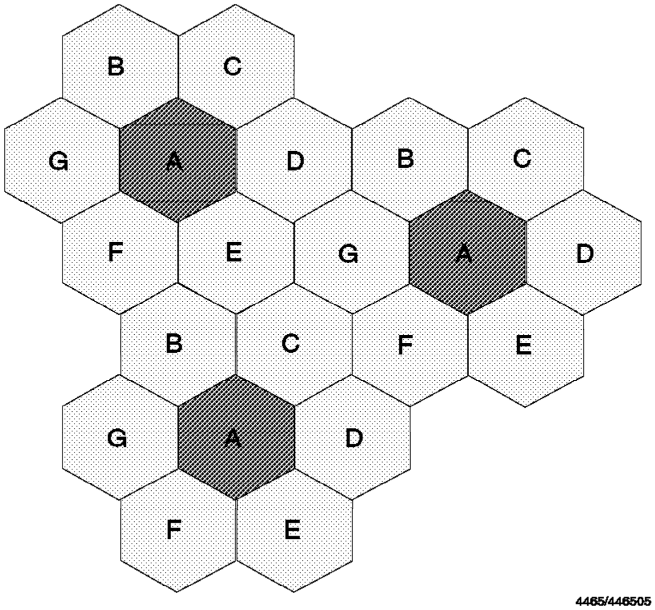


Figure 2. Cellular Structure

The diagram above shows how a cellular telephone network is organized. (The hexagon shapes are a convenient way of illustrating the network, but in real life, the cells can be very irregular shapes.) The letters in each cell represent the transmitting and receiving frequencies assigned to each cell. The center cell of each group of seven cells has a range of frequencies indicated by the letter "A". Other cells have different frequencies assigned to them indicated by "B", "C", and so on. You can see that no two adjacent cells have the same set of frequencies; there are always at least two intervening cells before the frequencies are re-used. The diagram shows a very simple arrangement with only seven different sets of frequencies. In real cellular networks, the patterns can be much more complex with many sets of frequencies.

At first, only the major cities were covered with cellular transmitters. It was not always economical to cover less populated areas as the initial costs were high (prices ranged upwards to tens of millions of dollars).

In the early 1980s the capacity of urban cells reached their limits and were divided up into smaller and smaller cells with lower power transmitters. Since a mobile cellular telephone (for example, in a car) can receive signals from different cell transmitters (known as base stations) near cell boundaries, a mobile switching center (MSC) was created to coordinate the frequencies used by the different mobile users and cell transmitters. As the mobile user moves out of a cell, the MSC must decide which is the proper cell to take over the call.

The MSC can communicate with all mobile phones in the area of the base stations which it controls by means of a special radio channel called a control channel. This channel is not used for voice communications but allows the MSC to send instructions to the mobile phone. The MSC contacts each adjacent cell and instructs it to measure the signal strength of the mobile unit. The results are transmitted back to the MSC and the strongest signal and cell are determined. A new channel is allocated in the destination cell and the current cell is instructed to relay this information to the mobile station. This is known as a “handoff”. Cellular handoffs today can take several seconds. This is fine if cells are large and not many cell boundaries are crossed, but mobile cellular units in a car can cross cell boundaries often in urban locations. For this reason, in 1984 an additional 10 MHz of bandwidth was allocated by the FCC in USA to bring the total to 50 MHz in the 800 MHz band for the Advanced Mobile Phone Service (AMPS). This allows 832 channels (full duplex) to be used.

Handoffs can also occur even when the mobile station is not moving. The MSC can balance the load of users between base stations by switching some of the users from a base station which is heavily loaded to an adjacent base station which has some spare capacity. This is, of course, only possible if some of the users are in an area where they can communicate with both base stations. The reason for doing this is to ensure that there is always some spare capacity for new callers to access the base station or for callers in vehicles that are passing through the area.

When a cellular phone is first switched on, it will scan a predetermined set of radio channels. These channels are the control channels that have been allocated to the particular cellular network on which the phone is registered as a valid subscriber. A different network in the same geographical location will have a different set of control channels allocated to it. The phone may have the ability to be registered with more than one network, but the user must decide which network the phone will register with at any one time. This is normally accomplished using a menu-driven selection from the keypad of the phone.

Once the phone has scanned all the control channels for the network, it will build a table of the frequencies of the strongest signals. Not all of the control channels available for a network will be within range and the phone will try and use the channel with the strongest signal first. It will initiate a registration with the base station whose signal is strongest. If it fails to do this, then it will try the next strongest signal and so on. If the phone cannot, for some reason, register with any base station, it will indicate the fact to the user by means of an “out of service” indicator. The most common reasons for not being able to register are:

- The phone is not in an area of cellular coverage
- The phone is in a “blackspot” (radio coverage hole)
- The base station is busy with other callers
- The phone is not registered as a valid subscriber to the network

Cellular phones have a physical identifier encoded in them as well as their mobile phone number. The physical identifier is known as the electronic serial number or ESN, and is assigned to the phone at the time of manufacture. The ESN is used to ensure that there is no fraudulent use of the phone network. The ESN and the subscriber′s mobile phone number are held by the network operator, and each time that a phone tries to register with the network, the subscriber number and the ESN are compared to ensure that the combination of the two is valid. In the early days of cellular telephones, the ESN was sufficient to prevent fraud, but today, ways have been found to re-write ESNs and fraudulently register stolen phones. Fraudulent use of cellular phones is a major problem in the US and is reaching other parts of the world very rapidly. The new digital phone technologies will have more sophisticated methods of fraud prevention.

Different cellular technologies (AMPS, ETACS, NMT) will have slightly different detailed implementations of the calling process, but the overall sequence is similar for all technologies. When a subscriber with a cellular phone wishes to make a call, the phone number is entered on the key pad of the phone and the SEND button is pressed. This causes the phone to send the dialled digits to the network via the control channel assuming that the phone is still registered with a base station. The cellular network will then assign a voice channel for the connection once the called party′s phone starts to ring.

While the call is in progress, the network can detect if a mobile phone is moving out of range of a particular base station. The network can then request that the phone switch channels to a closer base station to continue the call. This is achieved by the transmission of a short burst of data on the voice channel which is not passed to the audio circuits of the phone, and thus is not heard by the subscriber.

When a call is placed to a mobile phone the call is first routed to the MSC closest to the origin of the call. If there is more than one MSC in the network, the call will be routed to the MSC that the phone was last registered in. The MSC will then transmit a paging message to all mobile phones in its area. If the mobile phone responds, the MSC will assign a voice channel and route the call to it. If the mobile phone does not respond, the other MSCs will try paging mobile phones in their areas.

1.2.3 The Move to Digital

Analog mobile telephony served well as a first-generation technology; however, analog services are now straining to keep up with user demand. Analog transmissions are less efficient than digital transmissions when it comes to spectrum utilization. Most analog standards allow low-speed (up to 4.8 Kbps) data transmission such as fax or file transfer, but interface equipment is expensive compared to the cost of mobile phones, and performance can be unreliable (for example, fax only works well when sent from a stationary terminal). Roaming across national boundaries is only possible where neighboring countries implement the same standards.

For these reasons, efforts to develop next-generation mobile telephony networks focus on digital technologies in general and on GSM (Global System for Mobile Communications, formally called Group Spécial Mobile), a digital transmission standard accepted by all European countries and many other countries.

Analog cellular phone systems such as AMPS, TACS and NMT use the analog signal from the microphone to modulate the frequency of the radio carrier wave directly using frequency modulation. See 3.1.2, “Frequency Modulation (FM)” on page 59 for details of the way in which frequency modulation works. A digital cellular phone will convert the analog signal from the microphone into digital data which will then be used to modulate the carrier. This would normally use phase modulation. See 3.1.3, “Phase Modulation (PM)” on page 60 for a description of phase modulation. The analog signal is converted using a device called a vocoder which will sample the level of the analog signal many times during a single cycle of the signal. A single level sample will be encoded as a binary value and strung together with other sample values to form a continuous data stream. At the receiving end, the data stream is broken up into individual samples which are used to reconstruct the original signal. In order to keep the amount of data to a manageable level, the data is compressed at the transmitting end and decompressed at the receiving end. These compression techniques take advantage of the characteristics of human speech and the silent periods between words. Most digital cellular systems use this basic technology for transmission of speech, but will vary in the way they modulate the radio carrier and the structure of the network.

GSM will serve as the basis for forthcoming mobile telephony services. Compared with analog services, GSM, which operates in the 900 MHz band, offers greater signal quality and hence fewer transmission errors, better security through encryption and encoding, and more efficient use of the spectrum giving higher network capacity. The GSM networks now in place handle voice traffic and data services are just starting in a few countries, notably the UK and Germany. Other countries plan to implement data in the near future. The data services offer data transmission rates up to 9.6 Kbps for circuit switched connections and a Short Message Service (SMS) which provides the ability to do two-way paging using a GSM phone. In addition, fax services will be provided and a later implementation will include packet data services.

Digital mobile telephony services also can be provided via the Digital Communications System (DCS) 1800 standard, developed by the European Telecommunications Standards Institute (ETSI) as an extension of GSM. DCS1800 services, known as Personal Communications Networks (PCNs), operate in the 1800 MHz band in Europe. PCN and GSM are functionally similar in terms of voice quality, data facilities, and call handling. One difference between the two is that PCN is available only on hand-portable terminals, while GSM is available on hand-portable and higher-powered car-mounted terminals. Because PCNs use a higher radio frequency, they require more base stations than GSM networks, which means they will be more expensive to install and operate. For this reason, PCN service providers are expected to focus their attention on urban areas, which means users looking for wider geographic coverage probably will tend towards GSM networks. PCN is often referred to as Microcellular, since the cells are smaller than regular cells allowing phones to be smaller using less power.

GSM technology in the form of DCS1900 will be seen in North America as the first systems using Personal Communications Services (PCS) licenses are implemented. DCS1900 is the same as DCS1800 except that the operating frequency is 1900 MHz.

AMPS is based on analog technology and is available in North and South America as well as some Asian and African countries. D-AMPS is a digital cellular radio system now being implemented in North America.

An alternative digital cellular phone technology, CDMA, is being implemented by Qualcomm and may result in differing digital cellular services in different parts of North America.

1.3 Analog Cellular Network Types

Table 1. Analog Cellular Network Types

	AMPS	**TACS**	**NMT450**	**NMT900**	**NTT**
Channels	2 x 416	2 x 500	180	1999	2 x 500
Uplink Frequency (MHz)	825-845	890-915	453-457.5	890-915	860-885
Downlink Frequency (MHz)	870-890	935-990	463-467.5	935-960	915-940
Channel Spacing kHz	30	25	25	12.5	25
Modulation	FM	FM	PM	PM	FM

1.3.1 Cordless Telephones

In addition to the requirement for telephone equipment to be mobile across large distances, the desire to have mobile telephone access within a limited space, typically within 50 to 100 meters of a base station (such as the home or an office) led to the development of the cordless telephone. This does not offer mobile access as with the cellular systems. It is really an access technology into a business PBX system or a domestic telephone connection. The cost is low and it offers less function than cellular phones.

Early cordless phones suffered from a number of problems. Not all countries had standards for cordless phones and interference to essential services was caused by imported devices that operated in parts of the spectrum allocated for other services. Cordless phones had a very limited number of radio channels and users could eavesdrop on their neighbors conversations. In addition, fraudulent use of cordless phones could result in a third party making calls from a cordless handset by accessing a cordless base station that did not belong to them, thus avoiding paying for the call. These problems were overcome when standards for cordless phones were implemented.

Several cordless communications standards are now in use, including the analog Cordless Telephony 0 (CT-0) and CT-1 standards and the CT-2 digital standard. CT-2 has been adopted by ETSI as an interim European standard for domestic and business applications. CT-2 is likely to be superseded by Digital European Cordless Telecommunications (DECT), a digital standard which can be used for wireless LANs. Both CT-2 and DECT can support voice and data, but DECT has a wider range (up to 200 meters) and greater data capacity (up to 384 Kbps, compared with CT-2′s 32 Kbps). The actual throughput of data using DECT is closer to 320 Kbps because there are channels which are there for supervisory and control functions which use some of the capacity. Another DECT advantage is that connections can be handed off between base stations, a feature that CT-2 cannot provide, and the ability of the mobile station to receive calls as well as to initiate them.

DECT will use very similar technology to GSM/DCS1800, which should provide low-cost implementations and the ability to use common designs which could have the ability to access different networks in the future.

Telepoint is another cordless system that requires users to be within close range (100 to 200 meters) of a base station. Telepoint is being deployed as a wide-area service, with base stations typically located in public-access areas such as shopping centers, airports, and train stations. As in mobile telephony services, Telepoint users can place calls over the public dial-up network. A key difference, however, is that the CT-2 standard used for Telepoint services allows users only to place calls; CT-2-based systems do not handle incoming calls. Some service operators work around this limitation by providing pagers to notify users that someone is trying to contact them, while others allow incoming calls to users logged in to their nearest base station. Telepoint services are intended primarily for voice communications. France Telecom is developing an interface between Bi-Bop, its Telepoint service, and Personal Digital Assistants (PDAs).

The Telepoint services in both the UK and Germany have both been discontinued due to the limited functionality available, and the ubiquity and low cost of full cellular and PCN networks. Telepoint may be revived in these countries once DECT technology is implemented.

1.3.2 Paging Services

Like Telepoint services, radio paging networks offer low-cost but limited wireless connectivity. Paging services handle simple, one-way data transmissions, typically in the form of a simple alert, a short numeric message (such as a phone number), or an alphanumeric or text message of no more than 80 characters. Response times tend to be slow; it can take up to five minutes for a message to get through to a user. And because communications are one-way, callers have no way of knowing if posted messages have been received by their intended target. A number of analog paging standards are in use, enabling regional or national coverage. Although standardized codes (CCIR Radiopaging Code 1) are used in all European countries, roaming is not possible because of conflicting frequency uses. An emerging European digital standard, called European Radio Messaging System (ERMES) could allow cross-border paging networks, with message lengths up to 9000 characters. However, it remains to be seen if it can achieve commercial success.

Paging services can be used for one-way transmission of computer data and interfaces are being developed to provide connection to mobile computing devices such as notebooks and PDAs. A recent development has been the pager in the form of a PCMCIA card. This credit card-sized device is a pager in its own right, or can be plugged into a mobile computing device.

A number of value-added services are available using paging networks as a delivery method. News services and other information services such as stock market trading information are already available. Information about highway traffic delays are broadcast to in-vehicle paging receivers in the UK and the information is provided on a large LCD displaying a local area map.

Paging networks can also be used to provide automatic alerts for users of voicemail, faxmail and E-mail services. When an item of mail is received, the system will send out a paging message indicating the type of mail received and also the identity of the originator. The same system can provide diary alerts from an office system to send reminders of meetings a few minutes before they are due to take place.

Paging services are also used for automatic alerts for equipment monitoring. Services are available where equipment failure such as computer room air conditioning, issues an automatic alert to a service engineer.

A novel use of pagers has been implemented by some farmers who have wide areas of land on which their animals graze. Animals such as sheep will normally follow the dominant sheep in the herd. The farmer will fix a tone pager to a collar on the leader of the herd and train it to return to the farm when the pager “bleeps”. The other sheep will follow, and instead of the farmer having to go out and round up his sheep, he only has to make a single phone call to the paging service and all his sheep will come home.

Paging systems are sometimes considered to be the “poor relation” of mobile communication networks, but they can offer very powerful services at a low cost to the user.

1.3.3 Private Mobile Radio

Unlike mobile telephony services, which are linked to the public network, private mobile radio (PMR) and private access mobile radio (PAMR) services handle closed user groups only. In a typical PMR/PAMR application, mobile workers use the system to communicate both with a central control point and with one another. Primary users include providers of emergency services, public utilities and taxi companies. PMR networks are generally owned and operated by the organizations that use them, while PAMR (or trunked) networks are run by third-party providers that offer services on a subscription basis. One of the main benefits of using a third-party service is geographic coverage: PAMR operators have more resources to build widespread networks than most individual organizations. PMR services currently are based on a wide variety of proprietary analog transmission standards, while many PAMR services have adopted the UK MPT standard. Like mobile telephony services, PMR/PAMR services are optimized for voice, although some network operators such as National Band III in the UK are now offering data services. Some examples of the use of PMR/PAMR are as follows:

- Most police forces use their own PMR systems to communicate with officers in vehicles and on foot patrol.
- Utility companies use PMR systems to direct their engineers for maintenance or repairs.
- Ambulance services use PMR to direct vehicles to accident sites.
- Trucking companies will use PMR to stay in touch with drivers.
- In the UK, the Automobile Association uses mobile radio networks to send information about disabled cars to repair personnel.

A number of factors, including differences in frequency allocations, now prevent PMR/PAMR networks from handling communications outside national borders. Some of the trunked PMR networks make use of the older VHF TV frequencies which may be different in various countries. This limitation on roaming may be lifted in Europe in the future, thanks to a digital mobile radio standard now being developed by ETSI. That standard, known as TETRA (Trans European Trunked Radio), will provide improved voice quality, faster data rates, better security (through encryption), and more efficient spectrum use for PMR, PAMR and mobile data services (see below). However, specific decisions on frequency allocation and supported data rates have not yet been agreed upon. Although

PMR/PAMR networks tend to be less expensive than mobile telephony services, the fact that they accommodate only closed user groups limits their use. However, once an organization has been allocated a frequency to use for PMR communications, it would be very reluctant to give it up as there would be very little chance of getting another allocation. This situation is limiting the opportunity to move to Private Access Mobile Radio. Organizations that require mobile communications with third parties are obliged to use mobile telephony services or mobile data services.

1.3.4 Mobile Data Services

The cellular telephone networks of the 1980s could be used to transmit data in much the same way as it is done over the public-switched telephone network (PSTN). However, this technology was slow, unreliable, and expensive and it was recognized that a dedicated wireless data network could solve these problems.

In 1983, IBM developed a private packet radio data network called DCS (Data Communication System) for the use of its field engineers. This was used for call dispatch and call reporting and some other data applications. The terminal device consisted of a hand held data terminal about the size and shape of a house brick, by which name it was consequently known. The radio infrastructure was provided by Motorola and operated at 4.8 Kbps on a carrier frequency of 800 MHz. The network covered the major cities of the United States but the FCC licence did not allow the service to be sold to other users. At the same time, Motorola was building a network using the same technology for public access. In 1990, the IBM and Motorola networks were joined to form a public access network known as ARDIS (Advanced Radio Data Information System). The original implementation of ARDIS used a protocol known as MDC4800, but a new protocol called RD-LAP is being introduced alongside with the advantage of operating at 19.2 Kbps. See 2.5.2, “MDC4800 and RD-LAP” on page 53 for further information.

In 1984 a similar technology was being developed in Sweden by Swedish Telecom (now called Telia Mobitel) and Eritel AB. The technology was known as Mobitex and was supplied by Ericsson Mobile Communications AB. The first commercial operation started in Sweden in 1986. The first systems operated in Scandinavia were in various parts of the VHF band (dependant on country), and had a data rate of 1200 bps. The Mobitex system spread to other parts of Europe and was developed to operate at 8 Kbps in the 400 - 450 MHz band. In North America the same system is used but in the 800 MHz band.

Mobitex has now become the defacto standard in Europe with only Germany having an active RD-LAP network (Modacom). Both Mobitex and the ARDIS MDC4800/RD-LAP systems are available in North America. Both systems are used in other parts of the world, notably Southeast Asia and the Pacific Rim where the Motorola technology is known as Datatac. See 2.5.1, “Mobitex” on page 51 for further information on Mobitex and Appendix B, “Mobile Data Networks Worldwide” on page 165 for a list of mobile data networks world wide.

There are other radio packet data network technologies, but these tend to be unique to individual environments or countries. For example, in the UK there are two other radio packet data networks:

- Paknet - a wireless extension of the X.25 PSS network operated by Vodafone on VHF frequencies and using some of the Vodafone cellular telephone infrastructure.
- Cognito - a VHF two-way radio messaging system using hand held integrated data terminals.

At the moment there are no international recognized standards for mobile data networks, and no common frequencies available in all countries. There is only limited roaming capability between countries which have common frequency allocations.

Mobile data services also use radio-spectrum more efficiently than other mobile services, which means they tend to cost less. One problem with the use of packet switching in mobile data networks is that there usually is some delay in getting data to the intended receiver. With circuit-switched services like mobile telephony and PMR/PAMR networks, end-to-end circuits guarantee immediate delivery. Mobile data networks are like conventional X.25 networks in that packets are sent to a central network point which then forwards those packets to the receiver.

Mobile data services are ideal for organizations that require regular data transmissions between mobile terminals, such as those located in delivery vehicles. Where regulations permit, some companies are deploying mobile data services for stationary terminals, such as point-of-sale terminals in retail stores. Although mobile radio networks can accommodate transmissions of larger files, such as fax documents, the nature of most applications makes such file transfers impractical. Most packet radio applications are built to handle large numbers of very short transactions. A fax document or large file transfer could tie up an entire 9.6 Kbps channel for several minutes, disrupting the network′s main purpose.

The fact that mobile data networks require more customization has limited their appeal to larger organizations. But the arrival of some generic, off-the-shelf applications such as electronic mail transfer could make mobile data services more attractive to small organizations.

1.3.5 Home Applications

In the home environment, wireless systems have been in existence for many years. The spread of these applications was a direct result of the availability of cheap, non-licensed wireless technology. Among the first applications were ultrasonic remote control units for TVs. These were sensitive to other background sounds and were replaced over time by infrared controls.

Then, as transmitters and detectors in the infrared frequency range became generally available at an affordable price in the 1960s and 1970s we saw:

- Security motion detectors for burglar alarms
- Motion detectors for switching on lights or opening doors
- Remote locking/unlocking of car doors
- Remote opening of garage doors (now mainly radio activated)
- Remote TV/VCR/Radio controls

The development of new low-cost electronic components and integrated circuits in the 1970s and 1980s enabled radio-based systems operating in the VHF/UHF radio bands to become available. These can be divided up into one-way or half-duplex connections:

- CB Radio
- Walkie-talkies
- Baby alarms and monitors
- Remote control cars and boats

and two-way or full-duplex connections:

- Mobile phones
- Cordless phones

1.3.6 Automobile Communications

There are several ways in which information can be passed to or from a car in motion.

In the UK a system has been developed for interrupting the vehicle′s sound system to transmit traffic information, and most new vehicles will have the system fitted to the car entertainment system. The driver may be listening to a national radio broadcast or even tape or CD. When a local radio station traffic report is broadcast, the vehicle system switches over to receive the traffic report at a predetermined volume level. At the end of the traffic report the system switches back to the original program. This is accomplished by a high frequency audio tone at the start and end of each traffic report. The vehicle′s receiver can detect this on all of the local radio broadcast frequencies. The system is known as the Radio Data System (RDS).

A system known as Intelligent Vehicle Highway System (IVHS) or Intelligent Transportation System (ITS) has been tested in Europe and Japan. An Advanced Traveler Information System (ATIS) which provides electronic maps with navigational information is available in Japan; about 400,000 of these units are presently in use. In California, AVIS is testing a satellite guidance system to show the current position for a vehicle on an electronic map on a display.

Also in use are tollbooths that can read a bar code or RF identification tag on vehicles as they pass to determine toll charges, and road signs that give drivers real-time traffic information.

1.3.7 Satellite Applications

Satellite navigation systems can be used to show the position of a vehicle anywhere on the Earth′s surface.

1.3.7.1 Global Positioning System

The Global Positioning System (GPS) was developed for the US Military, but can be used to provide positional information for commercial and even leisure applications. The GPS system consists of a bracelet of satellites transmitting information about their position relative to the Earth, and very accurate timing information. A small receiver in a vehicle can determine its position on the surface of the earth by receiving signals from at least three satellites. With three satellites the position can be determined in two dimensions, but with four or more signals received the altitude can be measured as well. In open country, a receiver can normally receive information from five satellites. The positional information can be calculated by the receiver knowing how long the radio signal takes to reach it from each satellite (and thus its distance from it) and the position of each satellite in space. The US Military has built in a random error mechanism so that other users cannot achieve the same accuracy as official users, who access the GPS information on a separate encrypted radio channel. GPS equipment has now been developed that is highly miniaturized and ruggedized, may be carried by people who are walking in remote areas or by small boat sailors. The cost of these devices has reduced to the point where they are no more expensive than a good quality VCR.

1.3.7.2 Direct Broadcast Satellites

The satellite systems that are most familiar to us are the Direct Broadcast Satellite (DBS) systems. These can carry hundreds of TV channels in addition to other services. DBS satellites are normally in geostationary orbit, which means they appear to be in one position in the sky at all times. This is achieved by placing them in an orbit whose period is identical to that of the Earth′s rotation. The altitude required for a geostationary circular orbit is 35,803 km.

1.3.7.3 Communication Satellites

Communication satellite systems are used to access remote parts of the world, as well as providing intercontinental telephone, TV and data links. The intercontinental services are provided by fixed groundstations in each continent and form part of the international telecommunications network. Private satellite service operators such as Inmarsat and Eutelsat provide communication services to mobile groundstations. The mobile groundstations tend to be bulky and have to have their antennae accurately positioned to establish communications. These services include TV and voice reporting from remote locations as well as data services.

Companies such as IBM can offer communication satellite uplink and downlink services, providing communication satellite access without the need for the customer to invest in their own groundstations.

1.3.7.4 Satellite Phone Systems

Over the next few years we will expect to see a number of global phone satellite networks which will supplement existing cellular and other wireless networks. Satellite phone networks will provide global coverage to hand portable wireless phones and to fixed stations in remote parts of the world. This will allow communities is isolated locations to access to the switched network of the rest of the world. At present, there are many locations where it is either physically impossible or too expensive to provide land line communications and satellite phones will be able to bring normal telephone communications to these people. There are four systems proposed at the time of writing as follows:

- Odyssey
  - 12 satellites
  - Medium Earth Orbit (MEO)
  - Eight Earth Stations
  - Planned for year 2000
- Globalstar
  - 48 satellites
  - Low Earth Orbit (LEO)
  - 200 Earth Stations
  - Planned for year 1998

- Iridium
  - 66 satellites
  - Low Earth Orbit (LEO)
  - Planned for year 1998
- Inmarsat-P
  - 10 satellites
  - Medium Earth Orbit (MEO)
  - Planned for year 2000

Low Earth Orbiting systems typically orbit at around 750 km altitude and require around 50 satellites to provide global coverage. Medium Earth Orbiting systems have an altitude of 10,000 km and only need about a quarter of the number of satellites.

The LEO satellite systems discussed above are generally known as "Big LEOs" to distinguish them from another class of satellite called "Little LEOs". Little LEOs are primarily for low bandwidth applications such as locator service, two-way messaging and spot coverage for cellular carriers. They may use UHF or even VHF for communications.

1.3.8 Other Commercial Applications

The ability to access strategically important and mission-critical applications is vital to many companies. There is a need to extend communications beyond landlines. Time is a critical component. For example, a parcel delivery service must be able to redirect delivery vans at a moment′s notice.

There are many wireless applications already in operation:

- Radio and TV stations.
- Telecommunications links.
- Some utility companies can now remotely read gas or electricity meters from a vehicle parked in the street outside.
- Satellite communications.
  - Voice links
  - Data links
  - Video broadcasting
- Taxi communication.
- Military vehicle communications.
- Surveillance equipment.
- Wireless mouse/keyboard connections for the PC.
- Wireless LANs (refer to Chapter 5, "Radio Communication in LANs" on page 93 for more information on these applications).

1.4 Summary

Wireless data communication has been around for a very long time. When we talk about "wireless" in this book, we mean untethered, and when we say data we mean any communication method other than speech. "Radio" means radio frequency (RF), while wireless includes RF, infrared, ultrasonic and other technologies.

Wireless communications will make a significant impact to the information technology industry in the next few years and many new applications will evolve as a result.

Some of the main applications of wireless technology are as follows:

- Early voice communication systems
- Analog cellular telephones
- Digital cellular telephones
- Cordless phones
- Paging services
- Private Mobile Radio (PMR and PAMR)
- Mobile Data Services
- Satellite Communications
- Other domestic and commercial applications

Chapter 2. Wireless Methodologies

This chapter discusses some of the basic physics associated with wireless transmission techniques and goes on to describe how the technology is implemented in various applications. This description includes a more in-depth look at some of the networking technologies mentioned in Chapter 1, “Introduction” on page 1.

2.1 Radio Frequency Characteristics

The characteristics of radio waves in any frequency band determine how useful those frequencies are for the service required. The main characteristic of interest is how signals are changed or distorted, by absorption and reflection, by the air and other physical media before reaching the receiver. Since a radio signal is a particular form of energy, it is useful to consider the different forms of energy and how they can be converted and transmitted.

2.1.1 General Aspects

In order to understand some of the properties of radio and infrared propagation it is important that the underlying principles or the physics of electromagnetic waves be defined. A good starting point is a discussion of energy and the ways it can be transmitted. Energy is defined in physics as the result of multiplying power by time and may take a number of different forms (such as sound, electrical, kinetic, potential, chemical, heat, and nuclear energy). A fundamental principle of physics is that of the conservation of energy - energy can be neither gained nor lost, only converted from one form to another. When we talk about generating a particular form of energy, say electricity, what we are really doing is changing one form of energy (heat to electricity) in a power generating station.

Some forms of energy are mechanical in nature, for example, kinetic energy. An object is said to have kinetic energy by virtue of its motion. A moving vehicle has kinetic energy and this has been converted from chemical energy in the gasoline and air used to power the engine. If the vehicle is driven to the top of a hill, it is said to have gained potential energy. The energy is stored in the vehicle and can be released by coasting down the other side of the hill thus becoming kinetic energy again. If the vehicle is brought to a halt, it will lose its kinetic energy, which will be converted to heat by raising the temperature of the brakes. Whenever one form of energy is converted to another, the process may not be very efficient in changing the energy into the form desired. The internal combustion engine moving our vehicle will convert some of the chemical energy into kinetic energy, but quite a lot will be converted to heat. This energy is not lost, it is just not in a form which is useful in moving the vehicle. Even this wasted heat is welcome on a cold day!

A special form of potential energy is called elastic potential energy. An example of this is a clock spring which can store the kinetic energy used to wind it and release it again as kinetic energy to drive the clock.

A special form of kinetic energy is heat. The temperature of an object is due to minute vibrations of its molecules. As an object cools, it will transmit its heat energy to its surroundings, air and other objects, by means of infrared radiation and conduction. Eventually the object and its surroundings will all have the same temperature and no energy will be transferred. This is known as entropy, which is the tendency for all energy to have the same potential, and thus no useful work can be done.

Sound can also be looked upon as a form of kinetic energy, but in the form of pressure waves or vibrations in a fluid or solid. Because sound requires a medium, it cannot traverse the vacuum of space.

Chemical energy is energy that is released in a chemical reaction such as combustion. It is normally converted into light or heat, or even directly into electrical energy as in a battery.

Nuclear energy is released by nuclear fission (splitting an atomic nucleus), or nuclear fusion (joining of subatomic particles).

Electrical energy is transferred either by conduction or radiation. When an electric current flows in a wire energy is transferred by conduction. Electrical energy is also radiated by a radio transmitter.

An electric current will flow in a conductor such as a copper wire, if there is a potential difference between the two ends. A potential difference can be considered as an excess of electrons at one end and a shortage of electrons at the other end. As the current flows, an electromagnetic field is generated and if the wire has resistance, some of the energy will be converted to heat, thus warming the wire.

The relationship between the potential difference (voltage), the electrical resistance of the wire, and the current flowing through the wire was first described by Ohm for direct current in his well-known law:

$$E = I \times R$$

where E = Potential Difference in volts
I = Current in amps
R = Resistance in ohms

In other words, the greater the resistance (which is proportional to the length) of the wire, the less current will flow through the wire for a given voltage level. This law forms the basis for much of electrical theory and is valid for direct current (an electric current that does not vary in time). An electric current that varies in time is known as an alternating current, which is the normal method for distributing electricity for domestic and commercial use. When dealing with alternating current, the R (representing resistance) is replaced by a Z representing impedance:

$$E = I \times Z$$

where E = Potential difference in volts
I = Current in amps
Z = Impedance in ohms

Impedance is made up of two components:

1. R - the resistance of the wire.
2. X - the active or frequency dependent part of the impedance, 90° phase shifted with R.

where the following equation is used to describe the late relationship between them:

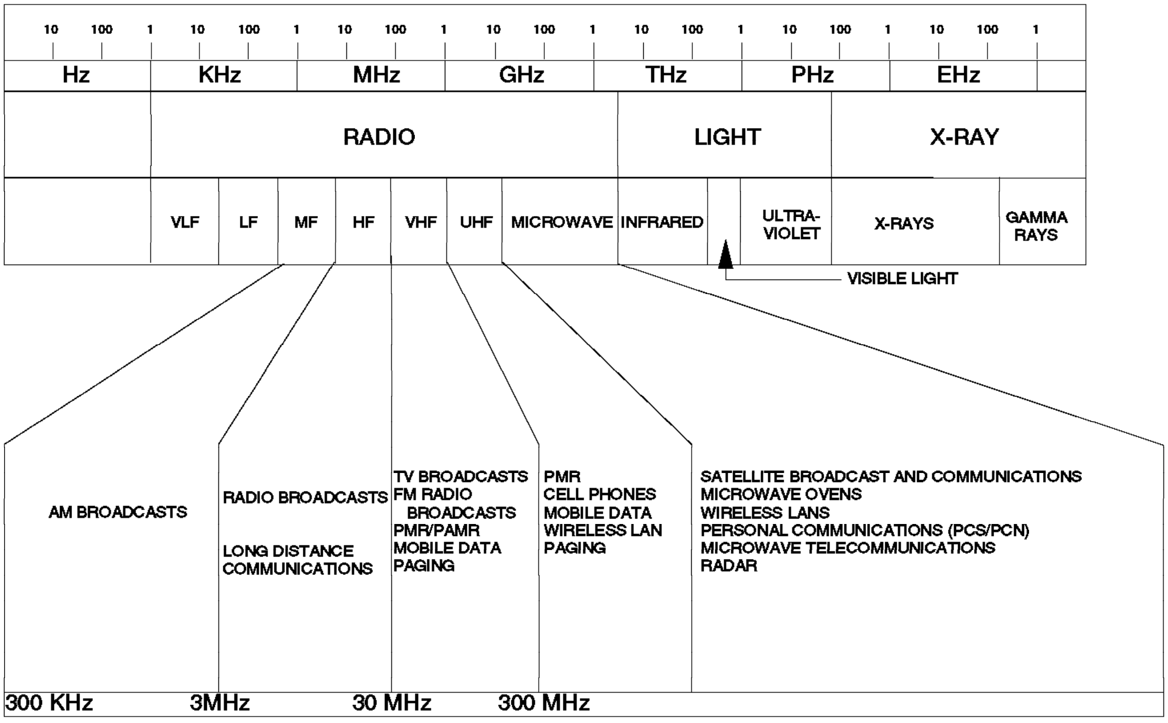
$$Z = R + iX$$

The “i” simply means 90° phase shifted.

This shows how impedance, or the characteristics of a wire or other material, changes with the frequency of the signal passing through it.

A high frequency alternating current will generate a radio frequency signal as it passes through a conducting wire, creating the simplest form of radio transmitter.

The different forms of electromagnetic radiation are defined by their frequencies and include radio waves, infrared radiation (heat), visible light, ultra violet light, X-rays and gamma rays. All these different frequencies of electromagnetic radiation form the electromagnetic spectrum as shown in Figure 3.



NOTE: THE FREQUENCY OF THE DIVISIONS OF THE SPECTRUM MAY VARY

ELECTROMAGNETIC SPECTRUM

4465/4465H02

Figure 3. The Electromagnetic Spectrum

For the purposes of this discussion we will consider radiant energy as an electromagnetic wave, but it can also be viewed as a series of particles or quanta, which is sometimes more convenient when explaining certain properties.

Electromagnetic radiation can travel through free space and can also travel through various solids and fluids to varying degrees dependent on the frequency and the kind of solid or fluid. For example, light can travel through air, water and glass, but not other solid material. Radio frequency waves can travel through some solids, but not through metal, while metal can be transparent to X-rays and gamma rays. You can see that the higher frequency waves have more ability to penetrate solids than those with lower frequencies.

Although radio frequency waves may be able to penetrate the material of a building, the construction of modern buildings may prevent radio transmissions from reaching the inside of an office block. Most modern buildings are constructed using a steel frame to provide the main structural integrity. The external cladding is fixed to the frame to enclose the space and provide an aesthetically pleasing appearance. Internal subdivisions for offices are constructed using steel or wooden frames to support partition walls. Radio waves are able to penetrate the cladding of the building but the steel frame acts as a “Faraday Cage” to effectively screen the interior of the building to radio waves of some wavelengths. This effect was named after Michael Faraday who was the first to demonstrate and explain it. If the construction of the frame or “cage” is such that the spaces between the steel girders equate to, or are smaller than the wavelength of a radio signal then the signal is drastically attenuated. Radio frequencies for use in buildings must be carefully selected to ensure that the best compromise be made between the Faraday Cage effect and the material penetration capability of radio waves. The Faraday Cage effect is used in electronic devices to provide screening of unwanted radio frequency signals without the need to used solid metal enclosures.

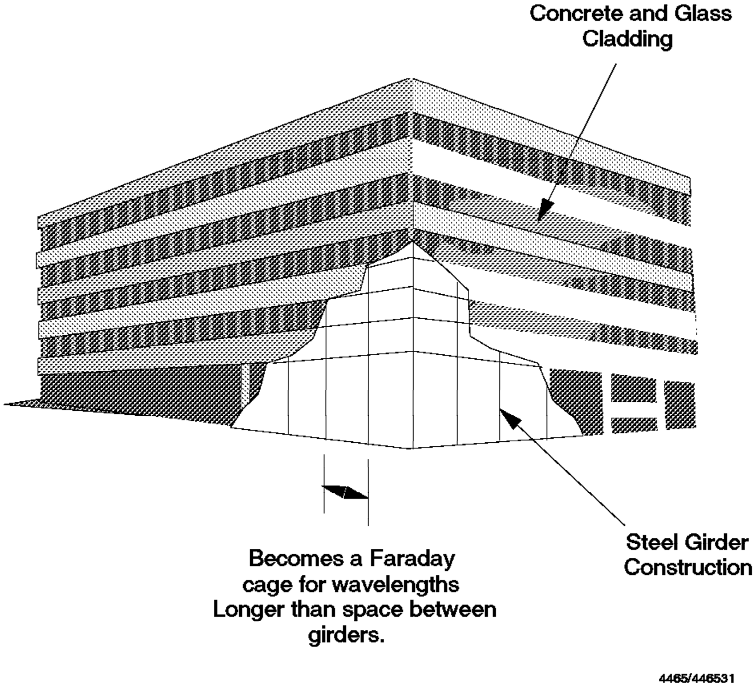


Figure 4. The Faraday Cage Effect in a Modern Building

In a vacuum, all electromagnetic radiation will travel at the same velocity, that is, 186,321 miles/s or 299,790 km/s. This is commonly termed “the speed of light”. The velocity in fluids and solids will vary according to the type of material and the frequency of the radiation. This can be easily demonstrated when white light is passed through a prism. White light is made up of a number of different frequencies corresponding to the different colors of the visible spectrum. The shorter wavelengths (higher frequencies) will travel more slowly through the glass of the prism and be refracted more than the lower wavelengths. Thus the violet light will be bent by the glass of the prism more than the red light and this will result in the white light being spread into a spectrum of all the colors. Some radio waves have similar properties to light and similar techniques may be used to control them.

Electromagnetic radiation is normally considered to consist of a sine wave which has the properties of wavelength, frequency and amplitude. This can be seen in Figure 5.

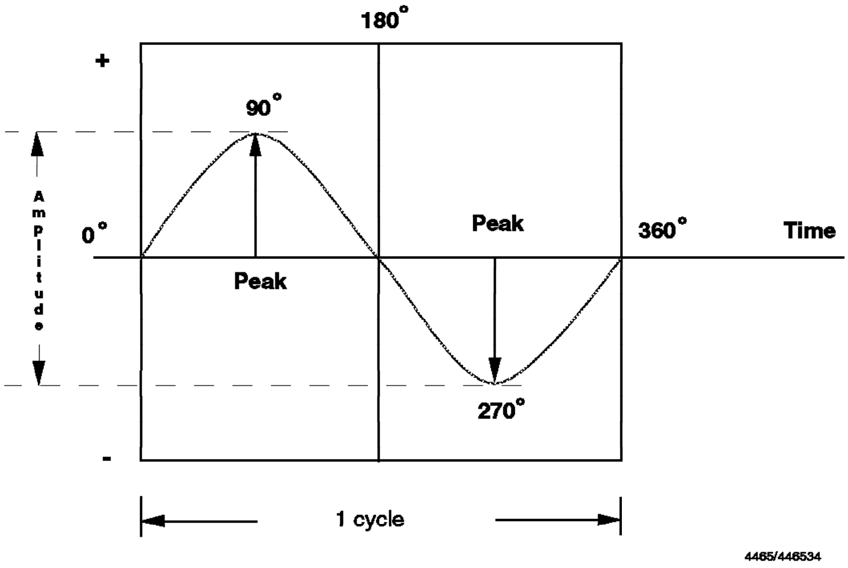


Figure 5. A Sine Wave

The relationship between frequency and wavelength is given by the following equation:

$$\lambda = (300 \text{ x } 10\bullet)/f$$

where f = frequency in Hz
and λ = wavelength in meters
(300 x 10• is the speed of light)

Electromagnetic radiation can be generated in various ways according to the frequency of the radiation required. Light and heat can be generated by simply raising the temperature of an object, while radio waves and X-rays need more sophisticated methods.

Note: Objects which are raised to very high temperatures will radiate energy over a very wide range of the electromagnetic spectrum. For example, the sun radiates radio frequency, heat, visible light, ultra violet light, X-rays and gamma rays. However, it is not practical to use this method to generate and control anything other than heat or light.

An alternating electric current will generate electromagnetic radiation. This is probably the most common method for producing most kinds of electromagnetic radiation in use today.

Electrical energy is transmitted in the form of electrical impulses or waves, regardless of whether the energy is conveyed across wires, air or water. The frequency is expressed in hertz (Hz), which represent impulses or cycles per second. The electrical energy, or signal, is changed by the medium that it passes through. It can be attenuated (absorbed) or reflected resulting in a signal that is distorted in some way. Waves are changed in size or amplitude (attenuated), direction (reflected), or shape (distorted), depending on the frequency of the signal and the characteristics of the medium that they pass through. By choosing the correct medium, a signal can be changed or controlled. An electrical signal will be attenuated when it passes through a wire.

High frequency light signals can travel through air, are reflected by mirrored surfaces, and are absorbed by most solid objects. For example, light signals can pass through the atmosphere but are blocked by solid walls, unless made of glass or transparent material. Low-frequency signals are not propagated well by air but can travel well through some solid objects depending on conductivity. For example, the electric power generated by public utility systems will remain mostly within the copper transmission wires which are a very suitable medium for electric current. (Some of the energy will be radiated in the form of electrical and magnetic fields around the wire.) On the other hand, plastic cladding for the wires is a good insulator for low-frequency electric utility power, effectively blocking current flow. Submarine communication is generally made at low frequencies since water attenuates high-frequency signals. Frequencies below 900 MHz can, in general, propagate well through walls and other barriers.

As radio frequencies increase and approach the frequency of light, they take on more of the propagation characteristics of light. Signals between 900 MHz and 18 GHz, typically used by wireless LANs, are not as limited as light but still do not pass through physical barriers as easily as typical radio broadcast band signals (1600 kHz, 100 MHz). Signals of 300 MHz or higher can be reflected, focused, and controlled similarly to a beam of light. Parabolic transmitting antennae use the properties of UHF and higher frequency signals to allow a relatively low-power signal to be focussed directly towards its destination. Still closer to light signals, infrared signals have properties similar to light. Experimenting with a remote TV controller at home can help you understand which surfaces reflect infrared signals and how directional they are. By choosing the most suitable frequency, you can achieve the best propagation or transmission characteristics.

The fact that only radio signals of certain frequencies are reflected by certain surfaces can be utilized to advantage. For example, the ability of high frequency microwave signals to penetrate the earth′s atmosphere without being reflected is useful for satellite communications. Lower frequency signals (200 kHz to 30 MHz) are reflected back from the ionosphere (upper layer of the atmosphere), depending on time of day, season, and sunspot activity. This characteristic enables radio signals to be bounced off the ionosphere for long-distance communications beyond the horizon, as shown in Figure 6 on page 27.

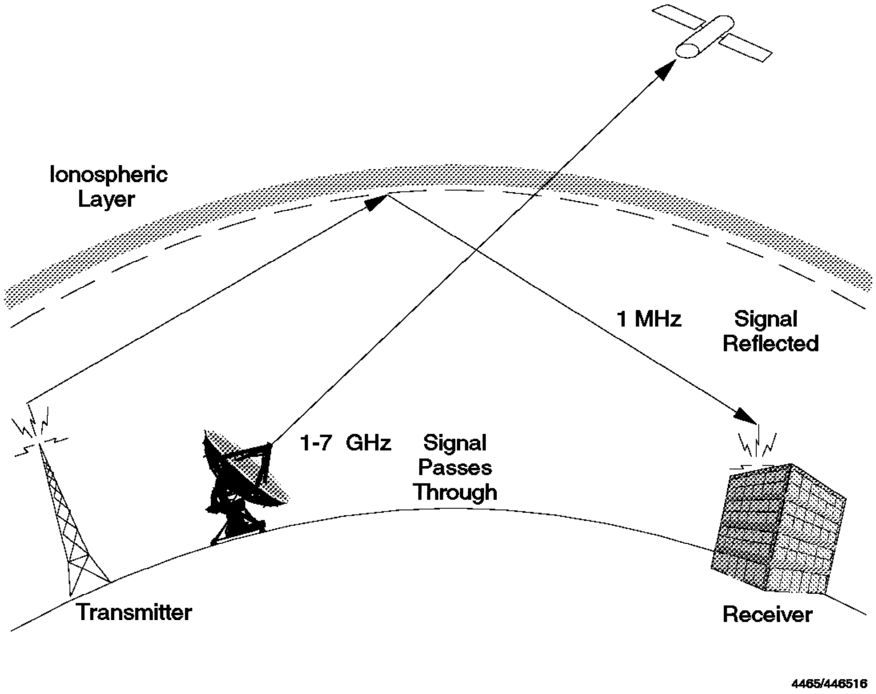


Figure 6. Reflection from the Ionosphere

When higher frequency carrier waves are used, there is normally more bandwidth available to transmit information. By increasing the bandwidth of a communications channel, more data may be transmitted in a given period of time since the information is directly proportional to the bandwidth of the signal. For example, a 100 kHz bandwidth channel can pass 100 times the amount of information per second that a 1 kHz channel can.

The frequencies of most interest to wireless transmission range from near the 200 kHz mark, where long wave radio transmissions are situated, up to infrared light in the Terahertz range.

There are some drawbacks in using higher frequencies. The technology to build radio transmitters and receivers at higher frequencies is more complex.

At higher frequencies, the wavelength of the radio signal approaches the physical length of the connections in the radio itself. Since a wire lambda/4 or multiples of this length is a good antenna, the actual connections within the radio itself must be kept short and become part of the circuit design because of problems with signal leakage. The individual radio components must also be capable of very fast switching rates. The path loss between transmitter and receiver is also a function of the wavelength:

$$\text{Path Loss in dB} = 20 \log_{10}(\lambda/4\pi R)$$

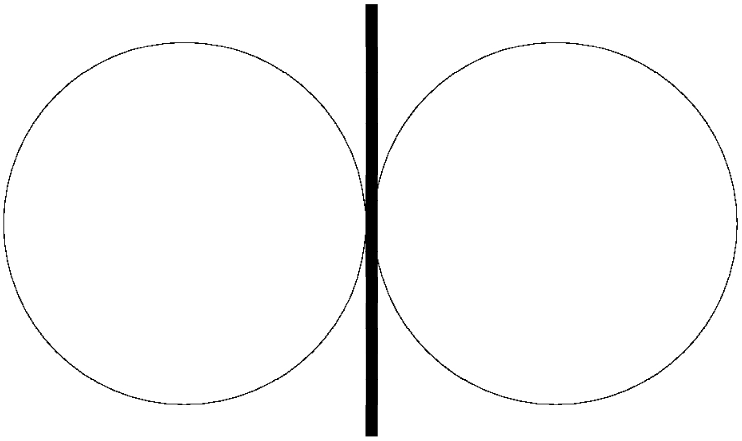
where R = range in meters
and λ = wavelength in meters

Another property of electromagnetic radiation is that it can be polarized. The concept of polarization is most familiar to us in the use of polarized sunglasses to eliminate reflections off shiny surfaces such as water. Polarized sunglasses will only allow light of one polarization to pass through them and will cut out light reflected from the surface. This is because electromagnetic radiation undergoes a 90° change in polarization each time it is reflected. Radio waves can be polarized in the same way and selection of polarization of a transmitted signal may be achieved by the position of the transmitting elements in a horizontal or vertical attitude. This property can be used to reject unwanted or spurious signals which may arrive at the receiving antenna with a different polarization to that of the wanted signal.

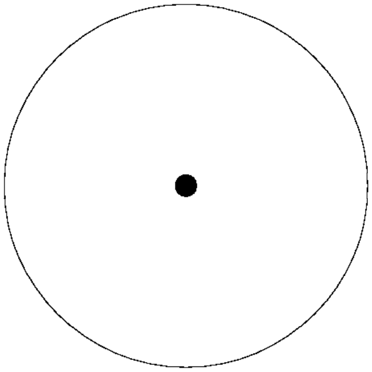
2.1.2 Antennae

Radio frequency signals are transmitted using an antenna which is designed to provide the most efficient method of radiating the signal. Its design will be dependent on the frequency of the signal, the spread of the signal required, and the environment in which it is to be used. In general, the same design of antenna can be used for both transmitting and receiving.

The basic form of antenna is known as the half-wave dipole. It consists of a single element with the feed from the transmitter or receiver at its center. Its length is exactly equal to one half of the wavelength of the signal.



Side View of Dipole Radiation Pattern



View from Above

4465/446512

Figure 7. Half Wave Dipole Polar Diagram

You can see from the diagram that it radiates (or receives) equally well from any direction (omni-directional), assuming that it is mounted vertically. In a vertical plane its radiation pattern is a figure-eight producing an overall three-dimensional pattern in the shape of a doughnut or torus. The half-wave dipole may be used as the standard antenna on which comparisons of other antenna designs are made. In this case it is considered to have unity gain (0 dB).

Note: An antenna is a passive device, and cannot amplify a signal. However, a uni-directional antenna will have most of its transmitting/receiving capability in one direction, and this is represented in terms of antenna gain.

The antennae commonly seen mounted on vehicles for broadcast reception are a special form of dipole. The top half of the dipole is the element mounted on the vehicle. The bottom half of the dipole is formed by a reflection from the metal of the vehicle body. The vehicle body is known as the groundplane.

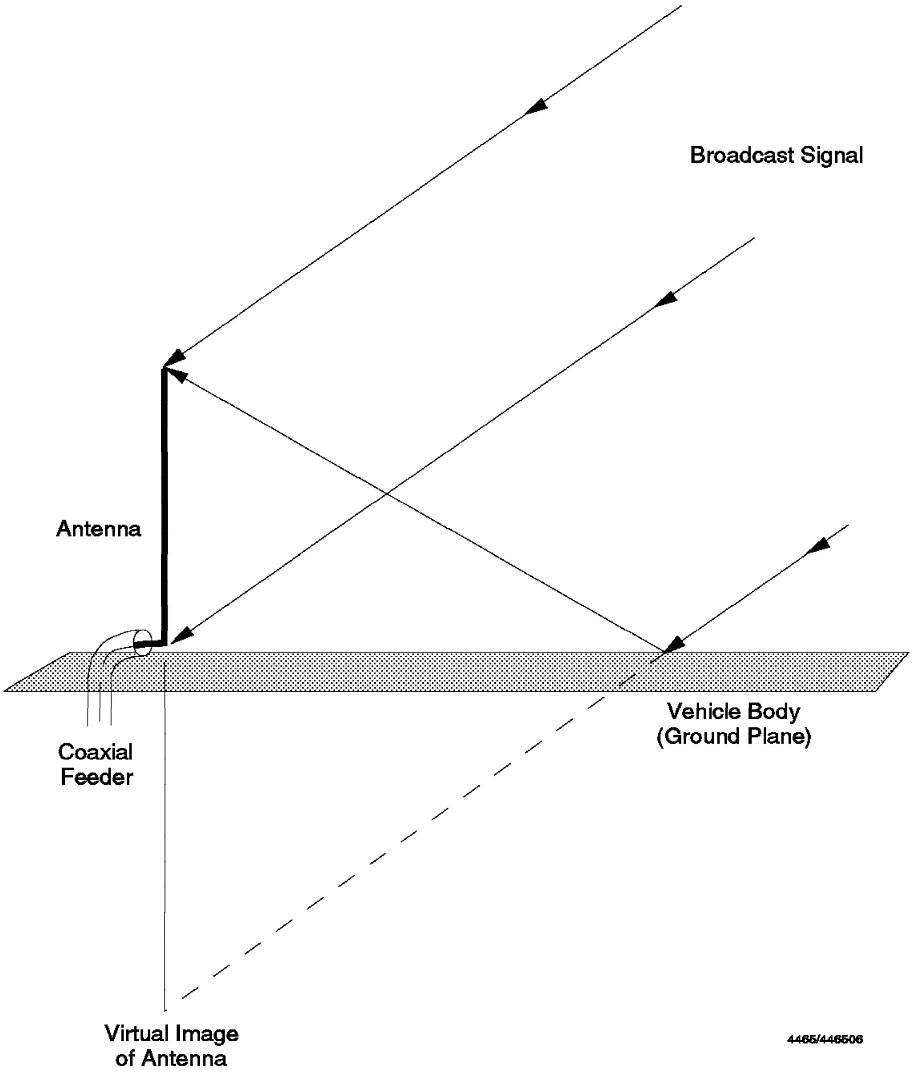


Figure 8. Vehicle Mounted Dipole

Another common type of antenna is the Yagi array. The familiar externally mounted TV reception antenna is called a Log Periodic antenna and is similar to a Yagi array.

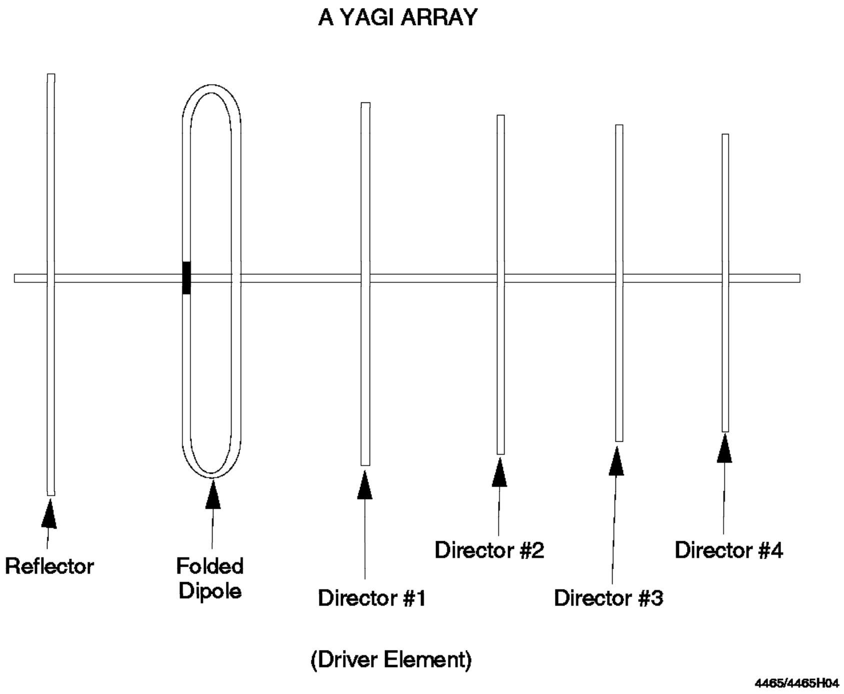


Figure 9. A Six-Element Yagi Array

A Yagi array consists of one element called the driven element and at least two other elements parallel to it. The driven element has the feed to the transceiver connected to it. The element is a reflector, normally slightly longer than the driven element and mounted just behind it, (away from the direction of transmission or reception). The second element is called a director. It is mounted in front of the driven element and is slightly shorter. There may be several director elements each shorter than the first and each other. The more director elements, the more directional the Yagi array antenna. The size and position of each element is carefully calculated to ensure the best performance.

In general, the more directive an antenna, the higher its gain. Antennae are reciprocal devices; that is, they provide directive gain in both transmitting and receiving modes. This means that a correctly designed system will benefit from enhanced radiated power from the transmitter and improved receiver sensitivity. The overall system performance will be improved by an amount that is equivalent to twice the antenna gain. A good antenna design has more effect on performance than any other single part of a radio communications system.

The performance of an antenna is quoted by its gain (dB) and its capture angle or beamwidth in degrees. The gain is the ratio of power transmitted or received for a standard half-wave dipole compared to that of the antenna being described.

The beamwidth is the angle between the two edges of the main lobe of the antenna polar diagram for a specific transmitted field strength or received sensitivity.

A different principal of antenna design is used for satellite TV reception and other satellite communications.

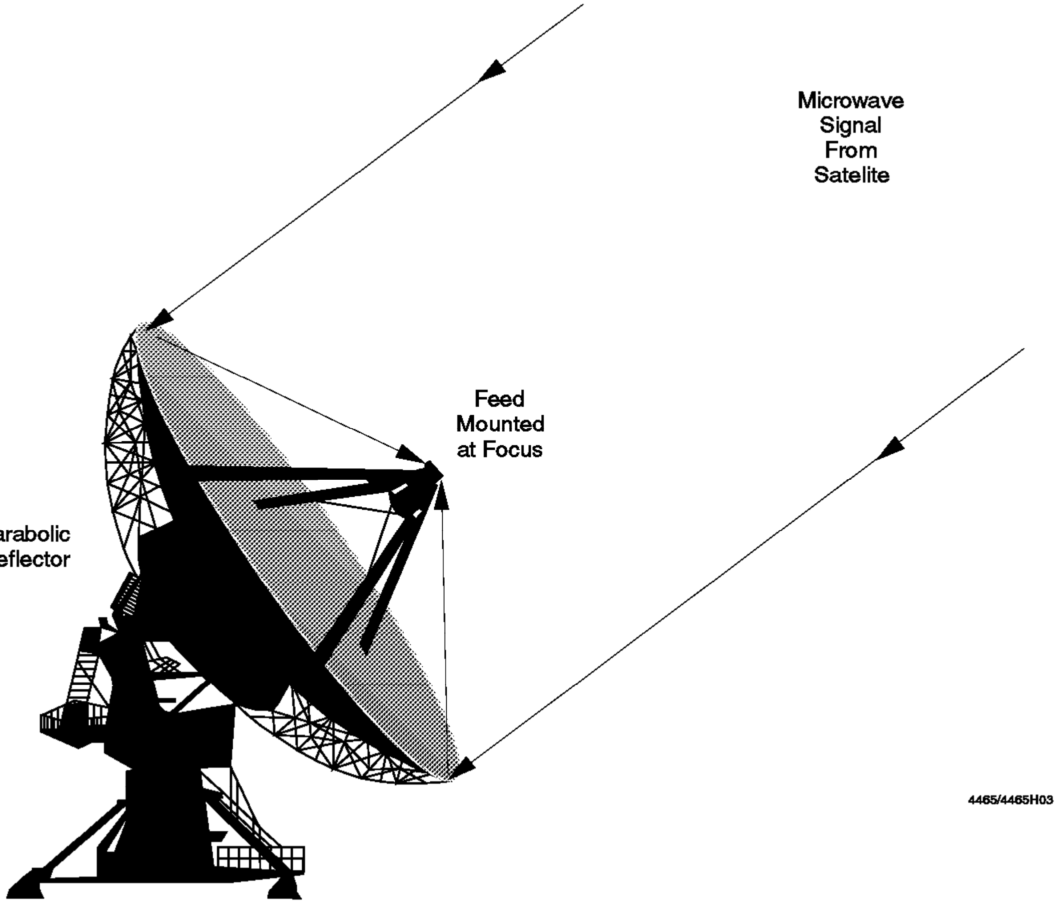


Figure 10. A Satellite Dish Antenna

As these radio signals are in the microwave region of the spectrum, they behave in a way that is similar to light. It is therefore convenient to focus the microwaves on to a detector by means of a parabolic reflector, commonly known as a dish.

A satellite dish has a very small beamwidth and thus must be very carefully positioned so that the dish is aligned precisely with the position of the satellite. This has the advantage that the system has immunity from interference outside the beamwidth of the antenna, but the disadvantage that it must be steered to align with different broadcasting satellites. The satellites used for TV broadcasting, called Direct Broadcast Satellites (DBS), are in geostationary orbits to obviate the need for steerable dishes.

Antenna dimensions are normally multiples of a quarter or half the wavelength corresponding to the frequency of the signal to be transmitted or received. If a hand-held cellular phone were operating in the 900 MHz band, a half-wave dipole would need to be 333.3 mm (one third of a meter) in length. This would be difficult to use and could not be considered as truly hand portable. Therefore, it is fortunate that a quarter or even one-eighth wave dipoles can be used. Even these can be reduced in length by designing them in the form of a helix, which has the overall correct electrical length but is packed into a smaller physical space.

Although it would appear to be possible to design very small antennae, there are limitations and penalties for making them too small. With the smaller fractional wavelength antennas, there is less physical length of antenna to radiate or receive, and thus they exhibit low gain.

A very different type of antenna is used for some specialized applications notably satellite GPS receivers and radio frequency LAN transceivers. The patch antenna consists of a square plate whose diagonal dimension is a sub-multiple of the wavelength of the radio frequency. See Figure 11 for an example of a patch antenna. The feed to the transceiver is taken from the center of the patch antenna.

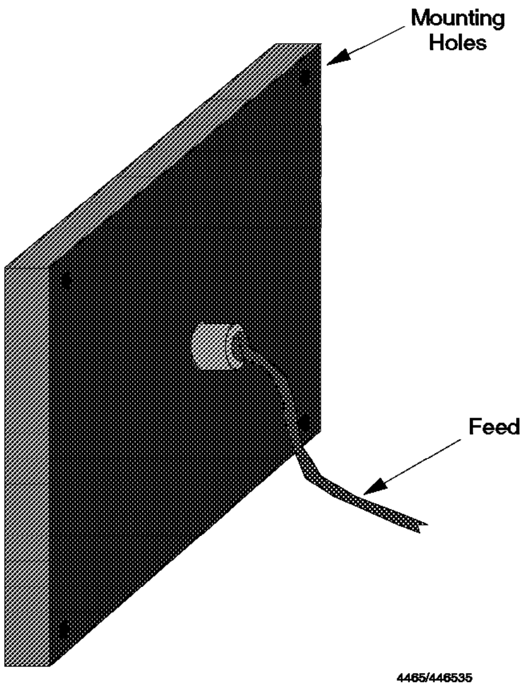


Figure 11. A Patch Antenna

The patch antenna has some significant advantages over conventional antenna designs, but can only be used for frequencies above 1 GHz. The antenna is very rugged and can be attached to the body of an aircraft or other vehicle traveling at high speed. In addition, the radiation pattern is such that it only transmits or receives from one side. In RF LAN applications this means that it can be mounted on a wall or ceiling and the maximum antenna gain is directed to the areas where it is most useful.

Antenna design is a highly specialized field and there are a multitude of different shaped designs to choose from. The most critical parts of an antenna design are its placement and orientation. It is obvious that for the best performance between a single transmitting station and a receiver, the main lobes of each antenna must be aligned to point towards each other. For many mobile applications such as cellular phones, the mobile station must have an omni-directional antenna, whereas the base station will have an antenna direct towards the coverage area.

Note: Cellular base stations are usually depicted as being at the center of their coverage area (cell). This is normal for open country, but in urban areas, a single base station may be used to cover several smaller cells by having a number of directional antennae aligned with each cell to be covered. This provides a more cost-effective way of covering urban areas. The placement of an antenna can be very important in order to achieve the best performance. If the antenna is placed close to other objects that are electrically conductive, then these can either screen the antenna from the signal or reflect the signal causing multipath interference. Objects which can cause problems are anything made from metal and the human body. When a dipole antenna is mounted on a vehicle, the antenna must be mounted as near to the center of the vehicle body as possible to ensure an adequate groundplane all round the antenna position. See Figure 8 on page 30 for clarification.

The tolerances get more critical with higher frequencies and smaller components.

Any antenna system must be matched to the transmitter and receiver, as well as being designed to work at a particular frequency. As in any transmission line, an antenna system will have a defined impedance, and the feed to the transceiver together with the transceiver itself must have the same impedance. If the impedances are different, significant amounts of RF signal will be lost. The higher the frequency and the lower the power, the more critical the impedance matching requirements. With higher frequencies, the design and quality of all components such as connectors becomes very critical. If the impedance between the antenna system and the transmitter are significantly different, it is possible to cause permanent damage to the electronics of the transmitter.

2.1.3 Wireless LAN Frequencies

The two most widely used methods for wireless LAN usage are Infrared (IR) and Radio Frequency (RF) channels.

Because most IR receivers detect the power (amplitude) of optical signals (not their frequency or phase), the systems that use them are simple in design, have no frequency conversions or precision components, and are readily available. It is possible to use phase or frequency modulation and there are some existing products, but they are not in common use. The cost efficiency of an infrared design can be enhanced if it can share components or subsystems with such mass-produced devices as television remote controls. Because infrared systems are not regulated (other than with limits on the permissible optical power densities), there are no regulatory constraints on a design. In comparison to radio systems, this freedom from regulatory constraints can help to keep costs down.

The worldwide demand for applications of RF technology has created extreme competition for frequency spectrum, causing regulatory agencies to place tight specifications on the use of an allocated band. The signal transmitted must be kept within the permitted frequency band to tight tolerances adding significantly to the cost of the transmitter. For some applications, the receiver must be able to select bands in order to be able to operate with transmitters at different frequencies, also adding to the cost. Selectivity is a measure of the ability of a radio to detect and receive a signal while rejecting signals at adjacent frequencies. Higher selectivity becomes more important in busy frequency bands with many transmitters. For a receiver to exhibit high selectivity, the individual components in the tuning section of the radio must be manufactured to very close tolerances.

Complex filters are often used to eliminate unwanted signals. Active filters are a common type of complex filter where the characteristics of active components, such as transistors or integrated circuits, are precisely controlled by electrical signals. These filters can be accurately tuned to accept a predetermined frequency signal and reject other unwanted signals. Filters using resistors, capacitors, and inductors without active components are known as passive filters. Drift is the tendency of transmitter or receiver frequency to change with time. This can be caused by temperature tolerance of radio components or slight voltage changes in the power supply source.

Digital tuning circuits and phase-locked loops can be used to lock on accurately to a signal in order to eliminate this effect. Higher tolerances and complexities of a receiver also add to cost. Sensitivity determines how well a receiver can detect a weak signal. In order to reduce interference with transmitters at adjacent frequencies and in adjacent areas the transmitter power is kept as low as possible. This places a burden on the receiver for being able to detect low-power signals from a noisy frequency band. Noise can come from a variety of sources. Man-made noise can be spurious signals radiating from electrical equipment such as electric motors. This is especially critical in industrial environments. Background noise can come from many natural sources such as lightning, sun-spot activity or other extra-terrestrial sources. This can become more significant in less populated areas. To prevent the low signal-to-noise ratio from being further degraded by noise at the receiver, the signal level is increased by a high-gain amplifier. Gain is a measure of amplification, and is expressed in the following form:

$$\text{Gain} = 10 \text{ Log } (\text{Power out} / \text{Power in})$$

and is measured in decibels (dB).

The need for selectivity and high gain leads to complex receiver structures involving amplification at higher carrier frequencies, frequency conversion involving precision local oscillators, and precision selective components. The need to coexist in the crowded RF spectrum places a cost burden on radio systems that does not exist for infrared systems. In the US, radio systems operating in the license-free ISM bands (Industrial, Scientific, and Medical: 902-928 MHz, 2400-2483.5 MHz and 5725-5850 MHz) bear an additional cost burden because of the need to implement spectrum-spreading techniques to prevent interference to or from other appliances and systems. These bands have been set aside for unlicensed operation provided that the transmitter and receiver comply with a set of regulations specified by the FCC (Federal Communications Commission). Typical applications now operating within these bands are cordless telephones, door openers, security motion detectors, remote controls and meter reading devices. Parts of these bands were auctioned off to commercial carriers in December 1994. (See 8.4, “PCS Auction in the US” on page 143 for more details.)

Low-cost radio systems can still be achieved, however, with volume production of components and systems. An example of this is the widespread use of cordless telephones. Wireless LAN implementations have benefited from the component volumes of cellular telephone production; when digital cordless telephones, wireless PBX, and PCS/PCN telephone systems stimulate high-volume component production, wireless LAN systems will benefit further. Advances in the fabrication of components promise higher levels of integration, more accurate passive filters rather than expensive active filters, and smaller, less expensive systems.

2.2 Analog Cellular Telephony

The development of mobile telephony systems as described in 1.2.1, “Voice Communication” on page 5 led to the cellular telephone systems in existence today. In this narrow-band FDMA-based system, voice is transmitted using Frequency Modulation (FM); channel spacing is either 30 kHz for the Advanced Mobile Telephone System (AMPS) in the USA, 25 kHz in Europe, or 6.25 kHz in Japan.

In the USA and Canada AMPS is the most widely available cellular system and is provided by two carriers in each service area to ensure competition. More than 25 carriers serve more than 734 service areas using base stations with 100 W power in the 800 MHz frequency band. See A.4, “Analog Cellular Networks in The USA” on page 157 for a list of US cellular operators. Portable units transmit with 0.6 W, transportable units with 1.6 W and car units with 4 W. The 50 MHz available band width is split into 25 MHz for base stations and 25 MHz for mobile stations. Each of these 25 MHz ranges is divided between the two carriers for that service area.

In Europe, mobile telephony services based on analog transmission standards operate in the 450 MHz and 900 MHz frequency bands. The primary analog standards are TACS (Total Access Control System) and NMT (Nordic Mobile Telephone). France, Germany, and Italy also each use different national standards:

- Nordic Mobile Telephone 450 MHz (NMT-450) is used in Austria, Belgium, Czech Republic, Denmark, Finland, Iceland, Luxembourg, the Netherlands, Norway, Poland, Slovakia, Spain, Sweden and Turkey.
- Nordic Mobile Telephone 900 MHz (NMT-900) is used in Denmark, Finland, the Netherlands, Norway, Sweden and Switzerland.
- Extended Total Access Communication System 900 MHz (E-TACS) is used in Austria, Ireland, Italy, Spain, and the UK.
- Netz-C 450 MHz is used in Germany, Portugal, and South Africa.
- Radiocomm 2000, 450 and 900 MHz and Ligne SFR/NMT-450 is used in France.
- NTT System 900 MHz and Japanese TACS 900 MHz are used in Japan.

See A.2, “Analog Cellular Networks in Europe” on page 152 for a list of European analog cellular networks.

It is possible to transmit digital signals using Public Switched Telephone Network (PSTN) modems and cellular phones. For example, V.32 modems operating at 4800 bps have been used successfully. However, the radio link introduces conditions which PSTN modems find difficulty in handling. During signal fade conditions, the modems try to adapt to noisy conditions by changing speed and may even lose their connection by the time the signal returns. Channel switching by the cellular phone to a less noisy channel may also be sufficient for the modem to drop the connection. Differences in bandwidth between different analog channels can also lead to problems. Since there are no industry standards for operation of PSTN modems connected to a cellular telephone through an interface adapter, proprietary error-control protocols have been developed by some manufacturers (for example, Microcom Network Protocol 10 or MNP 10). A special adapter is required to connect a PSTN modem to a cellular phone. Some manufacturers tap into the handset-transceiver connection (for example, CelJack from Telular) and others provide connections for their own cellular phones (Motorola). In the US, Spectrum Cellular offers a range of equipment for connection to the cellular phone network including fax machines and special modems.

It can sometimes be difficult to get type-approval for these kind of solutions in some countries, as the requirements of a data connection can be different to those for a voice-only system. There are no standards for data-over-cellular and the national approval authorities may not even allow these solutions in some countries.

2.3 Digital Cellular Telephony

Digital cellular telephony is based on the same network concept as analog cellular telephony with base stations and mobile stations. The move to digital, as described in 1.2.3, “The Move to Digital” on page 9, led to the development of different systems in Europe, Japan, and the US. It had been recognized for some time that the analog cellular telephone systems did not make efficient use of the available radio spectrum. In any voice conversation on an analog network, the whole channel has to be dedicated to the end-to-end connection. Most conversations consist of a small amount of time when information is actually being transmitted, and the rest of the available time is silence - between words, waiting for the other party to respond, pauses for breath, and thinking time. A digital system can use this “dead time” to allow other conversations to use the same radio channel. This is called Time Division Multiple Access (TDMA).

Using digital technology it is also possible to compress speech by making some assumptions about speech waveforms. In addition to using the “dead time” for other voice calls, compressing speech allows even more users to share the same channel. GSM in Europe can have up to eight two-way calls in the same pair of radio channels. Future developments will be able to double this within the next few years. With the analog cellular network capacity quickly becoming saturated, it is not surprising that a great deal of development effort has gone into digital cellular.

One other major advantage of digital cellular is the quality of the voice call. Because the digital data stream can have error correction built in, interference and other short breaks in transmission do not result in any loss of quality. If the error correction mechanism cannot recover the lost data, then a short period of silence will ensue. Listening to a digital cellular conversation compared to listening to an analog phone can be likened to the difference between a compact disk recording and a vinyl record. In fact, many of the same techniques are used in digital cellular as are used in the production of CDs.

The last significant advantage of digital cellular is the inherent security against casual eavesdropping. With analog cellular, a standard FM radio receiver capable of covering the cellular channels can be tuned to receive an analog cellular phone conversation. No special equipment is needed and a radio “scanner” can be readily purchased at an affordable price. The scanner may only be able to receive the channel being transmitted by the cellular base station, but both halves of the conversation can usually be heard due to the fact that they both share the same pair of wires in the land-based telephone network. If the cellular phone user is moving, then the conversation may only be heard for a short time until the phone moves into the next cell.

With more sophisticated computer controlled scanning equipment installed in a vehicle, it is possible to follow a moving cellular phone and switch to new channels in each cell automatically. A digital cellular phone conversation is much harder to decode. Special equipment is needed to select the required time slot for the particular voice conversation to be followed. Most digital systems encrypt the data representing the speech information, and may enable frequency hopping, thus making it even more difficult to eavesdrop. This does not make it impossible to eavesdrop, but it does increase the cost of the listening equipment to a point where it is unlikely that it would be worth doing. It must be remembered that the cost of breaking into a secure system must be less than the value of the information obtained if it is to be attempted.

A digital cellular system will ultimately have far greater potential for miniaturization and cost reduction of both the base station equipment and the mobile equipment. This will be helped by the move towards international standards using common systems, architectures and components, thus spreading development costs over a much larger customer base. Already the GSM architecture is becoming the accepted standard and the service is reaping these benefits.

The introduction of GSM provided a unique opportunity to define and develop a range of significant value added services such as data transmission, fax, and messaging.

2.3.1 Global System for Mobile Communications (GSM)

An introduction to GSM is given in 1.2.3, “The Move to Digital” on page 9. The GSM standard was proposed by CEPT in 1982 and completed by ETSI in 1990; the first networks were deployed in 1991. It is similar to the terrestrial ISDN network with its definitions of voice and data channels, and is designed to be compatible with it. However, the data rates are much lower due to the limitations of radio bandwidth.

The main driving force behind the introduction of GSM in Europe was to provide a common standard for European Cellular Communications which allowed subscribers to roam throughout Europe and access cellular networks in each country with the same equipment. It also allows the equipment manufacturers to sell identical mobile and fixed equipment in all countries. A digital system was chosen for all the reasons described above.

GSM operates in the 900 MHz band, the same as existing European analog cellular systems and more channels will be allocated to GSM from analog as the networks grow.

The system uses Time Division Multiple Access to enable multiple voice calls to use a single radio channel. For GSM there are eight time slots on each radio channel called burst periods (BPs) which together make up a TDMA frame of duration 4.615 ms. Each burst period has a duration of 0.577 ms.

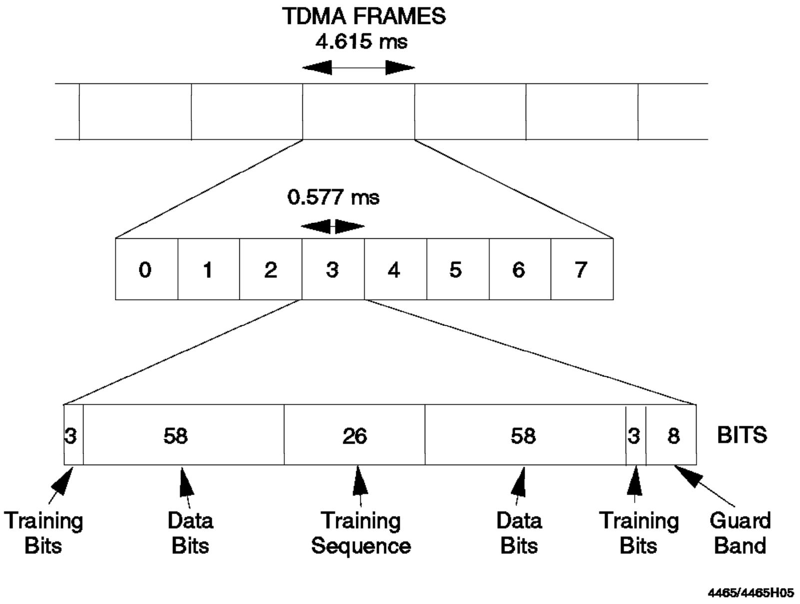


Figure 12. Typical GSM TDMA Frame

The radio channel has a bandwidth of 200 kHz compared to 25 kHz of the analog systems. The voice or data information is transmitted in a string of burst periods in consecutive frames, thus creating a logical channel.

Figure 12 shows a TDMA frame with a normal traffic channel burst as one of the time divisions. Burst periods can be of several different types including control and information bursts.

In order to provide some immunity to interference, the digital data is interleaved. This means that a single piece of information is spread over time and mixed with other discrete pieces of information. If an interfering signal causes a data error, the error will be spread over a number of separate pieces of information, but will be less significant and the error correction mechanism will be able to recover the lost data. Figure 13 on page 40 shows the principal involved but does not represent interleaving in GSM which has a much more complex scheme. You can see that only one bit in four records has been affected by interference.

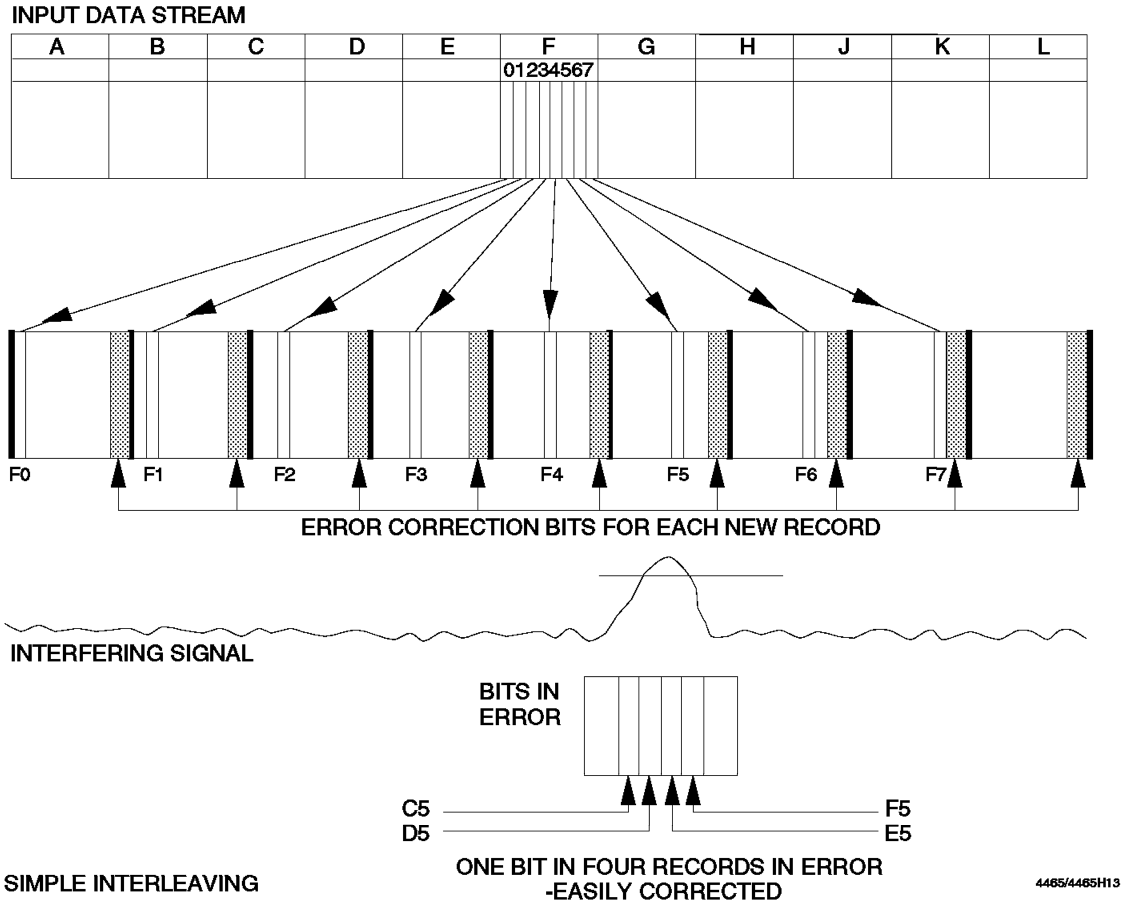


Figure 13. Simple Interleaving Scheme

GSM provides full-duplex operation (to be able to transmit information in both directions at the same time), and makes use of separate transmit and receive radio channels. The radio channel transmitting information from the mobile station is called the uplink, and is separated by 45 MHz from the downlink radio channel which sends information from the base station to the mobile. The mobile station is instructed by the base station to operate on a particular radio frequency and this will always consist of a transmit and receive pair separated by 45 MHz. The GSM specification allows for the use of slow frequency hopping, which occurs at 217 hops per second. This allows a complete TDMA frame to be sent at one frequency before a hop takes place.

In order to transmit analog speech over a digital network, the analog signal first has to be converted to digital information. The encoder takes a sample of the analog speech signal every 20 ms and encodes it to 260 bits of digital data. This gives a data rate of 13 Kbps. The data is then passed through a convolutional encoder which adds a special code based on the information content to the original bit stream. This provides an error correction capability built into the original information. This data is delivered to the transmitter in the form of blocks of data consisting of 456 bits every 20 ms. This results in a 22.8 Kbps data stream.

As each radio channel is capable of carrying data at a rate of 270 Kbps, eight logical channels can be used in one radio frequency channel with 87.6 Kbps spare for control signalling and error correction. The data is transmitted by modulating the radio frequency carrier using Gaussian Minimum Shift Keying. This is described in 3.1.6.10, “Gaussian Minimum Shift Keying” on page 68. If there is no voice signal (silence), then no data will be transmitted.

Although the network structure of GSM seems very similar to analog cellular networks like AMPS and TACS at first glance, the underlying structure is much more complex. One of the main reasons for this is that the architecture is structured to enable international roaming and the customer billing processes that ensure a mobile phone can be used in different GSM networks.

The following is a list of the main GSM network components:

- Base Transceiver Station (BTS)
  - The BTS transmits and receives to and from all GSM phones in its cell.
- Base Station Controller (BSC)
  - The BSC controls several base stations and ensures that a mobile phone can move from one cell to another and switch to the new radio channel without a break in communication.
- Mobile Switching Center (MSC)
  - The MSC is the way that the GSM network is connected to other networks such as PSTN, ISDN or other mobile networks. It also controls call setup and disconnect, call routing, and switching to other MSCs. It generates data for customer billing systems.
- Home Location Register (HLR)
  - The HLR contains information about the subscriber including level of service allowed and location information.
- Visitor Location Register (VLR)
  - The VLR obtains subscriber information from the subscriber′s HLR when the GSM phone is being used on a different network.
- Equipment Identity Register (EIR)
  - The EIR is a database which contains information about the validity of GSM telephones being used on the network. Each phone has an International Mobile Equipment Identity number (IMEI) which is independent of the subscriber number.
- Authentication Center (AUC)
  - The AUC provides a security function to ensure that a call is being made by an authorized phone.
- Operations Management Center (OMC)
  - The OMC manages the network on a regional and day-to-day basis.
- Network Management Centre (NMC)
  - The NMC manages the entire network on a global basis and is used for long-term planning.

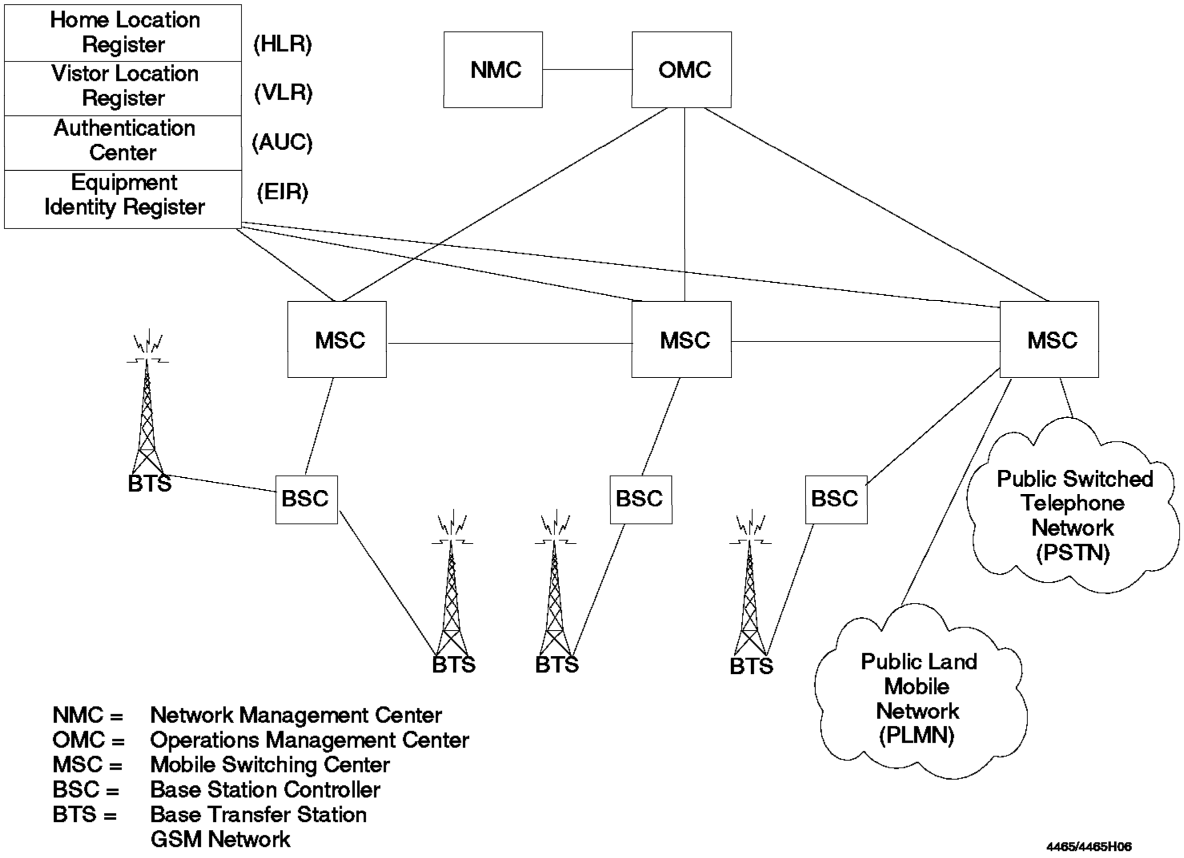


Figure 14. GSM Network Structure

The subscriber service on a GSM network is separate from the GSM phone itself. This means that the subscriber′s identity (or phone number) can be transferred from one physical phone to another, without reprogramming the phone. This is accomplished by means of a Subscriber Identity Module (SIM), in the form of a credit card-sized smart card device as shown below. The SIM has a small microprocessor with read only and read/write memory. It is used as the subscriber′s "identity" and has security functions, together with the ability to store the subscriber′s personal information (phone book) and short messages (SMS). The SIM can be inserted into a GSM phone, which then takes on the identity of the subscriber′s GSM phone. Some hand-held phones have only a very small aperture for the SIM, and for this reason the SIM card has a thumb-nail sized break-out section containing the electronics.

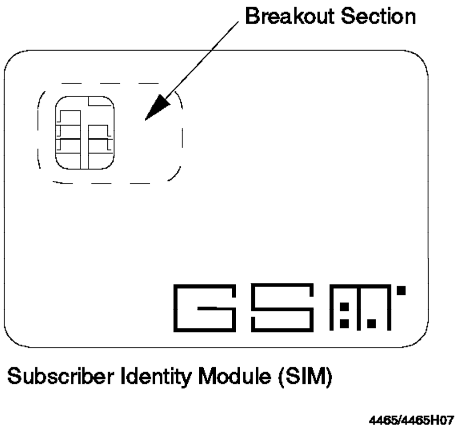


Figure 15. GSM Subscriber Identification Module (SIM)

The SIM allows subscribers to use a different phone (for example, in a rental car) and still retain their normal GSM phone number and be billed as usual for calls.

When a SIM is inserted in a GSM phone and the phone power is switched on, the GSM phone will listen on a number of predefined common control channels. These control channels contain information about the network and the current location. The mobile station can then inform the network of its location and its home location register (HLR) is updated with this information.

When the subscriber wishes to make a call, the number is keyed in and the SND button pressed. The network will check that the phone is authorized to make the call and the MSC will route the call to the appropriate number usually via PSTN. The MSC will also generate billing data and send it to the network billing system.

To make a call to a GSM phone from a fixed PSTN phone, the process is more complex. The PSTN network will route the call to the MSC closest to the calling PSTN phone. This MSC will look at the Home Location Register for the mobile phone and determine its location. If the mobile phone is in the same region as the MSC, it will send out a paging message on a control channel. Assuming that the mobile is switched on and in range, the mobile will respond and the MSC will authenticate its response. If it is a valid subscriber and device, the MSC will route the call to the mobile and the phone will ring. If the phone is in the region covered by another MSC, but still in the same network, the first MSC will route the call via the MSC local to the mobile phone.

The most complex process is where the mobile user is roaming in another network area. (This may be another country.) In order to understand how calls are routed to a roaming subscriber, we must first look at the telephone numbering schemes involved. With a fixed PSTN number, it is divided into three groups:

- Country number - 1 for USA, 44 for UK and so on
- Area or region number - this defines local areas for billing purposes
- Subscriber number - this may define groups as well as individuals

For calls within a local area it is only necessary to dial the subscriber number. For calls outside a local area but still within the same country, it is only necessary to dial the area code and subscriber number. With a cellular phone, the area number is replaced by a number which defines the network operator. A particular operator may have more than one number depending on the size of the network. Cellular phone numbers have the same structure as PSTN numbers. The PSTN numbering scheme is called the ISDN (Integrated Switched Digital Network) number and the GSM cellular phone number is called the Mobile Station International ISDN number (MSISDN). The GSM phone is identified over the air interface by a different numbering scheme. This is the International Mobile Subscriber Identity (IMSI) or Temporary IMSI (TIMSI). This allows the phone to be identified regardless of its home.

When a call is made to a phone roaming outside its home location, the call is routed to a gateway MSC (GMSC) in its home network. The GMSC interrogates the Home Location Register (HLR), which contains information about where the mobile phone is currently located. This information is obtained from the Visitor Location Register (VLR) of the network where the phone is located and includes a Mobile Station Roaming Number (MSRN) that is assigned to the mobile phone. Using this information, the GMSC routes the call to the new network MSC (which may be via an international link). The host MSC pages the mobile phone and the call is connected after validation.

A call directed to a phone roaming outside its home network will always be routed via a gateway MSC in its home network. One problem that arises from this is that if a call is made from one GSM phone to another, both roaming out of their home networks, then it is possible that they will be charged for a double international call even if they are next to each other in the same room. This is because the phone making the call will be charged for a call back to its home network GMSC and the phone receiving the call will be charged for a call from its home GMSC to its current location. There is no way of avoiding this situation without causing an unacceptable increase in billing complexity for average calls.

One of the main reasons for implementing GSM is the new services that can be offered. One of the first of these is the Short Message Service (SMS). This allows the GSM phone to send and receive short messages, using the network′s control channel to transfer the information. This means that no circuit-switched connection is established and the message can be stored and forwarded when the phone is able to accept the message. The GSM Short Message Service allows the phone to act like a two-way alphanumeric pager. Up to 160 characters can be transmitted in one message. One implementation of the service provides access via a normal paging bureau, or direct from a customer′s host system. The mobile phone subscriber can respond by entering a message using the phone′s keypad to emulate an alphanumeric keyboard. This can be quite laborious for longer messages, but useful for short acknowledgements.

One way to simplify this operation is to store a number of predefined messages in the phone′s memory and modify them as necessary before sending them. An alternative method is to connect the phone to a notebook computer or PDA and use that device′s keyboard. SMS messages can be sent from host to mobile, mobile to mobile, or mobile to host. In the latter case it will depend on the network operator′s implementation of the service. If a standard one-way paging bureau service is used for SMS access, then a direct connection back to a customer′s host system may not be possible. SMS messages can be stored in the phone′s own memory or in the subscriber′s SIM memory. This is especially useful if the subscriber is using a different phone from his own, but with his SIM inserted. SMS messages can also be broadcast to a number of subscribers at the same time. This is known as “cell broadcast”. All mobiles within a defined area that are equipped with this feature will receive the broadcast, and no special subscription is needed. This can be used for things such as traffic information, weather warnings and the like. The cell broadcast is limited to 93 characters. Apart from private messaging services, SMS can be used by network operators to communicate with subscribers and even download new phone configurations to enable other services. Other applications will be developed as networks grow.

In order to send circuit-switched data over a GSM network, it is important to understand that the air link is digital and that the encoding and compression algorithms are designed to expect speech information. It is therefore impossible to use ordinary PSTN compatible modems to send data over a GSM network. The GSM specification includes data services for fax, circuit-switched, and packet-switched data. The first implementation of GSM does not include packet-switched data. In order to send circuit-switched data, the network operator must provide a mechanism that allows digital information sent from a host computer to be encoded directly in the GSM air protocol. In addition, if the data is to be transmitted over the PSTN, the network operator must provide modems to match the end-user requirements. In the mobile phone itself, the data connection bypasses the analog/digital conversion and also bypasses the voice compression circuits. There is no need for a modem at the mobile end; the connections are all digital. At the fixed station (MSC), voice and data calls are separated.

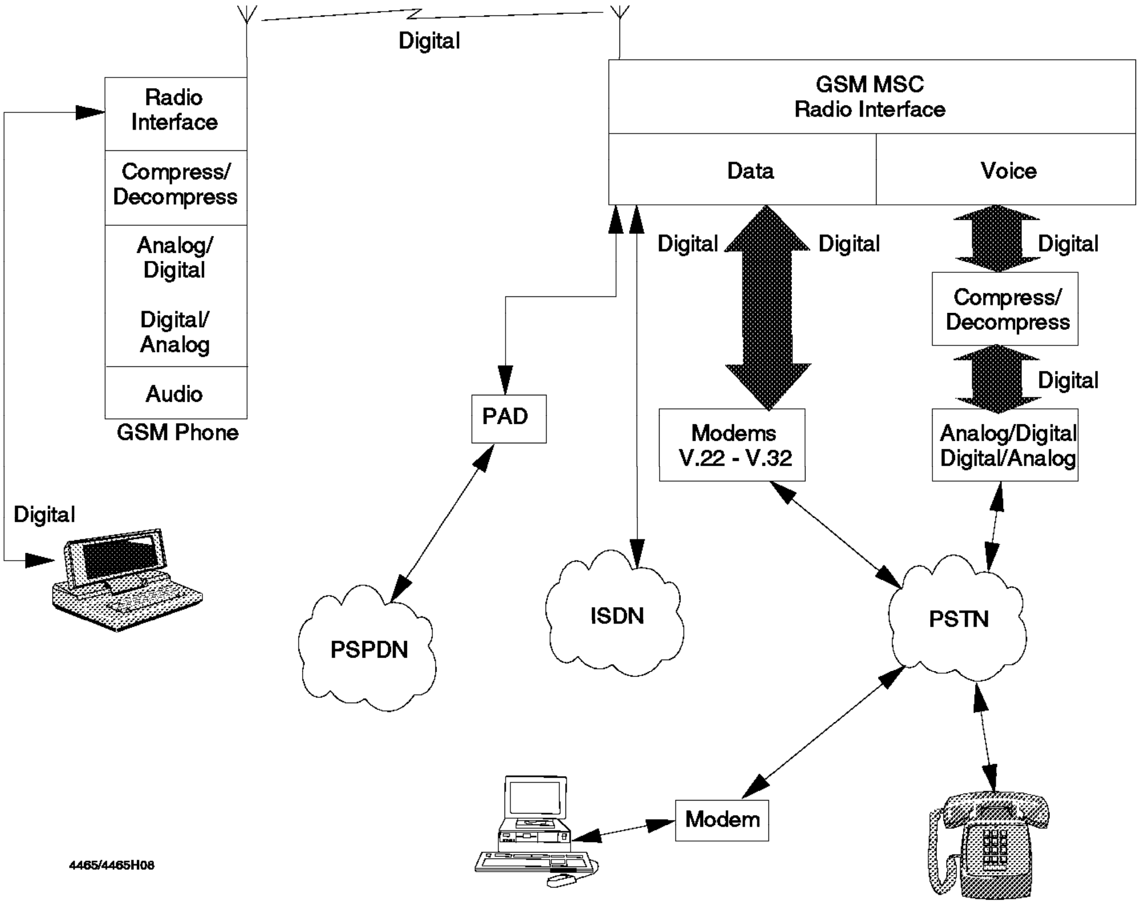


Figure 16. GSM Circuit-Switched Data

The data path bypasses the compression function and is sent directly to banks of modems which convert to a modem protocol to match the users requirements. As the GSM air link runs at 9.6 Kbps, the highest speed modem required is only V.32. Separate digital interfaces connect to ISDN or PSPDN (X.25). Not all GSM networks will offer these data services to start with, but all GSM equipment is designed to support them. GSM circuit switched data can operate in two modes, Transparent (T) and Non-Transparent (NT). Transparent mode uses a forward error correction scheme to ensure error-free transmissions, while Non-Transparent mode relies on the retransmission of data with errors using an Automatic Repeat Request (ARQ).

Group 3 fax services are handled in a similar way with the network operator providing fax modems to convert from the digital data stream to analog signals that can be sent over PSTN.

All the above considerations apply equally well to DCS1800 and DCS1900, the Personal Communications Network Technology (PCN). The key differences with PCN are in the implementation of the network. PCN networks are designed to work with hand-held phones. Vehicle installations with higher power transmitters are not allowed. The network structure is designed around microcells, to provide good coverage in metropolitan areas, both outside and within buildings. Coverage of rural areas will be limited.

2.3.2 US Digital Cellular (IS-54)

The EIA/TIA (see 8.1.2, “US Regulations and Environment” on page 140) has proposed a digital cellular standard called “Cellular System Dual-Mode Mobile Station - Base Station Compatibility Standard”, IS-54. The system is known by various names, North American TDMA (NA-TDMA), Digital AMPS (D-AMPS), and American Digital Cellular (ADC). Like GSM, it is similar to ISDN in the definition of channels. The system is similar to GSM in concept and only the major differences between GSM and IS-54 will be described.

The US analog cellular phone network in some areas is becoming very congested, with the demand for cellular phones beginning to exceed the available capacity of the networks. A method of increasing the number of telephone channels was required, but radio spectrum was not available to increase the number of radio channels. A method had to be found to increase the number of users for the same amount of RF spectrum. GSM in Europe had taken approximately eight years to define the standard, develop the equipment, and install the networks. It was decided to develop a digital standard that could coexist with the existing analog network and be quickly implemented. The key to this was to use much of the existing analog infrastructure and to develop dual-standard cellular phones that could use digital technology in areas where it was available, but could also access the existing analog networks.

In order be compatible with the existing AMPS network, the IS-54 network uses the same control channels as the analog network and has the same bandwidth traffic channels (30 kHz). In a later phase, new “digital-only” control channels will be defined and a data service provided.

The speech sampling is performed every 20 ms as in GSM, but due to the bandwidth constraints imposed by the existing analog network a TDMA frame has a duration of 6.67 ms and has six time slots in it. The six time slots are used in pairs by three logical voice channels. The overall bit rate per radio channel is 48.6 Kbps compared with 270.833 Kbps in GSM, but still provides a bit rate of 13.2 Kbps per logical voice channel.

The modulation technique employed is $\pi/4$-shifted Differential Phase Shift Keying (DQPSK). This gives two bits per symbol and is described in 3.1.6.7, “Quadrature Phase Shift Keying (QPSK)” on page 66.

Phase two of IS-54 will allow for more of the features similar to GSM to be introduced once compatibility with the analog AMPS service is no longer required.

2.3.3 US Digital Cellular (Qualcomm)

Qualcomm in San Diego has developed a digital cellular system based on Direct Sequence Spread Spectrum (DSSS) techniques, in contrast to the IS-54 system. The system is commonly known as Code Division Multiple Access CDMA, and offers a number of advantages:

- Easy transition from analog to digital
- 10 - 20 times more capacity than AMPS
- Less likely to drop calls on handoff (soft handoff)
- Immunity to interference and fading
- Built-in security

CDMA is described in 5.2, “Spread Spectrum and Code Division Multiple Access (CDMA)” on page 97.

The Qualcomm system uses ten channels of bandwidth 1.25 MHz and allows 118 users on each radio channel at any one time. This is achieved by encoding each bit of digital data with a unique code known only to the transmitting and receiving stations. Any other station listening on this channel will only hear low-level noise. The modulation technique used is Quadrature Phase Shift Keying (QPSK) and is described in 3.1.6.7, “Quadrature Phase Shift Keying (QPSK)” on page 66.

One of the significant factors of CDMA is that the mobile station can communicate with several base stations at the same time, thus avoiding fading and “blackspots” where the mobile station is shielded from the base station transmitter by buildings or geographical features. CDMA is most effective when the cellular phone is actually in a moving vehicle.

Many of the same network techniques are used in the Qualcomm system as in other digital cellular networks. The main difference is in the use of spread spectrum in the radio interface.

2.3.4 Japan Digital Cellular (JDC)

Japan′s Digital Cellular system is unique, but based upon IS-54 standards. The following are the key differences:

- Channel bandwidth is 25 kHz not 30 kHz
- Does not coexist with analog channels
- Three logical channels per frame
- 11.2 Kbps speech bit rate, 42 Kbps transmission rate

Japan was able to allocate dedicated radio channels to digital cellular and therefore did not have to provide dual analog/digital capability. Three discrete pairs of bands are available:

- 810 - 826 MHz downlink
- 940 - 956 MHz uplink
- 1429 - 1441 MHz downlink
- 1447 - 1489 MHz uplink
- 1453 - 1465 MHz downlink
- 1501 - 1513 MHz uplink

2.4 Cellular Digital Packet Data (CDPD)

Analog cellular systems throughout the world are becoming congested with voice traffic, but it is known that the total information carrying capacity of an analog cellular network is much greater than is currently being utilized. This is due to a number of factors which all relate with the fact that there are times when no information is being sent but the radio channel is kept open or idle. Some of these factors are as follows:

- “Quiet” time during voice conversations
  - Waiting for a response

  - Gaps between words - catching your breath
  - Thinking time
- Telephone call setup time
- Control channel idle time
- Traffic channel idle time

A test conducted on one of the most congested analog networks in the world, New York, revealed that 50% of the capacity of the network was not being used. CDPD is designed to make use of some of this spare capacity to send data. A key design criterion was that CDPD should not impact the voice traffic capability of the network in any way. This limited which of the factors influencing capacity usage could be addressed.

The other major factor in the development of CDPD was to provide more efficient and lower cost data services on the existing analog (AMPS) network. Analog cellular networks are designed for speech transmission, and the human ear can be very forgiving of short interruptions and distorted speech sounds. When data is sent over the same network, transmission breaks, distortion and interference all result in transmission errors which require resending of the data. This can slow down the data transfer rate, resulting in higher costs and sometimes causing the data link to fail, especially with heritage interactive applications. Reliable data transmission over analog cellular is only possible at a maximum speed of 4.8 Kbps in good conditions. When the mobile station is far from the base station, there are sources of interference, the mobile station is in a moving vehicle, or the terrain is rugged causing fading and blackspots, the data rate may have to be reduced to as low as 1.2 Kbps. This is because any error condition will affect more data, the higher the data rate. It can reach a point where no error-free data can be transmitted, and the only thing to do is to reduce the transmission speed. See 2.2, “Analog Cellular Telephony” on page 36 for more information on these problems. A method of transmitting data avoiding these problems was required.

One solution to the problem of transmitting data using radio frequency links is to build a dedicated radio data network. This can be very expensive and the return on investment would not occur quickly. It may take years for carriers to build a wireless data network that matches the geographic coverage of the existing cellular network. See 2.5, “Packet Network Methodologies” on page 51 for more about these networks. Another solution is to use the existing cellular networks and overlay them with a dedicated data network which is designed to overcome the transmission problems. CDPD is the result of extensive work and study in this area by Dr. Vic Moore of IBM, Boca Raton, Florida. The system was originally known as Celluplan II and is still sometimes referred to by this name. The original CDPD specification was based on Signaling System 7, a voice-oriented technology.

It was first thought that cellular networks would not be suitable for handling data unless they included digital technology to ensure better transmission quality and greater capacity. Both time-division multiple access (TDMA) and code-division multiple access (CDMA) were considered as efficient methods for sharing the available bandwidth. They were not compatible with the circuit-switching technology used for analog cellular telephony and are not implemented in CDPD.

The radio spectrum used by CDPD (30 kHz) is the same as that used for cellular voice. The difference is that CDPD bypasses the voice input and places a radio frequency (RF) modem directly on the 30 kHz channel. This RF modem provides 19.2 Kbps of raw data throughput. One key difference between CDPD and wired data transmission is that CDPD carries no amplitude information, which sacrifices throughput for improved error control. CDPD′s technique transmits at 1 bit per baud; in contrast, modems conforming to the V.32 wired standard transmit at 4 bits per baud. The higher the bit per baud ratio, the more likely errors will occur. Because wired transmissions are more reliable than wireless transmissions, they can use the higher bit per baud rate. CDPD uses the lower bit per baud rate so that wireless problems such as Rayleigh fading and other signal fading conditions are less of a problem. Other error control features specified in CDPD include the use of a forward error correction process based on Reed-Solomon code. Forward error correction allows errors to be corrected without retransmissions, as is required by conventional error correction protocols.

Along with error correction, CDPD includes protocols that take care of essential functions like authentication and encryption. The latter is required to ensure privacy. One sacrifice made for this robustness is relatively low throughput. The throughput varies depending on the fade conditions, but even under optimal conditions it is likely to remain under 10 Kbps. One of CDPD′s most useful characteristics is the ability to find open voice channels and use them for data. This is a critical advantage since a shortage of channels exists in many areas.

CDPD base stations, which consist of special equipment connected to an existing base station, monitor all the channels in the cellular network. When a base station receives a data transmission call, it picks out one of the unused channels and sends data over it. If a subsequent voice call needs that channel, the base channel gives up the channel and hops to another unused channel to continue the transmission. The development of an effective algorithm to handle channel hopping will have important results for cellular carriers. An effective algorithm will enable carriers to make maximum use of their cellular channels, thereby increasing network revenue.

At the time of writing a number of cellular carriers already offer CDPD services:

- AirTouch Communications in San Diego and San Francisco Bay area
- Bell Atlantic Mobile in Baltimore, Pittsburgh and Washington with tests in Philadelphia and New Jersey
- GTE in San Francisco Bay area and Houston
- McCaw Cellular in Dallas, Las Vegas and Miami, also partially available in New York, San Francisco Bay area and Seattle
- Nynex Mobile tests in New York
- Sprint Cellular in Farmington, NM

The success of wireless services using CDPD will depend on the availability of applications designed for these networks. At present there are only a few applications written for or well suited to packet-based networks. The recent announcement by IBM of a CDPD PCMCIA card will allow the user of a notebook computer to communicate with host data applications over the US AMPS cellular network, without the need for a separate cellular phone or modem. This device will also allow users to make voice calls as if they had a cellular phone.

2.5 Packet Network Methodologies

With the exception of CDPD, the cellular networks discussed so far have been designed primarily for use with speech information. Radio packet data networks are designed for data only.

Note: Some early Mobitex services in Scandinavia offered voice services, but these are being phased out.

Refer to 1.3.4, "Mobile Data Services" on page 14 for an overview of radio packet data networks.

2.5.1 Mobitex

The description which follows applies to the newer UHF Mobitex systems in North America and Europe. The original VHF systems which operated in Scandinavia are being replaced by UHF systems with much higher data rates.

Mobitex in the US transmits from the base station on channels in the range of frequencies 935-940 MHz, and receives in the range of 896-901 MHz. The transmit and receive frequencies for any channel are always 39 MHz apart.

Mobitex in Europe has different frequency allocations for each country but they are all in the range of 410-459 MHz. Apart from this difference in radio carrier frequency, the European and North American systems are the same.

The radio channels are 12.5 KHz wide and each Base Radio Station (BRS) can have up to sixteen different channel frequencies. The physical BRS can be used as a number of logical base stations using directional antennae. The radio channel is modulated using a modified type of Gaussian Minimum Shift Keying (GMSK). GMSK is described in 3.1.6.2, "Shift Keying (ASK, FSK, PSK...)" on page 63. The Mobitex network is cellular in structure, but because the system uses packets of data instead of continuous connection, there is no requirement for dynamic handoff as in a cellular telephone network.

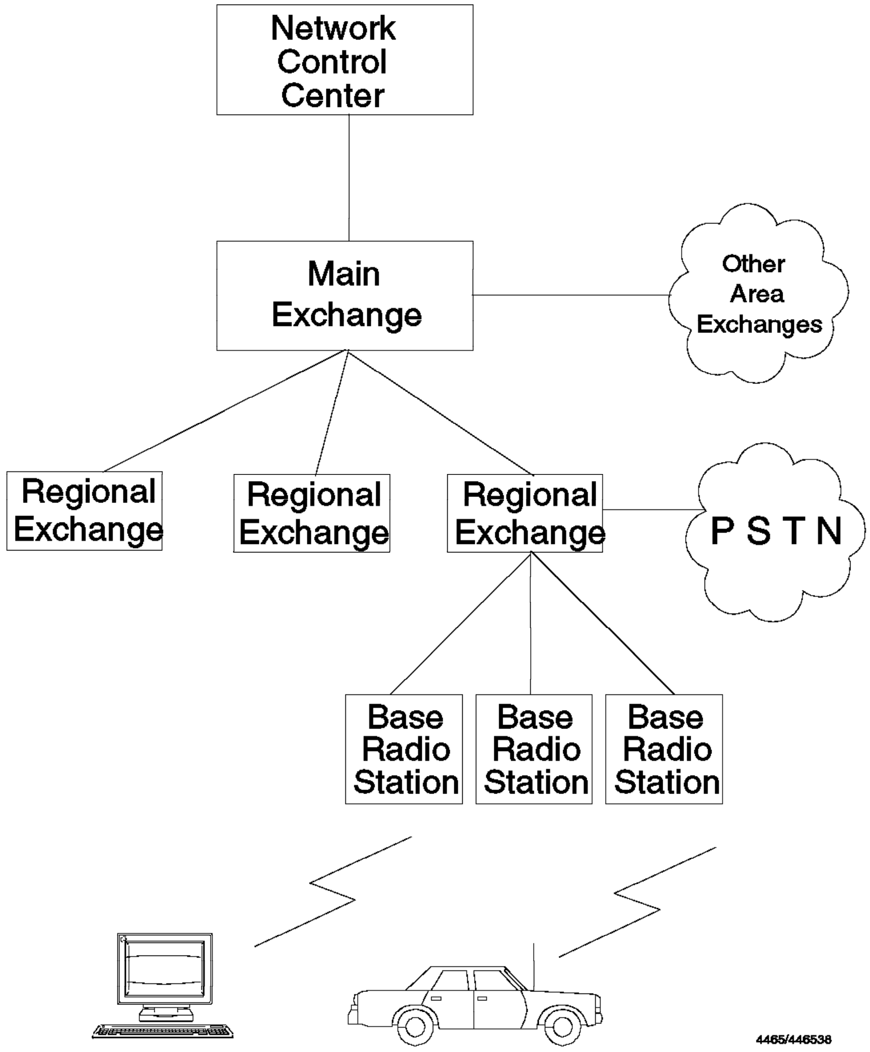


Figure 17. Mobitex Network Structure

The data rate of the Mobitex network is 9.6 Kbps, which gives a maximum end-to-end throughput of 8.0 Kbps. One of the key factors when dealing with a packet data network is the network delay. The delay can vary according to the load on the network and may be a few seconds. Network operators are careful to ensure that no single application will load the network in such a way that other users are affected. Legacy host applications may need to be modified to work properly with packet networks, which may be a key factor in choosing a suitable network.

Access to the Mobitex network from external host systems is provided by a number of different gateways. The availability and definition of these gateways will vary from network to network, but will normally include:

- X.25
    - MTP/1 transport layer is optional
- TCP/IP
    - Host connection - X.25 or SLIP (Serial Line Internet Protocol)

- SNA/3270
  - MTP/1 transport layer is required.

Mobile units on the network can take the form of vehicle-based installations with application dependent displays and data entry functions. A simple two-line display with a number of predefined data entry keys may be used for a taxi application, while a notebook computer may be attached to a Mobitex radio/modem for a full-screen data application. A recent development from IBM consists of a PCMCIA card which contains a complete Mobitex radio/modem. This will allow a notebook computer to communicate over the Mobitex network without attaching to any external device.

Applications using the Mobitex network can also be fixed-station telemetry where the difficulty or cost of installing a fixed wire connection would not be economical. A packet radio data network is ideal for sending small amounts of data at irregular intervals.

2.5.2 MDC4800 and RD-LAP

The second major radio packet data network type is a Motorola technology known as ARDIS in the US. The same technology is used in other countries, notably Germany where it is known as Modacom, and Southeast Asia and the Pacific Rim where it is known as Datatac. The following description will use ARDIS as an example of a network implemented using this technology.

Refer to 2.5, “Packet Network Methodologies” on page 51 for an overview of radio packet data networks.

The ARDIS network uses two different protocols. The original protocol is called MDC4800 (Mobile Data Communication 4800), and as its name suggests operates at 4.8 Kbps. The newer services use a protocol called RD-LAP (Radio Data-Link Access Procedure), which provides a data rate over the air link at 19.2 Kbps. Whatever air link protocol is used, the underlying network is the same.

In North America, ARDIS uses radio frequency channels in the 806-824 MHz band for base station receiving, and 851-869 MHz for base station transmitting.

ARDIS provides a number of protocols to access the network including:

- SNA LU 6.2
- X.25
- SNA 3270 terminal emulation and bisynchronous 3270
- Bisynchronous point-to-point
- Asynchronous

These protocols are used over a leased line connection with dial backup at either 9.6 Kbps or 19.2 Kbps.

The topology of the network is similar to that of Mobitex networks. A number of base stations are connected to a switching center known as an RF/NCP. These in turn are connected to a message switching center. See Figure 18 on page 54.

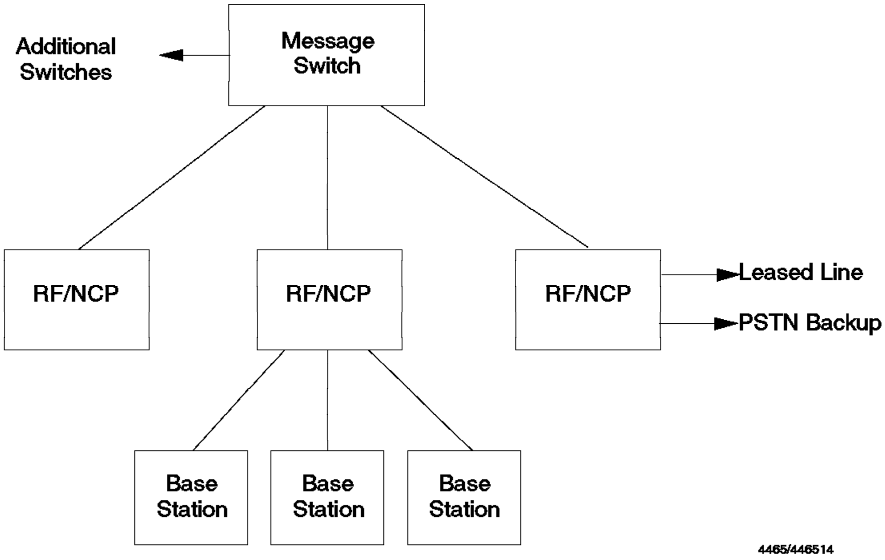


Figure 18. ARDIS Network Structure

The connections to customer host systems of Value Added Networks (VANS) are made at the RF/NCP level, while the message switches control routing between regions.

The following table compares the parameters associated with MDC4800 and RD-LAP.

Table 2. MDC4800 and RD-LAP Compared

	MDC4800	**RD-LAP**
Channel bit rate	4800 bps	19,200 bps
FM signalling	2-level FM	4-level FM
Bit/symbol speed	4800 bps	9600 bps
Information per block	6 bytes	12 bytes
Block length	23.3 ms	7.2 ms
Logical message length	256 bytes	512 bytes
Channel access method	ASYNC NP-DSMA	Slotted NP-DSMA
FEC coding	Rate 1/2 convolutional	Rate 3/4 trellis

2.6 Summary

In this chapter we have reviewed some principles of physics in order to understand how radio waves and infrared light behave and can be generated. These basic principles have provided an understanding of the electromagnetic spectrum and the relationship between various forms of electromagnet radiation. An important aspect of any radio system is the antenna and we have looked at some of the more common types and discussed their relative merits for different applications. A section on how RF and IR LANs are implemented completes the first part of this chapter.

The second part of the chapter discusses the various wide area wireless network technologies and includes:

- Analog cellular networks
- Digital cellular networks
- CDPD
- Packet networks

Chapter 3. Radio Technology

Electromagnetic spectrum is a limited natural resource, the use of which is governed by physical laws as well as national legislation. It has been estimated that as much as 75% of usable radio spectrum is reserved for use by various national governments and military applications. The amount of bandwidth available for commercial, private and public use is severely constrained and use of particular frequency bands is limited to individual countries or groups of countries. Although there are moves to define internationally recognized frequency allocations (notably the World Administrative Radio Conference (WARC)), it will take many years for different countries to free up radio spectrum for international commercial use. This situation not only makes it more difficult and costly to provide radio devices for use in all countries, it provides a major incentive to develop techniques to make the very best use of any available spectrum. There are two complementary strategies for achieving this:

- Modulation techniques - maximizing the throughput for a given bandwidth
- Multiplexing techniques - enabling many users to share the same bandwidth

Many current techniques used were originally developed for the land-based telecommunications market and thus have a firm foundation in the telephony arena. Some of the technologies in use include:

- Modulation techniques
- Access methods
- Detection methods
- Synchronization methods
- Equalization techniques

Both analog and digital modulation techniques are described in this chapter. Although analog techniques are well suited to voice communications, data communications are more suited to digital technology. Analog systems can be used successfully, but can experience more problems. These advantages include improved performance, lower costs, better security, error detection and error correction.

3.1 Transmitting Information by Modulating a Carrier

Voice signals can be transmitted over copper wires directly at their original frequency, as was the case for the first telephone systems. This is known as baseband transmission. In order to send several channels across the same wire simultaneously without interference, the voice signals can be superimposed or modulated onto higher frequency signals. These higher frequency signals can then be combined with other signals and transmitted across long distances. In many situations information cannot be sent directly but must be carried as variations in another signal, as is the case with radio broadcasting. Radio communication is perhaps the most common example of using a modulated carrier to convey information but the use of modems to carry digital information through the analog telephone network is also very common. This is often called “wideband”, “broadband”, or ”passband” modulation (these terms mean roughly the same thing).

A carrier signal is almost always a sinusoidal wave of a particular frequency. Information is carried by introducing variations in this carrier signal.

There are many variations on how a modulated signal is created and how it is received. Many systems operate as shown in Figure 19 on page 58.

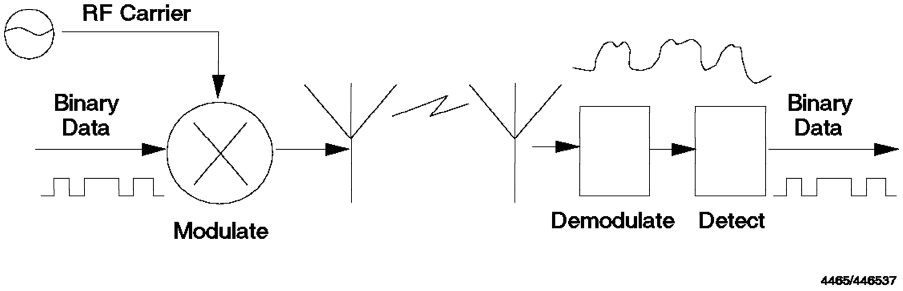


Figure 19. Transmission and Reception of a Modulated Signal

Notes:

1. A baseband binary data stream is created representing the bits to be sent.
2. A sinusoidal carrier signal is generated (for RF this is usually a crystal controlled oscillator).
3. The digital signal is then used to modulate the carrier signal and the resultant signal is sent to the antenna.
4. In the receiver, the signal is first filtered (to separate it from all other radio signals around) and then the carrier is removed.
5. The result is a baseband signal containing distortion and noise which then has to be processed by a detector in order to recover the original bit stream.

3.1.1 Amplitude Modulation (AM)

This is the simplest form of modulation and was the first to be put into practice. The strength of the signal (loudness or amplitude) is systematically changed according to the information to be transmitted, that is the amplitude of the carrier signal varies with the amplitude of the signal to be transmitted. The bandwidth required by the sidebands using AM is large so that effective use of the frequency spectrum is not made. AM is used by radio broadcast stations in the Long Wave, Medium Wave, and Short Wave radio bands.

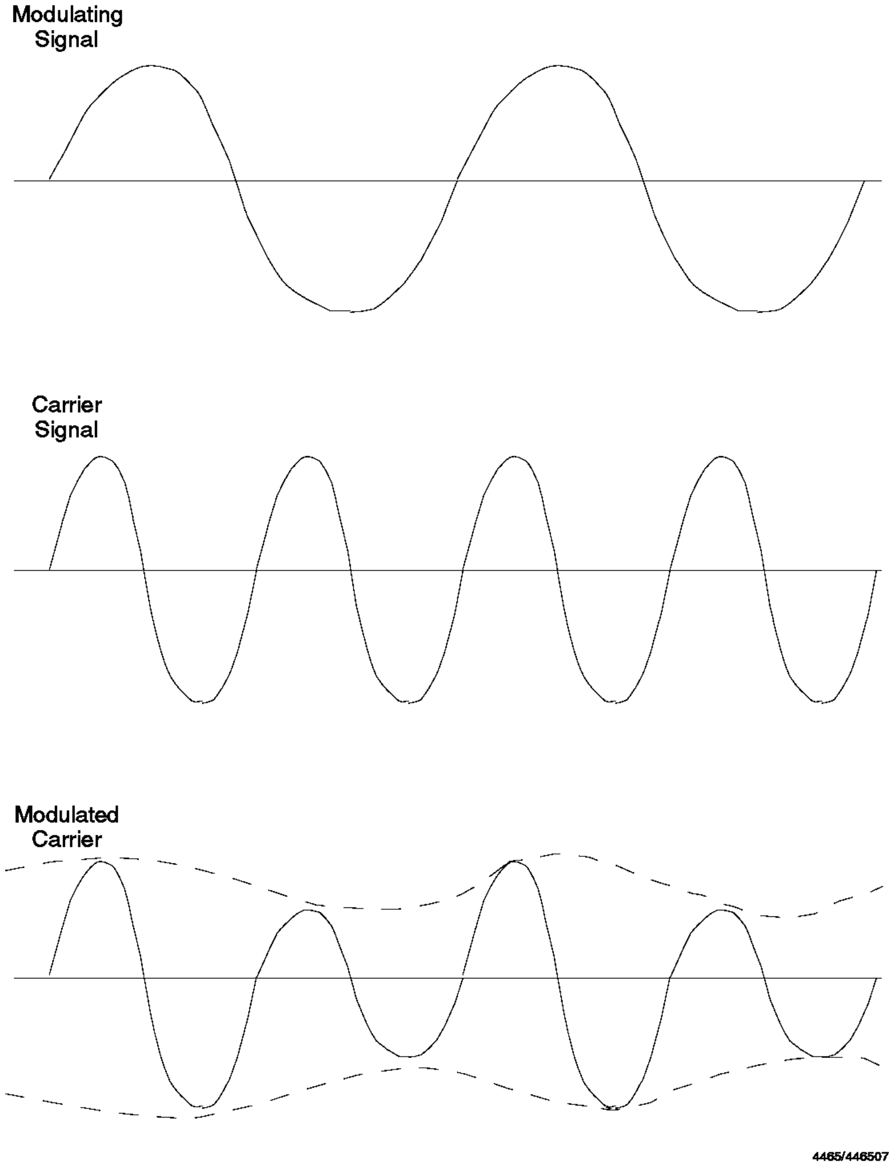


Figure 20. Amplitude Modulation (AM)

3.1.2 Frequency Modulation (FM)

In Frequency Modulation, the frequency of the carrier is varied by the signal to be transmitted. The maximum frequency deviation from the carrier frequency is proportional to the modulating signal. An advantage of FM is that the width of the sidebands is limited and more efficient use is made of the frequency band. FM is used extensively by radio broadcast stations in the VHF band.

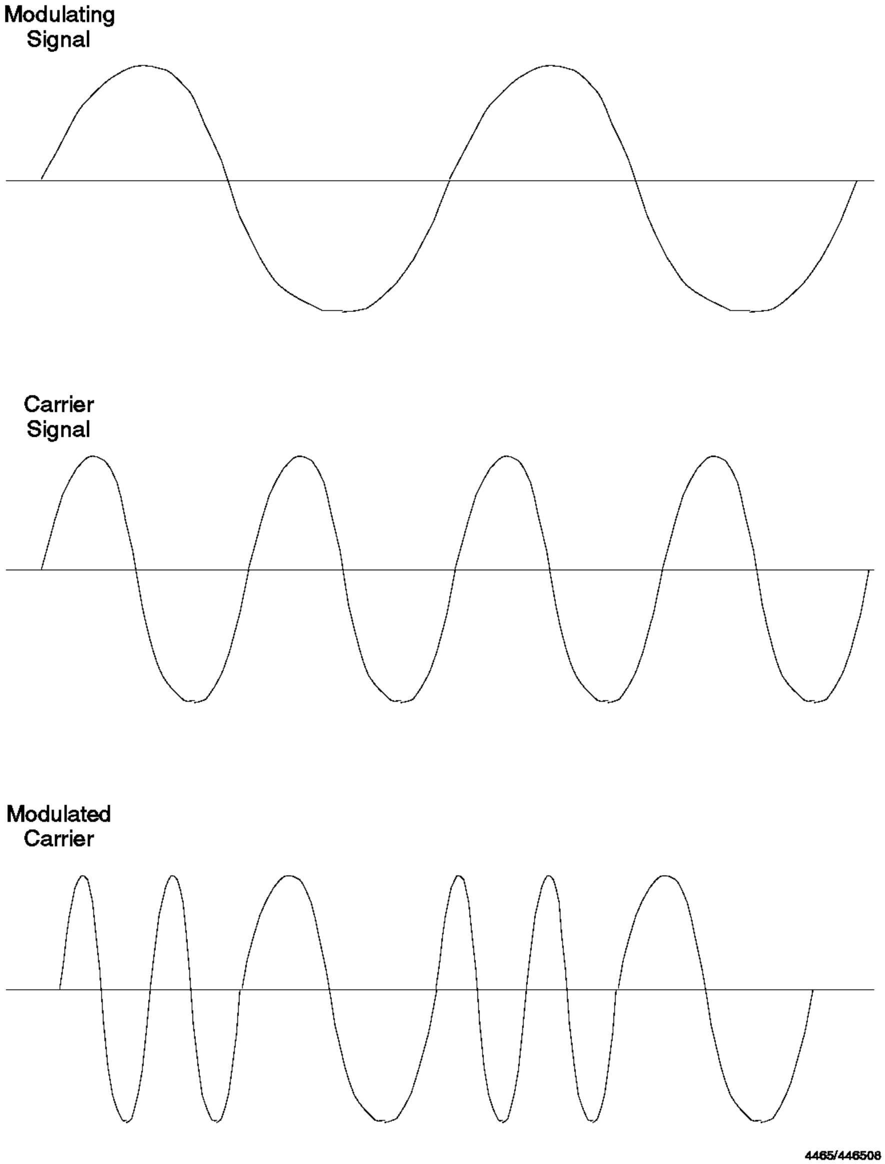


Figure 21. Frequency Modulation (FM)

3.1.3 Phase Modulation (PM)

In Phase Modulation, systematic changes in the phase of the carrier are used. The frequency of the carrier remains constant while the phase is shifted in proportion to the modulating signal. PM requires more sophisticated receivers than FM or AM and is sensitive to multi-path errors.

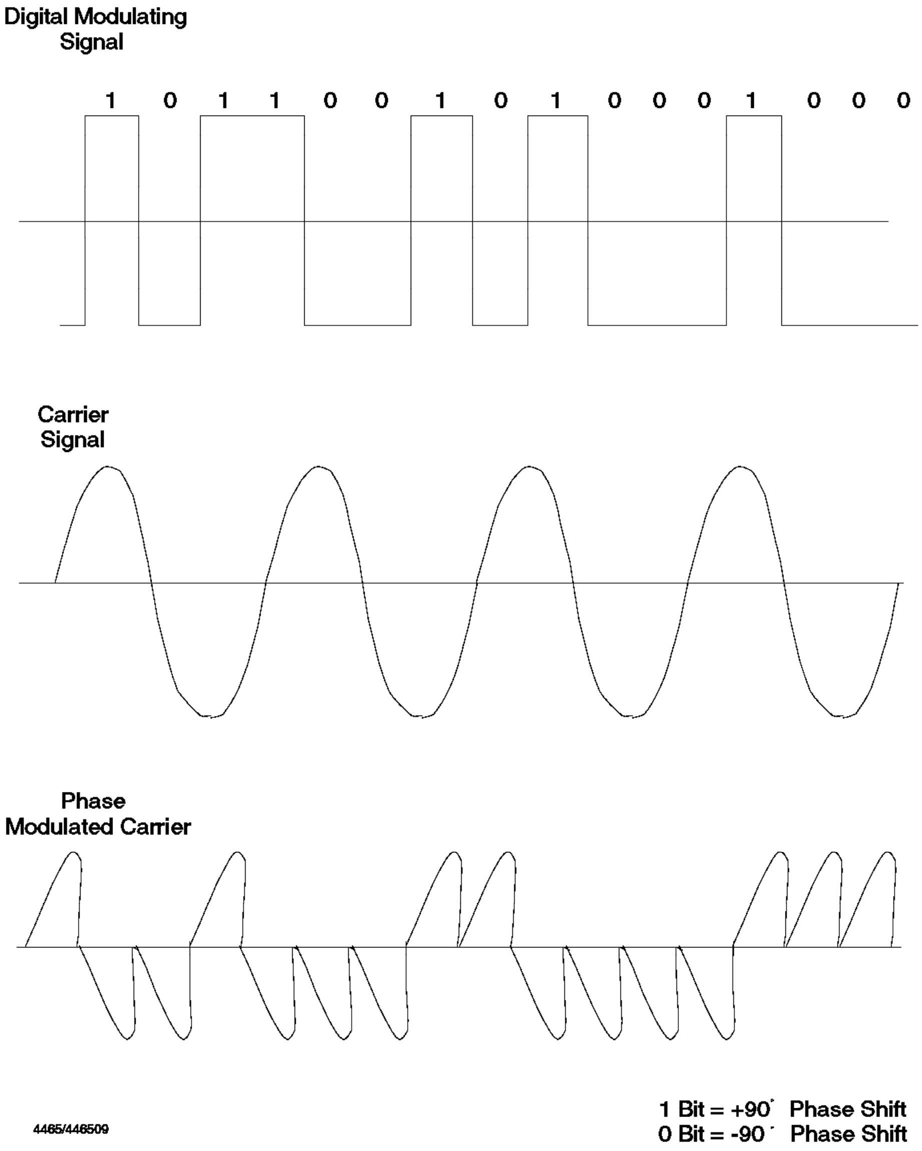


Figure 22. Phase Modulation (PM)

3.1.4 Pulse Code Modulation (PCM)

Analog signals are subject to distortion and noise along their transmission path. With each link and amplifier along the path, the signal-to-noise ratio deteriorates and there is no easy method of signal regeneration since the shape of the signal cannot be predicted. On the other hand, digital signals can easily be regenerated by pulse-shaping circuits in the receiver so that distortion and noise is much reduced. PCM is a method of sampling a signal at a higher frequency to produce a digital signal which can then be multiplexed with many other digital signals and transmitted error-free to the receiver. It is widely used in telephone equipment to ensure quality of service on multi-channel links.

3.1.5 Sidebands

When a sinusoidal carrier signal is generated it varies by only a very small amount. That is, the range of frequencies over which the carrier is spread is very narrow. When such a signal is modulated, it seems reasonable that the frequency spread (at least for AM and PM techniques) should remain unchanged. *Sadly, it doesn't work quite this way.* Modulation of a carrier *always* produces a signal such as that shown in Figure 23. You get a spread of frequencies equal to twice the maximum frequency of the modulating signal. What you get is a carrier signal (*carrying no information*) surrounded by two "sidebands" (above and below). Each sideband uses a frequency spread of exactly the maximum modulating frequency. All of the modulation information is carried in the sidebands - the carrier contains no information (it is nevertheless quite useful to have in some systems).

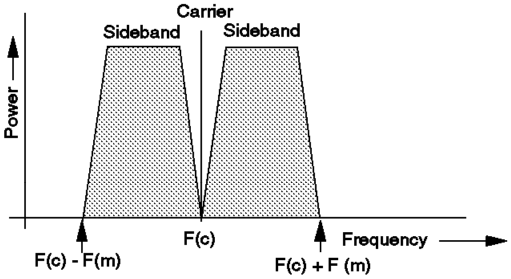


Figure 23. Sidebands

Some transmission systems suppress transmission of the carrier (it is pointless to waste power sending something that contains no information) and others suppress both the carrier and one sideband (Single Sideband - SSB Transmission).

It is important to note that sidebands are generated for all three modulation schemes. They are different in the sense that the precise form of the sidebands is different for each different modulating technique.

3.1.5.1 Bandwidth

The above leads us to the concept of bandwidth. A signal doesn't use just one frequency. It uses a band of frequencies equal in width (from lowest to highest) to twice the maximum frequency of the modulating signal. (If SSB transmission is used the bandwidth occupied is just the maximum frequency of the modulating signal.)

3.1.6 Digital Modulation Methods

There are a large number of methods of digital modulation. When digital information is used to modulate a sinusoidal carrier, changes in characteristics of the signal are used to carry information rather than changes in voltage or current.

Most of the methods used for baseband transmission can be used as methods of modulating a carrier. However, carrier modulation is used predominantly in environments where bandwidth is very limited and baseband techniques are most often used in situations where bandwidth is not the primary concern.[1] This leads to significant differences in the approach used in the two environments.

The most important criteria when choosing a digital modulation technique are as follows:

- Efficiency of bandwidth use
- Error performance
- Suitability to cellular use
- Cost of implementation

3.1.6.1 On-Off Keying (OOK)

On-Off Keying is the simplest method of modulating a carrier. You turn the carrier on for a one bit and off for a zero bit. In principle this is exactly the same as early Morse code radio.

OOK is not often used as a modulation technique for radio transmissions. This is partly because the receiver tends to lose track of the signal during the gaps (zero bits) but mostly because it requires a very wide bandwidth for a given data rate. Other transmission techniques are significantly better. OOK is the primary method used in optical fiber communication.

3.1.6.2 Shift Keying (ASK, FSK, PSK...)

Shift keying techniques involve having two carrier states. Modulation is achieved by keying between the two states. In principle, one state represents a zero bit and the other a one bit - although it is common to use techniques like NRZI to encode the data first.[2]

The common variants of this are:

- Amplitude Shift Keying (ASK)
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK)

Such signals are very simple to generate and to receive and hence necessary equipment is inexpensive but they do not offer optimal performance in a bandwidth constrained environment. However, some variations on these techniques are in very wide use.

The most common 1200 bps modems use FSK. In FSK, the carrier frequency is changed from one frequency (corresponding to a binary 1) to a second frequency (corresponding to a binary 0) according to the baseband signal.

PSK is also commonly used. The carrier is modulated by a binary signal so that the signal generated is a constant amplitude signal alternating between two different states, 0° and 180°.

FSK is commonly used in spread spectrum WLAN systems, and has been adopted by the IEEE 802.11 committee.

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[1] There are many exceptions here such as the use of spread spectrum techniques in some radio environments and the use of baseband techniques to get the maximum throughput from a telephone subscriber loop circuit.

[2] The word “keying” in general implies that the carrier is shifted between states in an abrupt (even brutal) manner. That is, there is no synchronization between the shifting of the carrier and its phase.

3.1.6.3 Bandwidth

If you examine the composition of a square wave (or stream of pulses with square corners) you find that it is composed of a number of sinusoidal waves of different frequencies and phases. A square wave (stream of pulses) can be represented as follows:

$$\cos(2\pi \times t) - \frac{1}{3}\cos(2\pi \times 3t) + \frac{1}{5}\cos(2\pi \times 5t) - \frac{1}{7}\cos(2\pi \times 7t) + ... + \frac{1}{13}\cos(2\pi \times 13t) + ...$$

In the equation t = time and represents the frequency of this component. Only the odd numbered harmonics are present in a square wave. Notice that this is an infinite series.

Another way to look at this is to consider that the bandwidth required is proportional to the rate of change of the signal waveform. A sine wave has a small rate of change for any given frequency, but the rate of change will increase with the frequency. A square wave has a rate of change that is very high, and therefore the bandwidth necessary to transmit a square wave is much higher than that of a sine wave. The point here is that a square wave with repetition frequency of 1 kHz has sinusoidal components strong enough to matter up to about 9 kHz. This means that to faithfully reproduce a square wave signal through carrier modulation you must use quite a wide bandwidth.[3] When digitally modulating a carrier it is common to "shape" the modulating pulses in such a way that the required bandwidth usage is minimized.

3.1.6.4 Timing Recovery

As shown in Figure 19 on page 58, what we get after demodulation when the signal is received is a baseband signal. An important problem for the receiver is to decide what is a bit and what is not - that is, we must recover not only the variations in the signal but also the timing. It is important that the data encoding system used provide frequent state changes so that the receiver can accurately determine the transitions between states.

3.1.6.5 Scrambling

If we transmit the same symbol repetitively in many situations there will be a problem with keeping the signal within its allocated frequency band. This applies in both radio and voiceband telephone environments. If we use an encoding scheme that provides frequent transitions and is DC balanced (provides an equal number of 0s and 1s over a period of time) then this is normally sufficient. If not, we need to use a "scrambler" to change the data into a form suitable for transmission (and a descrambler in the receiver).

3.1.6.6 Many Bits per Symbol

Perhaps the most popular (and obvious) way of limiting the bandwidth required for a given data rate is to use one signal state to represent more than one bit. We could have (say) eight different amplitude (or phase or frequency) states and then each state could represent three bits. Table 3 on page 65 shows how eight states of amplitude, frequency, or phase could be used to represent three bits in one symbol time. This is a simplified representation to show how one of three

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[3] Of course this is also true when using a baseband medium. The medium must have capacity to pass quite a wide bandwidth if it is to pass square pulses accurately.

parameters describing a waveform could be varied in eight discrete steps and be interpreted as three data bits.

Table 3. Encoding Many Bits per Symbol

Level	Amplitude	Frequency	Phase	Binary
7	0.7v	F_7	315 °	111
6	0.6v	F_6	270 °	110
5	0.5v	F_5	225 °	101
4	0.4v	F_4	180 °	100
3	0.3v	F_3	135 °	011
2	0.2v	F_2	090 °	010
1	0.1v	F_1	045 °	001
0	0.0v	F_0	000 °	000

If we had 16 states then we could potentially represent four bits. The rate at which we switch between states (the number of state changes per second) is called the baud rate. Each discrete signaling state is commonly called a “symbol”.

If we send a succession of different states at a rate of (say) 1000 per second, then the bandwidth used depends on just what the sequence is. However, the worst case is when we change from one extreme to another on alternate symbols. When this is the case we have a square wave of 500 Hz. (Remember that in this case 500 Hz will not be enough bandwidth because we need to carry some harmonics.)

The complicating factor here is noise. If it were not for noise a fairly simple receiver could discriminate between a very large number of states and we could get very large numbers of bits per symbol. Unfortunately, noise and distortion in the channel prevents this scenario. In some environments the effects of noise can be mitigated by using more transmitter power (or a shorter distance) but most times this is not possible. In practice, noise sets a maximum limit on the number of usable states regardless of the complexity of the receiver.

A baudy story

The term “baud” when referring to the speed of data transmission is more often misused than used correctly. *The baud rate is the signaling rate. That is, it is the rate of state changes of the modulating signal (the symbol rate).* Thus if you have three bits per symbol and the baud rate is 2000 then the bit rate is 6000 bps.

It is common to see advertisements and even articles in the technical press referring to voiceband modems as “9600 baud” when they mean 9600 bps. *There is no voiceband modem on the market with a baud rate higher than 2600* (in fact you couldn′t have one since the telephone voice channel has a bandwidth of 3400 Hz). Fast voiceband modems currently use QAM with six bits per symbol and achieve a bit rate of 14,400 bps using a signaling rate of 2400 baud.

3.1.6.7 Quadrature Phase Shift Keying (QPSK)

When each symbol transmitted represents more than one bit, higher data rates can be achieved. QPSK provides twice the data throughput of PSK in the same bandwidth by allowing each symbol to carry two bits. A serial to parallel converter at the transmitter provides pairs of binary digits that are used to modulate two carriers that are offset from each other by 90°. These output signals are then added together to provide the transmitted signal which alternates between four different phase states: -90°, 0°, 90° and 180°.

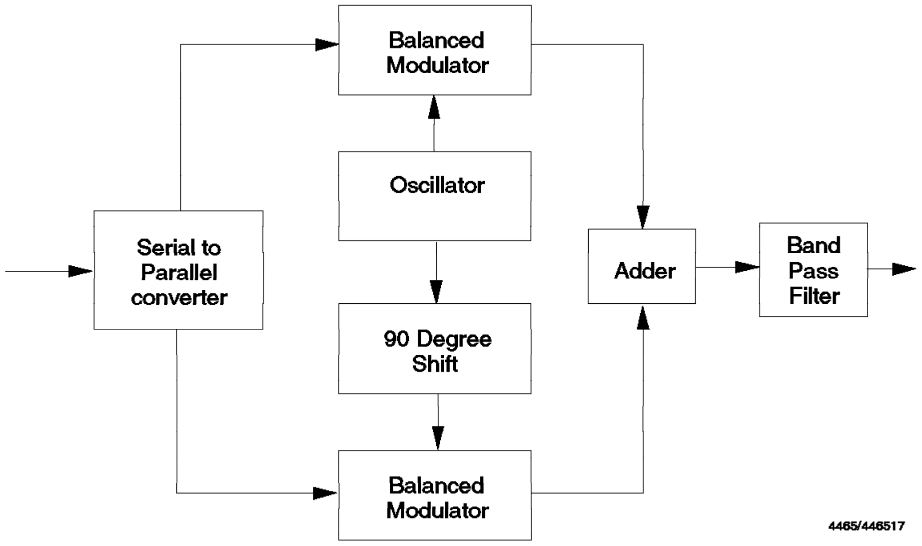

Figure 24. QPSK Modulator

A further variation on this is Multilevel PSK, where more than two bits are represented by each symbol transmitted. If n bits can be sent, then 2• different symbols can be represented. For QPSK and Multilevel PSK, as for PSK, the transmitted signals change only in phase and are of constant amplitude.

3.1.6.8 Quadrature Amplitude Modulation (QAM)

In order to send as many bits as we can within a restricted bandwidth many techniques modulate more than one variable (dimension) simultaneously. This is the concept behind QAM. QAM is the predominant modulation technique in high-speed data modems and microwave radio systems.

In QAM multiple states of amplitude and phase are used together. It is usual to show this as a “quadrature” illustrated in Figure 25 on page 67. Note that the position of the axes bisects the number of states. This is just for illustration - there is no such thing as a negative amplitude. In the example shown (more correctly called QAM-16) there are now 16 states and thus four bits can be represented. In higher quality channels QAM-64 (representing six bits) and QAM-256 (representing eight bits) are sometimes used.

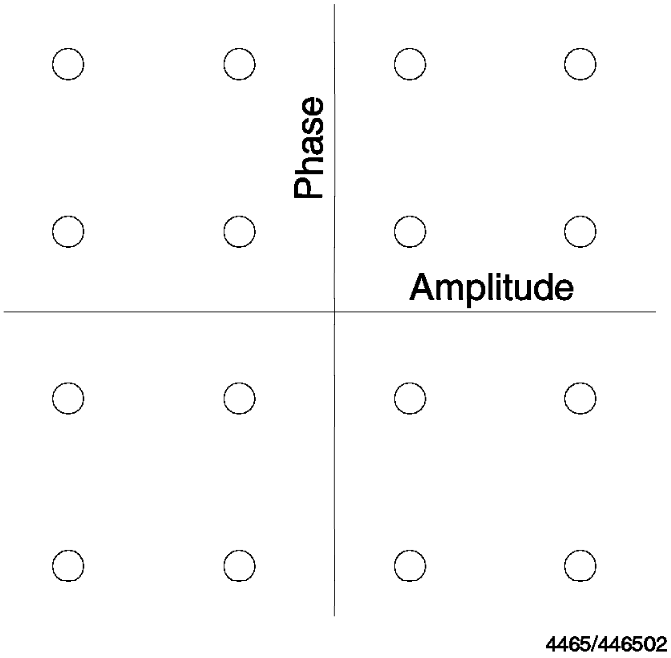

Figure 25. Quadrature Amplitude Modulation

One of the big advantages of QAM is that the amplitude and phase of a signal can be represented as a complex number and processed using Fourier techniques.

3.1.6.9 Trellis Coding

Trellis coding (and Vitterbi decoding) are commonly used in conjunction with QAM systems. The concept is quite simple although the implementation is sometimes very complex.

When a QAM symbol is received, the receiver will measure its phase and amplitude. Due to the effects of noise, these measured values seldom match the points on the quadrature exactly and a QAM receiver typically selects the nearest point and decides that this is the symbol received. But what if this received value was in error because noise changed it? In regular QAM this is just an error. Trellis coding is a way of avoiding a substantial proportion of these errors.

The concept is that the transmitter only sends a limited sequence of symbols. If a particular symbol has just been transmitted then the next symbol *must* be from a subset (not all) of the possible symbols. Naturally this reduces the number of bits you can represent with a particular quadrature. Typically, in a 16-state quadrature, only eight states will be valid at any point in time (which eight depends on the last one sent). This means that you can represent only three bits rather than four.

This relies on the concept of a sequence of line states. If you start out transmitting a particular line state then the next state must be one of eight states. When you transmit that state then the next one must be one of eight also. Therefore if you start at a particular line state there are 64 possible combinations for the next two states transmitted. The receiver correlates the sequence of line states received with all the possible sequences of states. This works as follows:

1. When the receiver detects a line state, it does not immediately decide which symbol has been received. Instead it allocates a “weight” (the mean squared distance) between the detected point and all surrounding points.
2. As time progresses the receiver adds up the weights of all possible paths (this is an enormous processing problem since the number of possible paths grows exponentially).
3. After a number of symbol times a particular path is chosen to be correct based on the minimum total weight accumulated along all the possible paths.
4. The sequence of symbols is then decoded into a sequence of bits.

The important characteristic here is that it is the sequence of line states that is important and not any individual received line state. This gives very good rejection of AWGN (Additive White Gaussian Noise) and many other types of noise as well.

Vitterbi decoding is the process usually used in conjunction with Trellis coding. It is simply a way of performing the path calculation such that the number of possible paths stays within the ability of a signal processor to handle the computation.

Depending on the number of points in the constellation, Trellis coding can show a gain in signal-to-noise terms of 4 to 6 dB.

3.1.6.10 Gaussian Minimum Shift Keying

A special form of phase shift keying modulation is used in a number of wide area radio networks. It is known as Gaussian Minimum Shift Keying (GMSK). It relies on equating changes in phase to transitions from one to zero or zero to one in a data stream to changes in phase of the carrier. The data stream must be in an NRZ form as shown in Figure 26 on page 69. The technique relies on passing the NRZ data stream through a Gaussian low-pass filter before modulating the carrier. The filter has the effect of suppressing high frequency components of the input data and also ensures that there are no overshoots in the waveform which would create excessive modulation deviation. The filter design also ensures that each output pulse has sufficient area for successful detection in the receiver.

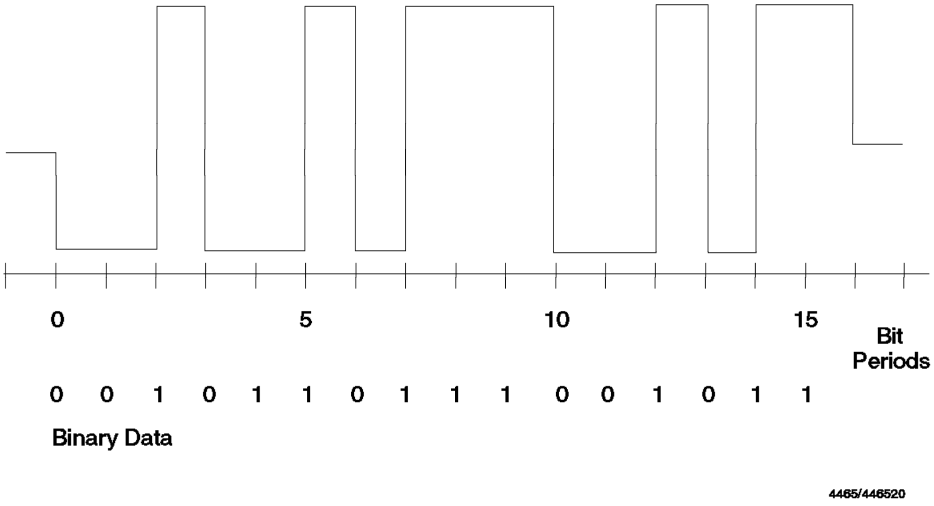

Figure 26. GMSK Input Data Stream

Figure 27 on page 70 shows what would happen in the case where the data stream is not passed through a Gaussian filter and modulated the phase of the carrier directly. Note that if you start from the outer edge of the diagram you can see how a negative going edge produces a phase shift of −90°, and a positive going edge produces a phase shift of +90°.

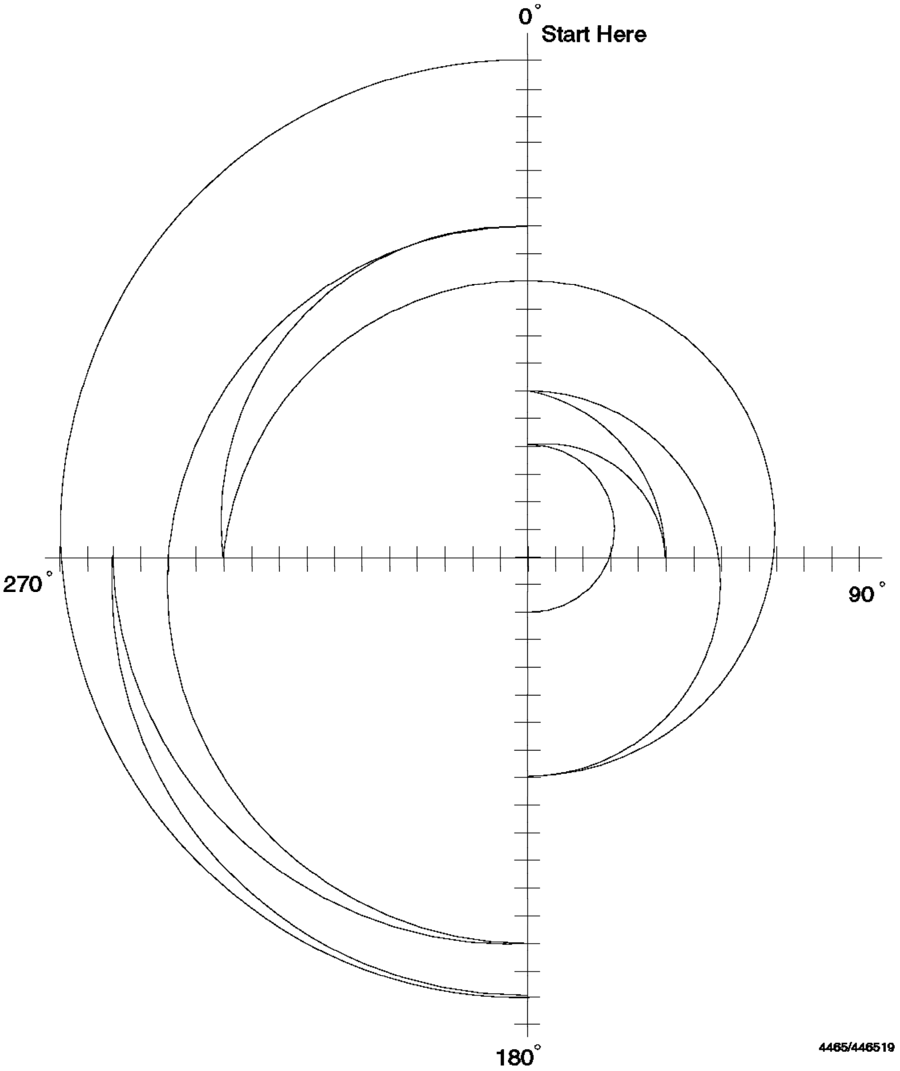

Figure 27. Phase Shift Keying Modulation

Figure 28 on page 71 shows the resulting modulation pattern if the data is passed through a Gaussian filter first. You can see how the modulation deviation has been reduced thus helping to limit the bandwidth required.

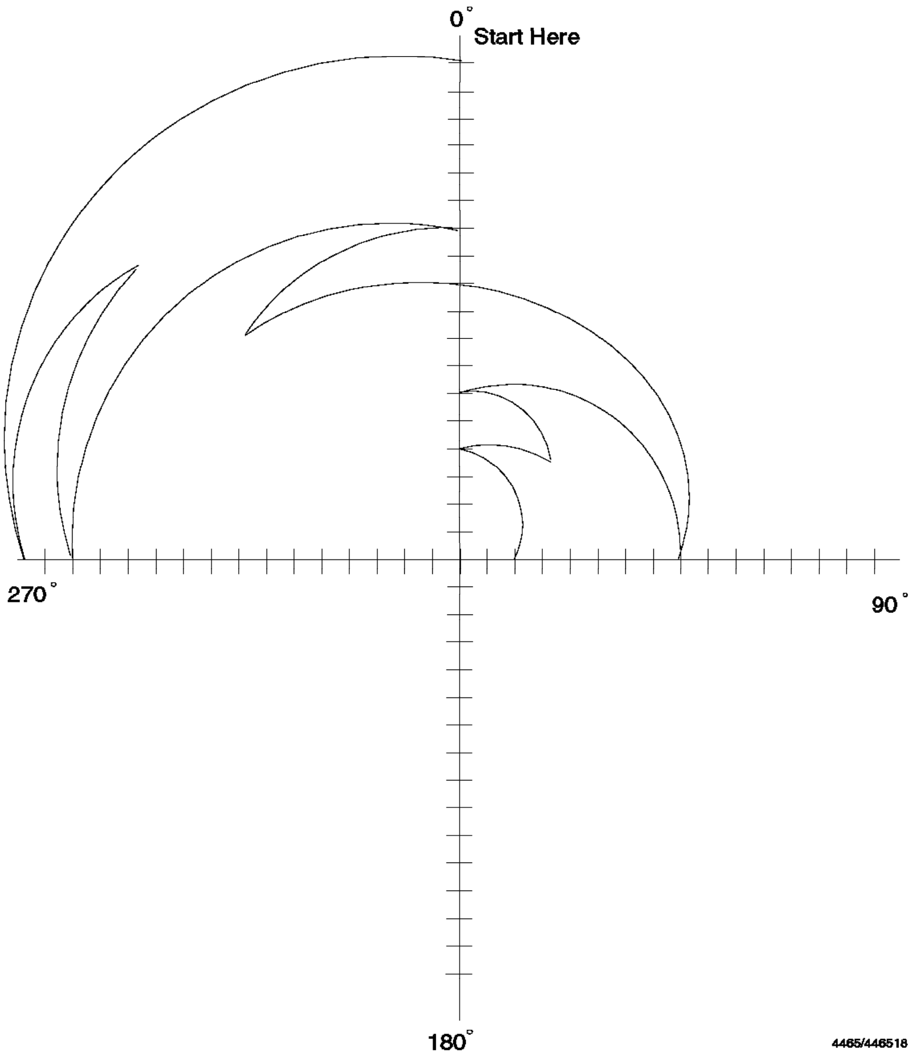

Figure 28. Gaussian Minimum Shift Keying

GMSK is the preferred modulation technique for a number of digital networks including GSM.

3.2 Multiplexing Techniques

This section describes techniques for allowing several users to transmit and receive over a limited amount of the electromagnetic spectrum. The technologies described will become more and more important as the need to make the most efficient use of the spectrum becomes a very high priority in radio frequency technology development.

3.2.1 Frequency Division Multiplexing (FDM)

This technique (FDMA) is exactly the same as used for radio or television broadcasting. A transceiver is allocated a range of frequencies; a signal may be sent and information may be encoded on that signal using a range of modulation techniques. The receiver must be able to receive that frequency and to decode the modulation technique used. On a cable or on a microwave carrier signal, the available band of frequencies is limited but the principle is still the same. The amount of information that can be carried within a frequency band is directly proportional to the width of that band and is also dependent on the modulation technique used. The bandwidth is an indication of the range of frequencies available within a frequency band. There are theoretical limits that cannot be avoided; every frequency band has a finite limit. Because of the inherent imprecision of the equipment involved, there are “buffer zones” (guard bands) provided between bands so that one band will not interfere with either of the adjacent ones. The size of these buffer zones is also determined by the modulation technique; you need a lot less for Frequency Modulation (FM) than for Amplitude Modulation (AM) and by the precision (and hence cost) of the equipment involved.

Frequency division multiplexing has in the past found use in telephone systems for carrying multiple calls over a microwave link. It is also the basis for cable TV systems where many TV signals (each with a bandwidth of 4 or 7 MHz) are multiplexed over a single coaxial cable. It is also used in some types of computer shared-bandwidth local area networks.

Frequency division multiplexing is sometimes referred to as “broadband multiplexing”.

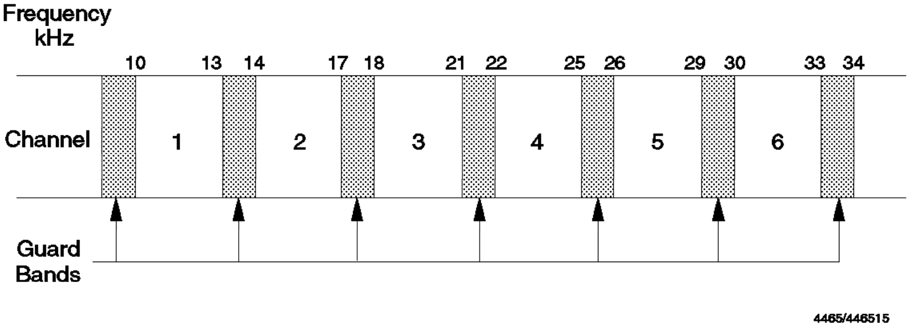

Figure 29. The Concept of Frequency Division Multiplexing. The physical carrier provides a range of frequencies called a “spectrum” within which many channels are able to coexist. Notice the necessary “buffer zones” between frequency bands.

3.2.1.1 Characteristics

- FDM is an analog technique and applies to the kind of “interexchange carrier” systems still in use by many telephone companies (although it is being rapidly replaced by digital TDM techniques).
- Subchannels are separated from each other by “buffer zones” which are really wasted frequency space or wasted capacity, albeit necessary to avoid interference.
- The analog equipment needed to make this work is extremely sensitive to “tuning” of frequencies and to the stability of filters.

- This equipment is also very expensive because of its analog nature and its sensitivity to tuning. It requires a large amount of labor to install and maintain. Another factor contributing to the overall expense is the difficulty in applying large scale integration techniques to analog systems. Analog equipment tends to have many more separate components than comparable digital systems (digital ones have more circuits but are packed together into a single component). This leads to a higher cost for analog technology, although at first the opposite was true.
- It requires retuning and maintenance whenever the physical channel changes (for example, is rerouted or repaired, etc.).
- It is customary to use two channels per conversation, one in either direction. A reasonable estimate of “good” channel use by this technique (for voice traffic) is 10%.
- The equipment is extremely modular and a failure in one element most often does not affect the operation of the rest of the system.
- AMPS and ETACS cellular networks are good examples of FDM techniques.

3.2.2 Time Division Multiplexing (TDM)

This technique is shown in Figure 30. With TDM, many signals take turns at using the same high-speed transmission link. Each signal is allocated a time interval or a “frame” in which to transmit. “Frames” are transmitted over a single high-speed channel. Within each frame there are many slots. A low-speed channel is allocated one (or more) time slots within a high-speed frame. Thus a 2.048 Mbps channel can be subdivided into 32 subchannels of 64 Kbps. The start of each frame is signalled by some unique coding which allows the sender and the receiver to agree on where the beginning of the frame is. The synchronization coding is sometimes a special (unique) bit stream (as when SDLC or BSC traditional data transmission is used) but with digital transmission it is usually signaled by some special state in the underlying Pulse Code Modulation (PCM) coding. (The most common one is called a “code violation”.) For more information on PCM see 3.1.4, “Pulse Code Modulation (PCM)” on page 61.

Attaching equipment is assigned a slot into which data can be inserted or read. Thus while the medium can run at a very high speed, each attachment point can operate at a much lower data rate.

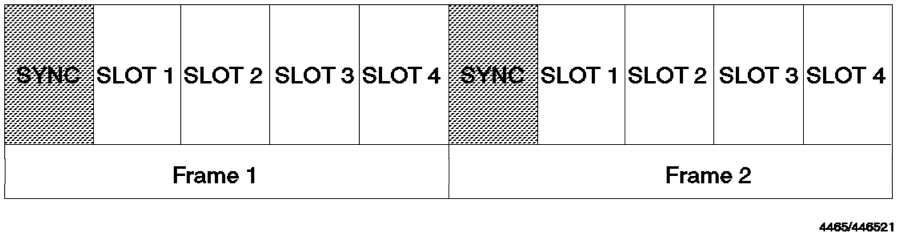

Figure 30. Time Division Multiplexing Principle

TDM is now the most common method used in telephone systems for carrying multiple calls over microwave and other radio links.

3.2.2.1 Characteristics

- This method is quite simple and can be built in single chip hardware logic.
- The hardware is low in cost (compared to other techniques).
- It will operate at very high speeds.
- It provides sharing and channelization of the link; it does not take into account the fact that telephone traffic is logically half-duplex (only one person talks at once) and though a channel is provided in each direction, only one is in use at any one time. Nor does it take advantage of “gaps” in speech. There are intelligent multiplexing techniques (called statistical multiplexors) which do this. For these reasons “good”, utilization for telephone traffic is considered to be around 40%. This is a lot better than the analog frequency division technique.

3.2.3 Packetization

This technique involves the breaking of incoming bit streams (voice or data) into short “packets”. Different techniques use variable or fixed-length packets. Packets have an identifier appended to the front of them which identifies the circuit or channel to which they belong. In the TDM example in Figure 30 on page 73, a time slot was allocated for a low-speed channel within every frame, even if there was no data to be sent. In the packet technique, blocks are sent only when a full block is available and “empty” packets are not sent. Thus, utilization of the high-speed link can be dramatically improved.

In the TDM example, the 2 Mbps high-speed channel provided 32 subchannels of 64 Kbps. If each subchannel is only used on average for half of the time (as in voice conversation) then perhaps 64 subchannels could be used with packetization. However, now there will be statistical variations and there will be a finite probability that all 64 channels will want the same direction at once. In this case some data would be lost, but the probability of this occurring is very small. However, the probability of 33 channels wanting to operate in the same direction simultaneously is quite high. It is a matter for statisticians to decide how many channels can be safely allocated without too much chance of losing information (overrun). This will depend on the bandwidth available and the number of channels. The larger the number of channels the smaller the variation and the greater the safe utilization. A good starting assumption is that the channel can be utilized to about 70% of its capacity safely (in a 2 Mbps circuit).

3.2.4 Characteristics

- The equipment required for packetization is much more complex and expensive.
- Operation at very high speeds increases the complexity of the required equipment.
- Use of the packetization technique results in very much improved (optimal) use of the trunk. This is because when there is silence a packet is not transmitted. There are overheads inherent in the addressing technique which must be used to route and to identify the packet but nevertheless, an efficiency of perhaps 80% can be approached if the bandwidth is wide enough to permit a large number of simultaneous calls.
- GSM and IS54 are good examples of TDMA wireless systems.

3.2.5 Sub-Multiplexing

It is quite possible, indeed usual, for multiplexors to be “cascaded” as suggested in Figure 31. A “high-order” multiplexor is used to derive a number of lower-speed channels that are then further reduced by other (lower order) multiplexors. This may then be reduced even further by lower and lower order multiplexors.

Since a derived channel is just like the original channel only “narrower”, different multiplexing techniques can be used within one another. For example, it is possible for a wideband microwave channel to be frequency divided into a number of lower channels and for one lower-speed channel to be further divided by the frequency technique, another to be shared using the TDM digital technique and yet another to be shared using the packet technique. There are however, limitations. For example, a digital channel cannot be shared using frequency division multiplexing and a TDM technique would not be a very attractive way of subdividing a packet technique. Still, mixtures of techniques can be used relatively freely.

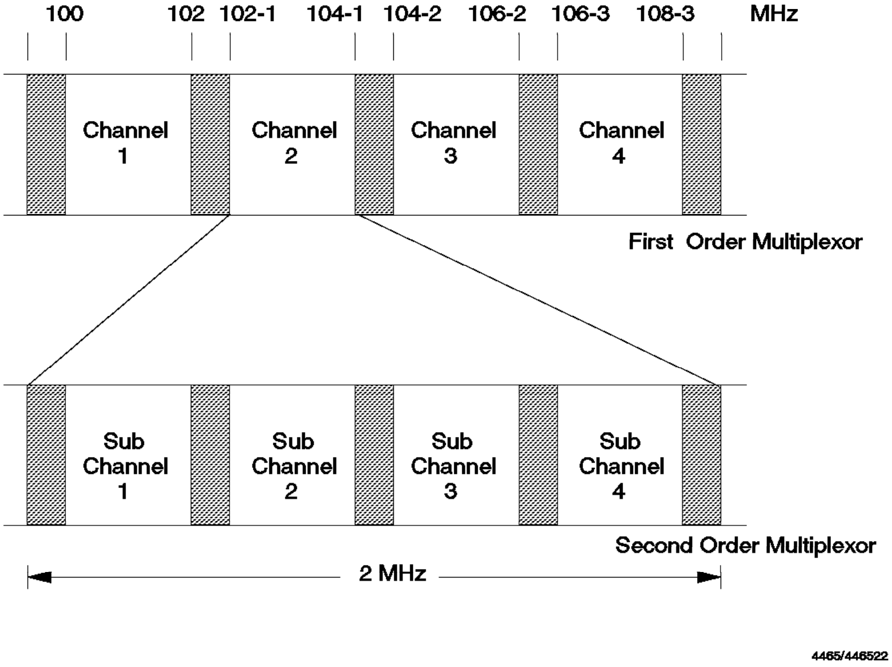

Figure 31. Sub-Multiplexing Concept. This is a frequency division technique used within a frequency-derived channel.

The hierarchies of multiplexors used in different parts of the world are shown below:

Table 4 (Page 1 of 2). PCM Hierarchies

	North American		**Japanese**		**CCITT-CEPT**	
Order	**Bit Rate (Mbps)**	**No. of Chan**	**Bit Rate (Mbps)**	**No. of Chan**	**Bit Rate (Mbps)**	**No. of Chan**
Single Channel	64 Kbps	1	64 Kbps	1	64 Kbps	1
First Order	1.544	24	1.544	24	2.048	30

Table 4 (Page 2 of 2). PCM Hierarchies

	North American		**Japanese**		**CCITT-CEPT**	
Order	**Bit Rate (Mbps)**	**No. of Chan**	**Bit Rate (Mbps)**	**No. of Chan**	**Bit Rate (Mbps)**	**No. of Chan**
Second Order	6.312	96	6.312	96	8.448	120
Third Order	44.736	672	32.064	480	34.368	480
Fourth Order	274.176	4032	97.728	1440	139.264	1920
Fifth Order			397.200	5760	564.992	7680

3.2.5.1 Characteristics

- This technique is popular because it allows for great flexibility and for modularity of equipment. For example, a first order TDM multiplexor might break up a 140 Mbps fiber circuit into 64 (2 Mbps) channels. Some of these can then be further multiplexed into 30 (64 Kbps) voice channels or perhaps several 2 Mbps channels combined to provide a television circuit. The derived 64 Kbps voice channels can perhaps then be broken up further by (third order) multiplexors to provide many 4800 or 9600 bps data channels. The equipment modularity introduced also assists in reliability and serviceability management.
- The ability to mix techniques is very important. (There are some limits here; frequency division multiplexing cannot be used within a digital channel, for example). A wideband analog carrier can be frequency multiplexed into several high-speed digital channels and then one of these could use packet mode techniques for carrying data and others could use TDM techniques for carrying voice traffic.

3.2.6 Statistical Multiplexing

Statistical multiplexing is a generic name for any method that aims to utilize bandwidth capacity only when there is information to send. This is in contrast to the techniques of allocating fixed capacity channels whether those channels are used or not. Packetization is one form of statistical multiplexing.

The technique offers bandwidth capacity conservation for voice in that the gaps in speech and the “half-duplex” characteristic of speech can potentially be exploited for other conversations. Likewise, the gaps in traditional data traffic can be exploited. There are multiplexors available that allocate a large number of voice channels over a smaller number of real channels using this technique. Listening in to any one of the virtual voice channels on the one real voice channel would provide the listener with intermixed phrases and sentences from different conversations on the one real voice channel. In data communications, the use of statistical multiplexors that derive (for example) six or eight slow (2400 bps) channels from a “standard” 9600 bps line are in common use.

All of these techniques have problems in that they require some mechanism to recognize “silence”, that is, to determine when not to send. In voice, a delay buffer is used. When a word is spoken following silence, the buffer is analyzed and the need for a channel is recognized. The channel is made available and the whole word is sent without chopping off the beginning of the word since the data is available in the buffer.

In the past statistical multiplexing has been used to improve utilization of expensive undersea telephone cables but is not in common use for other situations because of the cost and impact on quality caused by the additional delays and the interposition of yet another piece of equipment which potentially degrades the signal quality. There are examples of statistical multiplexing being used on some international satellite connections.

3.2.6.1 Characteristics

- Statistical multiplexing uses bandwidth only when required.
- Virtual circuits are allocated to a lower number of actual circuits.
- Statistical multiplexing is very efficient in the use of bandwidth, but requires high processing power.

3.2.7 Block Multiplexing

Block multiplexing is the usual method of operation for data communication networks. It is another form of statistical multiplexing.

A single channel is used to transmit “blocks” of varying lengths depending on the logical characteristics of the data to be transmitted and the physical characteristics of the devices involved. Often maximum limits are imposed on block lengths (though sometimes not). Blocks are usually queued for the link according to various criteria such as priority, length or message type. In IBM′s Systems Network Architecture (SNA), this method is used on all links but different characteristics apply to different kinds of links. For example, on links between IBM 3745 front-end processors block lengths can be very long (4000 bytes or more) and on links between 3745 front-end processors and controllers, blocks are “segmented” (broken up) to fit into the I/O buffers of the receiving device.

3.2.7.1 Characteristics

Block multiplexing can be considered a special case of packetization (in the sense of variable-length packets). Alternatively, packetization can be considered a special case of block multiplexing with fixed-length blocks. In the data processing industry, the use of variable-length blocks prevails. In data networks constructed by telephone companies (generically called X.25 networks because of the “standard” they use to interface with their users), packetization is the normal method.

Historically, data communications was susceptible to errors injected by network equipment used for transmission. Techniques were developed to compensate for this inherent unreliability. While the equipment is vastly improved and is more reliable by an order of magnitude or better, the techniques originally developed are still widely employed.

In a network where data integrity is of supreme importance, a block must be fully received by an intermediate node before it is sent on to the next node. Whether the routing header in the beginning of the block is correct is not determined until the end of the block has been received and the Frame Check Sequence (FCS) is checked. The FCS is a small redundant packet of data sent at the end of each frame to allow the integrity of the data in the frame to be verified. So the block cannot be sent on until it is checked. Since the whole block must be received before it is sent on, the longer the block, the longer the delay in the intermediate node. If there are many nodes through which the data must pass, then the delay for each node add to the total delay for the network transit. So the shorter the block, the more quickly it can be sent through a network. Thus, if there are 2000 bytes to be sent, the transit time will be much faster if this is sent as ten 200-byte “packets”.

There is another problem with widely varying block lengths. Queueing delay for links becomes uneven and parallel link groups tend to operate erratically. In SNA, for example, “Transmission Group” (GP) operation could be greatly degraded by the presence of widely varying block lengths. Another problem is that varying block lengths create erratic demands on buffer pool utilization in switching nodes. It would seem sensible, therefore, to keep data block lengths to a minimum in all networks. However, there is a very important characteristic of computer equipment that must be taken into account. Processing a block (switching or sending or receiving) takes almost exactly the same amount of computer processing regardless of the length of the block. This applies to computer mainframes as well as switching nodes and terminal controllers. So, in the example of a 2000-byte block, the processing time in each involved processor (including the sender and receiver) will be multiplied by 10 if blocks are sent 200 bytes at a time.

Since the amount of processing involved is a cost factor, it costs a lot more for processing hardware if short blocks or packets are sent. Hence, the computer industry tradition of sending variable, long blocks.

When considering voice transmission, where network transit delay and uniformity of response are paramount, it would seem that mixing voice into such a data system would not be feasible.

However, the above applies to traditional systems where the block is “long” in time as well as in bytes. That is, the link speed is low compared to the length of the block. With high link speeds (for example, 4 Mbps on a local area network), block lengths that were considered “long” in the past become short enough not to be a problem (for example, 5000 bytes take 10 milliseconds at 4 Mbps).

New equipment designs in the future will allow vastly reduced cost in the switching node; the cost of short packets may become less of a problem.

The two most common access methods in use today for wireless LANs are CSMA and TDMA.

3.2.8 Carrier Sense Multiple Access (CSMA)

CSMA is a contention-based access method. The CSMA access method is to wireless LANs what Ethernet is to wired LANs. CSMA is also used on PMR networks where a station listens to the control channel to ensure that it is free before transmitting. With CSMA all stations access the network randomly without coordination or synchronization. Each station wishing to transmit first listens to see if there is anyone else transmitting on the frequency it intends to transmit on. If the frequency is free, then that station transmits. One difference between CSMA in the wireless environment and Ethernet in the wired environment is that the wireless CSMA station cannot detect any other station starting to transmit at the same time. The reason is that each station transmitting cannot “listen” at the same time as transmitting. Its own signal effectively drowns out all other signals on that frequency at that time. As for Ethernet, CSMA works fine at lower utilization rates. When the utilization of the radio link capacity increases, the number of collisions also increases and the effective data throughput can fall dramatically. This can lead to ineffective use of the bandwidth. A CSMA system is also vulnerable to interference. Implementation can be based on relatively inexpensive Ethernet chip-sets which are based on Carrier Sense Multiple Access / Collision Detect (CSMA/CD). The CD part of the system is simply replaced by Collision Avoidance (CA) to give a CSMA/CA system. The reliability and robustness of this method are limited and does not lend itself to integrating voice and data since there are only limited prioritizing possibilities. There are limited power-saving possibilities for battery-operated stations since the receiver is always listening. The CSMA method lends itself to a peer-to-peer network topology.

3.2.9 Time Division Multiple Access (TDMA)

TDMA is a deterministic-based access method. The TDMA access method is to wireless what token-ring is to wired LANs. It is effectively a system of polling. One station asks each of the other stations in turn whether they have any information to transmit. Each station is allocated a timeslot when it can respond. If a station indicates that it has data to transmit, then it is allocated a time interval in which to send its data. The number of time intervals allocated depends on the amount of data being sent.

One advantage of the TDMA method is that priorities can be allocated to chosen stations or certain types of data. This could be used to allow voice and data to be carried on the same wireless LAN with higher priority being allocated to the voice traffic. The ability to mix isochronous and asynchronous traffic is required for multimedia applications. The effective data rate can be determined fairly accurately since there are no collisions between stations in the same LAN. Time Division Multiple Access (TDMA) divides each communication channel into time segments so that a transceiver or radio can support multiple channels or time slots for reduced power consumption.

The TDMA access method lends itself to a base-to-remote network topology since communication between stations is synchronized and time slots are allocated to remote stations by a scheduling function in the wireless base station. This also leads to more efficient use of the bandwidth. There are also power-saving possibilities for battery-operated stations using TDMA. The receiver needs only to listen at assigned time intervals.

The TDMA base stations are more complex than CSMA since the synchronization is carried out by the base station. They may be more expensive since a microprocessor will be required. On the other hand, the remote stations will be less complex. TDMA is relatively new to wireless LANs. Many of the existing wireless LANs are based on CSMA methods, but these methods are also used in many other wireless environments. Most high-speed satellite communications, GSM and the standards being worked on in Europe as well as the CDPD networks are based on the TDMA method.

3.3 Radio LAN Systems Considerations

There are special considerations to be taken into account when implementing a radio LAN. The main problems are set out below, together with some solutions:

3.3.1 Collocated but Unrelated Radio LANs

One important requirement for a radio LAN system is the need to allow multiple *unrelated* LANs (of the same type) to be located in the same area. This requires a system for channel sharing and LAN administration that allows each independent LAN to be set up and operated without the need to consider other (similar) LANs in the same space. As radio LANs operate in the ISM bands, there is no license required and other organizations may install a radio LAN whose coverage are overlaps with one already installed. The new LAN may or may not be compatible with the existing LAN. For this reason, radio LAN systems must be capable of avoiding interfering with or being interfered with by another LAN. The use of spread spectrum technology ensures that radio LANs may coexist.

3.3.2 Countering Multi-Path Effects

As mentioned above, multi-path effects are the most serious problem for the indoor radio environment. The following are some of the general approaches used to counter them:

Antenna Diversity

Antenna diversity can mitigate both ISI and Rayleigh fading effects. There are many different ways of approaching this:

1. Multiple Directional Antennas

   An example of this is the Motorola "Altair" radio LAN system which uses a six-segment antenna. Antenna segments are arranged in a circle at an angle of 60 degrees from each other. Each antenna segment is highly directional; thus, signals coming from different directions (reflections, etc.) are received on different antenna segments. As signals are received the system selects the antenna segment receiving the strongest signal and uses that signal alone. This severely limits the number of possible paths. Moreover, surviving paths will have lengths that are not too different from one another. This provides an excellent solution to the ISI problem but does not do a lot for fading. Notice, however, that with a narrowband microwave system (1.6 cm wavelength) Rayleigh fading is not as significant as it is at longer wavelengths.

   See page 80 for a discussion of this phenomenon (Rayleigh fading).

2. Multiple Antennas

   Other systems use multiple dipole antennas separated from one another by more than half a wavelength. Signals are added together before detection and this does provide a measure of protection against fading (but not against ISI).

3. Multiple Coordinated Receivers

   Two antennas are situated exactly 1/4 of a wavelength apart. Each antenna services a different receiver circuit. The signals are then combined in such a way as to minimize multi-path effects.

4. Polarization Diversity

   Because the signal polarization changes as reflections occur, a good counter to fading is to provide both horizontal and vertically polarized antennas acting together. The signal is transmitted and received in both polarizations.

Data Rate

The ISI problem is most severe when the delay spread covers more than one data bit time. See page 94 for more information on ISI. The easy way to avoid this is to limit the data rate to less than the inverse of the delay spread. However, if the objective is to operate at LAN speeds (above 1 Mbps) then this will not always be practical.

Spread Spectrum Techniques

As discussed above, spread spectrum techniques provide a good measure of protection against ISI and fading. Spread spectrum is mandatory in the ISM bands. Thus in the indoor radio situation spread spectrum is a preferred method of controlling the multi-path effects.

Frequency Diversity

Fading in a narrowband system can be combatted by transmitting the signal on two different frequencies with sufficient separation for the channels to have different fading characteristics. When the signals are received, the station just picks the strongest.

You could call this “half-baked spread spectrum” since all it is doing is spreading the spectrum through an adhoc method.

Adaptive Equalization

See 6.1.3, “Adaptive Equalization” on page 123 for more information on adaptive equalization.

Adaptive equalization is a very good way of countering the ISI form of multi-path interference. It is, however, relatively expensive to implement at high speeds.

There is some disagreement among specialists as to under which circumstances (if any) adaptive equalization is needed. However, to the knowledge of the author, *no current radio LAN system uses adaptive equalization*.

3.4 Summary

We have seen in this chapter some of the techniques used to make the best use of the available electromagnetic spectrum. These techniques include improving the throughput by sophisticated methods of modulation, and enabling several users to share the same part of the spectrum by means of multiplexing. Many of the technologies are analogous to those used in wireline communications, but are adapted to meet the different requirements of wireless technology.

Chapter 4. Infrared Technology

Visible light is energy at wavelengths between 380 and 780 nm. Ultraviolet (UV) has a wavelength shorter than visible light and Infrared (IR) wavelengths are longer than 780 nm. The following list shows the approximate frequencies for the different forms of light:

- IR - 3 x 10^{11} Hz to 4 x 10^{14} Hz
- Visible light - 4 x 10^{14} Hz to 7.5 x 10^{14} Hz
- UV - 7.5 x 10^{14} Hz to 3 x 10^{17} Hz

4.1 Infrared Sources

Infrared (IR) light is produced by many natural and man-made sources. Sunlight produces light between 300 and 1200 nm, which includes light at the IR wavelengths. Direct sunlight can degrade the performance of an IR transceiver but diffuse sunlight can be tolerated. Incandescent lights can also affect the performance of an IR transceiver since tungsten filament lights emit IR light around 900 nm in wavelength. Fluorescent lights do not affect an IR transceiver. Other sources of interference to IR communications can be smoke, water vapor (mist), and heat haze or “shimmer”. Therefore it is more usual to find IR communications used in indoor environments rather than outdoors.

In the 1960s, gas and solid-state lasers were used to transmit information from one building to another across short distances. In the 1970s laser diodes (LDs) and light-emitting diodes (LEDs) were developed and the availability of relatively cheap optical fiber led to the installation of fiber links rather than connections through the air for point-to-point connections. As manufacturing techniques improved and the price of LEDs dropped in the 1970s, many new applications came to use infrared communications. Typical applications in use today include:

- Remote controls for VCR / Radio / Television
- Security systems
- LANs

The three most important items to consider when setting up an IR connection are:

- Optical power transmitted
- Multi-path inter-symbol interference
- Background noise

For more details on multi-path inter-symbol interference see 5.1.1.1, “Multi-Path Effects” on page 93.

Optical power is critical in achieving maximum distance. This is one of the factors in choosing between LDs and LEDs.

4.1.1 Laser Diodes (LDs)

Laser stands for Light Amplification by the Stimulated Emission of Radiation. The first lasers used ruby crystals which were excited by a flash tube to produce laser light. Further developments included the gas laser where a gas such as carbon dioxide or a helium/neon mixture was exited by a powerful RF signal. These types of lasers are used for industrial and medical applications and are powerful enough to perform cutting and welding of metals. They are expensive and require precise control of temperature for them to function correctly. A more recent development is that of the Laser Diode (LD). LDs are used for communications on a line of sight system and will normally operate in the IR region of the spectrum.

- LDs are normally more powerful than LEDs but not as powerful as gas lasers.
- They produce single wavelength of light. This is related to the molecular characteristics of the material used in the laser. Laser light is "coherent" as it is formed in parallel beams and is in a single phase.
- Lasers can be controlled very closely. The shortest pulse length that a laser can produce is 0.5 x 10^{-15} seconds.
- In communications applications, lasers with power ratings up to 20 mW are available.

Some of the disadvantages of lasers include:

- Lasers have been expensive in comparison with LEDs (recent development has improved this). The main cause of lasers′ high cost is the necessity to use temperature controls to maintain a stable power level.
- The wavelength that a laser produces is a characteristic of the material used to build the laser and of its physical construction. Lasers have to be designed for each wavelength they are going to use.
- Lasers allow beams to be focused on small areas. When this beam of light is directed onto a small area, high power densities are obtained. This can damage the retina of the human eye if struck. From a safety point of view, lasers are not suited for indoor applications. They may be used for outdoor communication between buildings if proper safety precautions are taken.

4.1.2 Light Emitting Diodes (LEDs)

Light Emitting Diodes are safer to use than LDs since the power is not focused intensely on a small area. The maximum light output has typically been much lower than a laser (about 100 microwatts). However, recently a new class of LEDs with output of up to 75 mW has become available allowing greater distance coverage. In fact, it is the power-speed product which is the limiting factor. Many of the higher powered LEDs (above 30 mW) cannot switch at high speeds, while the high speed LEDs (less than 10 ns switching time) are low-powered devices. The high powered LEDs were developed for remote controllers and the high-speed devices were developed for fiber-optic communications. There has not been the need for high-speed, high-powered LEDs until now; the advent of WLAN applications will provide the market for them.

LEDs are very low in cost (perhaps 1/10th to 1/100th that of a laser).

LEDs do not produce a single light frequency but rather a band of frequencies. The range of the band of frequencies produced is called the "spectral linewidth" and is typically about .05 of the wavelength (50 to 100 nm). The linewidth can be reduced (and dispersion reduced) by using selective filters to produce a narrow band of wavelengths. However, this reduces the power of the signal too. IR LEDs are used for many of the communications and control applications. This is because the receiving element (the photo-diode) can be designed to reject visible light frequencies and thus avoid much of the light interference in a room. The other main use of LEDs is in displays and indicators. Most modern domestic electronic equipment will use LED indicators which have the advantage of very low failure rates and low power requirements when compared to incandescent signal lamps. These visible light LEDs come in a variety of colors.

The light produced by an LED is not directional or coherent. This means that you need a lens to focus the light. Most small LEDs have the lens molded as part of the LED enclosure. For this reason LEDs are not suitable for use with single mode glass fiber (it is too hard to focus the light within the narrow core).

LEDs cannot produce pulses short enough to be used at gigabit speeds. However, systems using LEDs operate well at speeds up to around 300 Mbps, which is acceptable for most current wireless LAN applications.

4.1.3 Regulations and Licenses

In the US, the FCC controls and regulates the usage and allocation of wireless frequencies. Other countries and regions have their own regulatory authorities. Since infrared light does not fall into the wireless part of the frequency spectrum infrared transmitters are not regulated by the FCC and other authorities and, hence, require no license. Signal strengths are low and are attenuated by the air so that it is unlikely that an infrared signal will interfere with other infrared signals being used in close proximity.

Various national and international standards specify what optical emission levels should be considered safe for wireless communications systems. The International Electrotechnical Commission (IEC) standard 825-1 (1993-11) defines equipment classification and requirements. There are five different classifications for Laser/LED products defined by the IEC: Class 1, Class 2, Class 3A, Class 3B and Class 4. A Class 1 product is a product which is safe for use under normal commercial conditions. The IBM Infrared Wireless product complies with the 825-1 Class 1 standard of the IEC.

4.2 Infrared LANs (IR LANs)

Diffuse infrared light produced by an LED can be used for data communications. At the transmitter, an LED converts electrical signals into infrared signals. At the receiver, a photodiode convert the infrared signal back into electrical signals. It is normal for the transmitter and receiver of one station to be in the same enclosure called a transceiver. Since the infrared light is diffuse, the signal will bounce off ceilings, walls and floors before reaching the receiver. The transmitter and receiver need not be in direct line of sight. Typically, the area covered by an infrared transmitter is about 10 x 10 meters, with a line of sight range of up to 17 meters. In an enclosed area such as a room, flat surfaces will reflect the signal although there will be some signal loss. Typical reflection values are:

- Ceilings - 80%
- Walls - 50%
- Floors - 20%

After several reflections, the signal will become too weak to allow reception. The signal to noise (S/N) ratio determines how well a signal can be received. Room size and layout play an important role in determining the levels of signal and noise. Ambient lighting, both sunlight and artificial incandescent light, creates background noise. Other sources of interference can be heaters, water vapor and particulate contamination (dust) in the air. At maximum range there is a sharp cutoff due to the limits on receiver sensitivity and noise produced by incandescent lighting.

4.2.1 Topology

Since infrared light needs to have either a direct or a reflected path between transmitter and receiver, IR LAN signals cannot pass through an obstruction such as a wall or door. Radio frequency LAN signals can pass through such objects. Various techniques are used to enable the IR signal to reach all LAN receivers in a room. One common method is to place all transmitters and receivers higher than about 2.5 meters to avoid interference from most office furniture. The transmitters can be aligned with the receivers to improve reception but a direct line of sight connection is not necessary. This is the preferred method for point-to-point communications.

A second method is to direct all signals directly at the ceiling using what is known as a diffuse link. The transmitter sends the signal at a wide-aperture angle and after several reflections from the walls and ceiling, the signal reaches the receiver from different directions at different angles. This is called isotropic radiation.

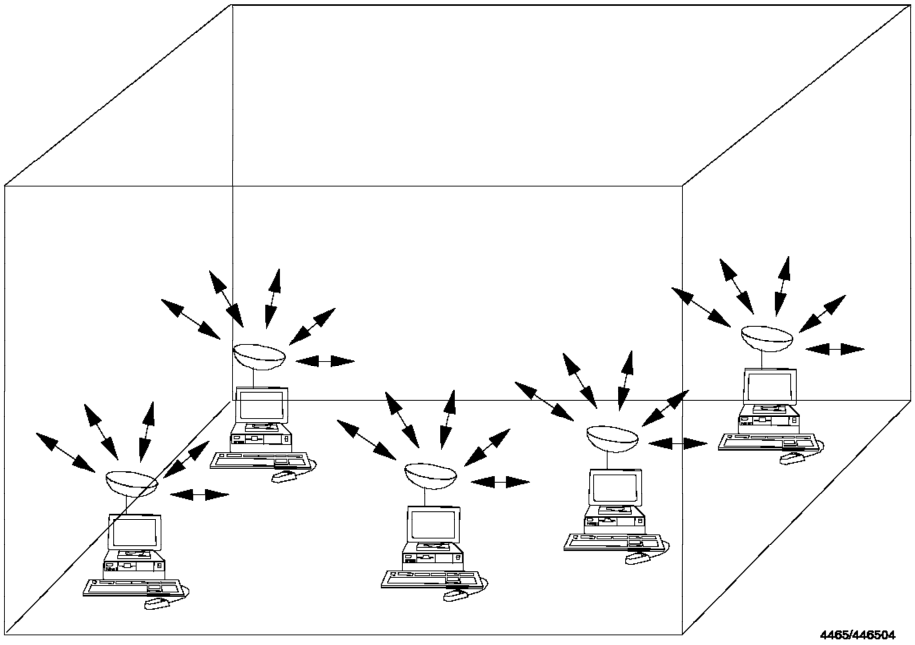

Figure 32. Diffuse Links

The main drawback to this approach is the limitation on the channel speed due to multi-path propagation. A short pulse sent will be received as a longer one, after several reflections. A mathematical model has been developed by J. Barry et al (see "Related Publications" on page xvi) to define the room response time. Using this model, they calculated a channel bandwidth to room length product of roughly 60 Mbps per meter for rooms with 3 meter high walls. As a result, for a room of size 5 meters x 5 meters x 3 meters, 60 Mbps per meter / 5 meters = 12 Mbps is the expected maximum data rate. Higher data rates would be expected to produce severe intersymbol interference due to multi-path dispersion.

Another method is to aim all signals at a single point on the ceiling, as shown in Figure 33.

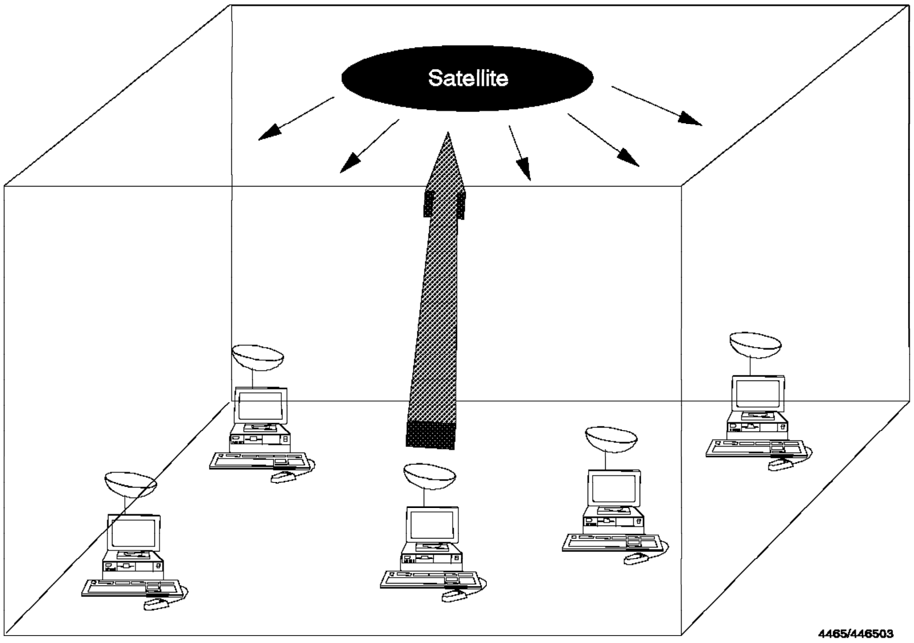

Figure 33. Quasi-Diffuse Transmission

This method is known as quasi-diffuse transmission. A narrow light beam is aimed at a common point on the ceiling, called the satellite. The receivers then face the satellite. The simplest form of satellite is a small area on a painted white ceiling, which then acts as a passive satellite. For larger rooms, an active satellite is needed. This can take the form of a repeater with several photodiodes and LEDs to cover the whole room. The satellite could have a high-powered transmitter, allowing the terminals to use low-power transmitters (a useful feature for battery-operated portable and hand-held terminals where power consumption must be kept to a minimum). Several satellites can be used to cover larger areas and they can be connected by point-to-point links. Multipath dispersion is not a problem for both passive and active satellites since the signal is only received by the terminal directly from the satellite, and not from the walls or ceiling.

4.2.2 Modulation

Fast LEDs can switch at speeds of up to about 30 million pulses per second so that the modulation and coding systems used to carry data on an infrared link are restricted to this value. Also, techniques used in radio frequency technology such as CDMA cannot be used. Four modulation schemes widely used in IR WLANs are:

- On-Off Keying (OOK)
- Multisubcarrier
- Frequency Shift Keying
- Pulse Phase Modulation

4.2.3 On-Off Keying

This simple method of modulation turns the carrier signal on for a one bit and off for a zero bit. Because of the difficulty in determining the difference between a zero bit and the transmitter actually switching off, the data signal must be coded. The most suitable coding method depends on the data rate and the bandwidth available. The data rate is limited by the IR LEDs switching rate. With diffuse links, the intersymbol interference will also increase with increasing data rates. The most common coding methods used with OOK are:

- NRZ code
- Manchester code
- Miller code

4.2.3.1 NRZ Code

NRZ code represents the "1" as a high signal and the "0" as a low signal. Redundant bits are added to ensure that signal transitions are transmitted and to allow the timing to be synchronized at the receiver.

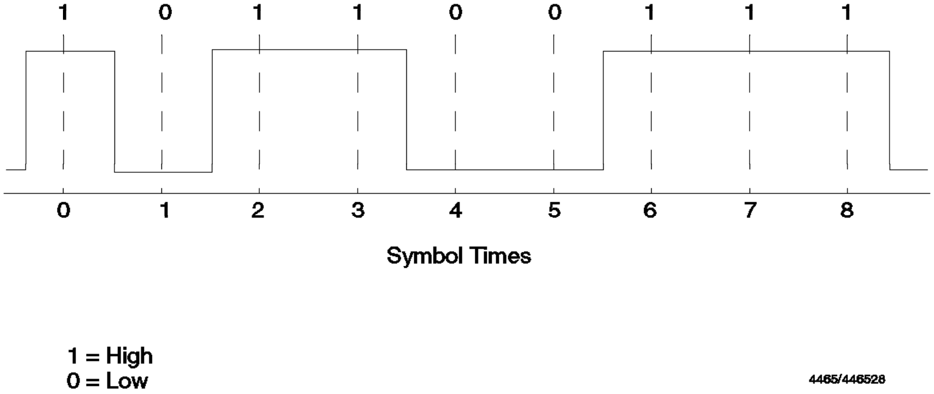

Figure 34. NRZ Coding

The use of 4B/5B coding with NRZ coding is suitable for transmitting 8-bit bytes, since each byte is split up into four-bit lengths and an extra bit added. There are fewer transitions with NRZ coding than with either Manchester or Miller coding. The transmission rate of the data link must be at least 5/4 times the data rate to accommodate the extra redundant bits.

4.2.3.2 Manchester Code

This method codes the symbol "1" as a falling edge in the center of a symbol time and the symbol "0" as a rising edge in the center of a symbol time.

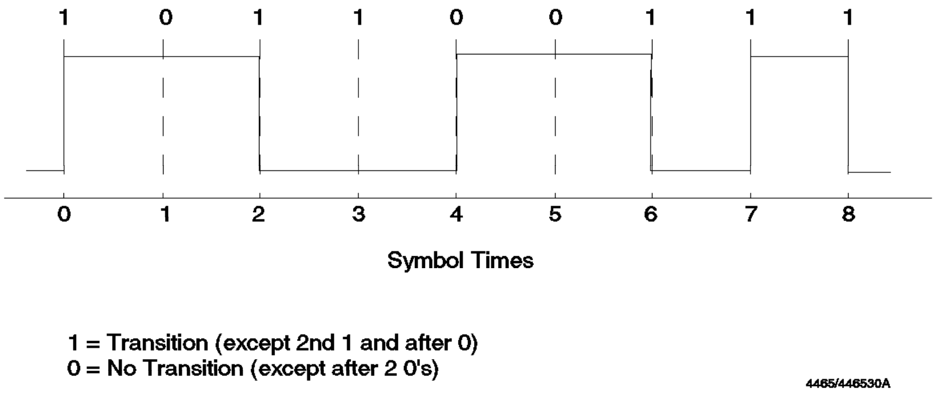

Figure 35. Manchester Coding

A transition is now always present in each symbol. One drawback of this is that the bandwidth used is twice the bandwidth required for NRZ since a transition can occur either once or twice for each symbol.

4.2.3.3 Miller Code

Miller Code codes the symbol "1" as a transition in the center of the symbol time, and the symbol "0" as no transition. However, when a "0" follows another "0", a transition is present at the end of the first "0".

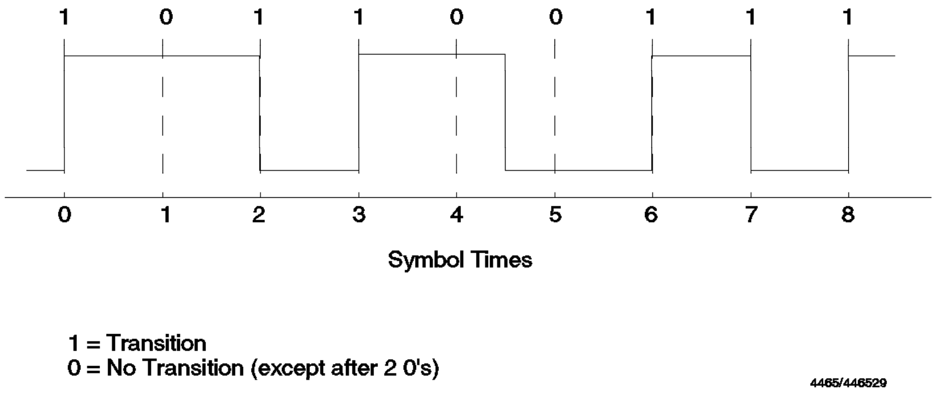

Figure 36. Miller Coding

Using this method, a transition occurs at least after two symbols and at most for each symbol.

Squared Miller code uses the same method as for Miller coding except that when an isolated symbol "0" is followed by an even number of symbols "1" then the transition on the last "1" is removed. Using this method, a transition occurs at least after three symbols and at most for each symbol.

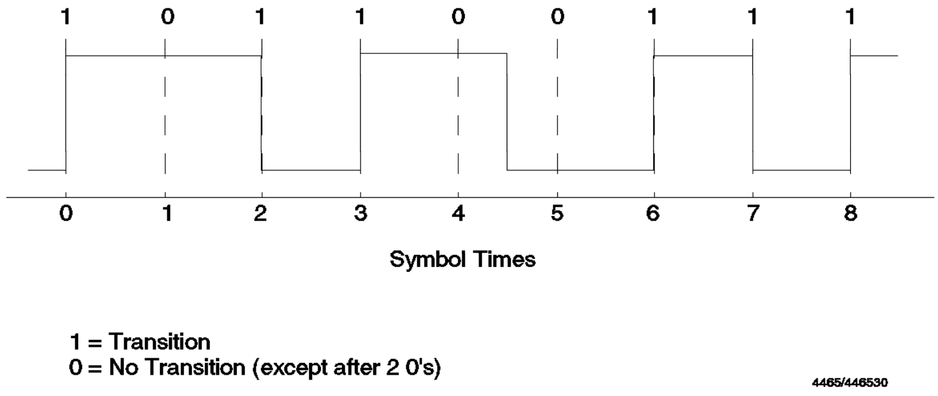

Figure 37. Squared Miller Coding

The coded signal has less transitions than for Manchester coding.

4.2.4 Multisubcarrier Modulation

With this method, the data stream to be transmitted is divided up into a series of fixed length blocks. Each of these blocks is then passed to a modulator. The modulator can transmit on several carrier frequencies at the same time, and each of the frequencies is called a subcarrier frequency. Each bit of the block fed to the modulator is used to modulate a different subcarrier frequency. The result is a number of subcarrier signals, each modulated by one bit of the block. All these subcarrier signals are then added together and the result used to modulate the intensity of the transmitted infrared signal. This is a kind of Frequency Division Multiplexing, as described in 3.2.1, “Frequency Division Multiplexing (FDM)” on page 72.

4.2.5 Frequency Shift Keying

Frequency Shift Keying (FSK) is simply the use of two different frequencies to represent 1s and 0s. This is not a common technology for IR systems as it uses special IR devices which have to be frequency selective.

4.2.6 Pulse Phase Modulation (PPM)

PPM is also known as Pulse Position Modulation. The position of the impulse in time varies depending on the amplitude of the input signal. The width of the impulse remains constant while the pulse is shifted in time.

4.2.7 Security

As the signal from an IRLAN can be contained within a closed room, IRLANs do not pose any great security exposure. Even in an open area, any person trying to receive information from the IRLAN would have to be in close proximity, and thus, normal methods of physical security can be used to prevent unauthorized access.

As with any method of transmitting information, if the cabling system is outside a secured area, then the normal rules of security should apply.

4.3 Summary

There are two types of infrared light suitable for communication:

- Diffused infrared
- Coherent infrared

Coherent infrared light as generated by a LD can be used for short line-of-sight connections. However, the beam of light must be focused on the receiver making it unsuitable for use in mobile equipment. Diffused infrared light as generated by an LED can be successfully used in mobile equipment since the signal can be reflected from walls and ceilings before being received. There are no frequency licensing limitations and spread spectrum techniques are not required as for wireless communications in the ISM bands. As a result, IR devices are in general less expensive than RF wireless devices.

Chapter 5. Radio Communication in LANs

The task of a radio LAN is the same as that of any LAN: to provide peer-to-peer or terminal-to-host communication in a local area. Ideally, it should appear to the user to be exactly the same as a wired LAN in all respects (including performance). The radio medium is different in many ways from wired media and these differences give rise to unique problems and solutions. This section will concentrate on the aspects unique to the radio medium and will only briefly discuss aspects that are held in common with wired media.

5.1 Radio LAN Technology

5.1.1 Characteristics of the Indoor Radio Medium

5.1.1.1 Multi-Path Effects

At the extremely high frequencies involved, radio waves will reflect off solid objects, which means that there are many possible paths for a signal to take from transmitter to receiver. Figure 38 shows some of them. In this case both transmitter and receiver are in the same room. Part of the signal will take the obvious direct path but there are many other paths and some of the signal will follow each of these. (Reflection from the floor is especially significant.)

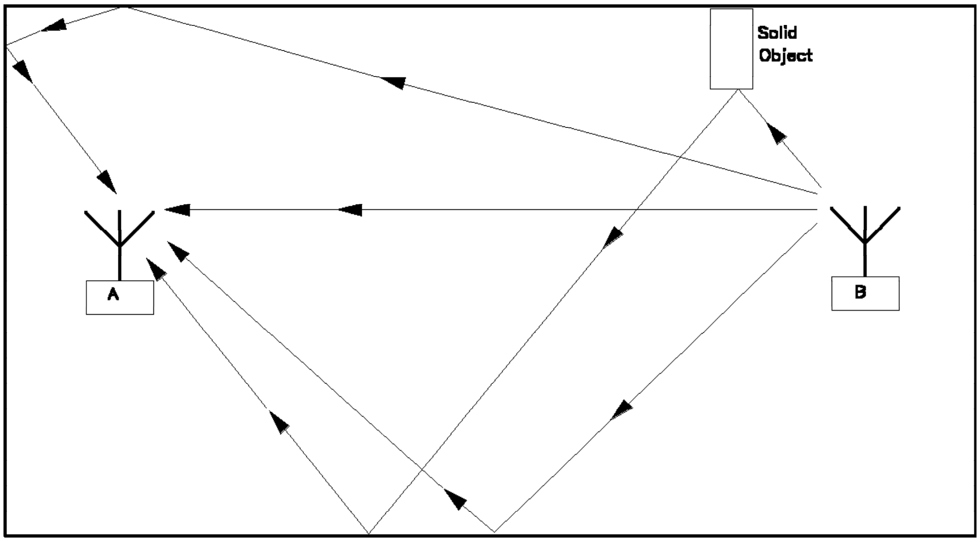

Figure 38. Multi-Path Effect. The signal travels from transmitter to receiver on multiple paths and is reflected from room walls and solid objects.

This has a number of consequences:

1. To some extent the signal will travel around solid objects (and can penetrate others that are “radio transparent”). This is what gives radio its biggest advantage over infrared transmission in the indoor environment.
2. As shown in Figure 38, a signal arriving on many paths will spread out in time (because some paths are shorter than others). More accurately, many copies of the signal will arrive at the receiver slightly shifted in time.

Studies have shown that in office and factory environments the delay spread is typically from 30 ns to 250 ns depending on the geometry of the area in question. (In an outdoor, suburban environment, delay spread is typically between .5 µs and 3 µs.) Delay spread has two quite different effects which must be countered.

Rayleigh Fading

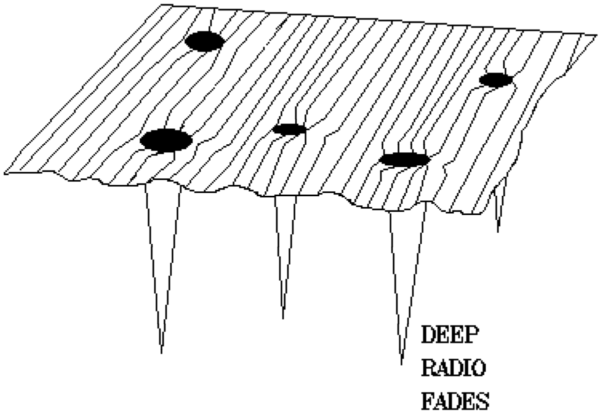

Figure 39. Rayleigh Fading. The signal strength pattern in an indoor area can look like this. The strength can be relatively uniform except for small areas where the signal strength can fall to perhaps 30 dB below areas even one meter away.

After traveling different distances, two signal components are added together in the receiver. If the difference in the length of the paths they traveled is an odd multiple of half the wavelength of the carrier signal, then they will cancel one another out (if it is an even multiple they will strengthen one another). At 2.4 Gbps the wavelength is 125 mm.

In a room there can be dozens or even hundreds of possible paths and all the signals will be added in quite complex ways.

The result is that in any room there will be places where little or no signal is detectable and other places, a few meters away, where the signal could be very strong. If the receiver is mobile, rapid variations in signal strength are usually observed.

Inter-Symbol Interference

When we are digitally modulating a carrier, another important consideration is the length of the symbol (the transmission state representing a bit or group of bits). If we are sending one bit per symbol and the bit rate is 1 Mbps then the “length” of a bit will be slightly less than 300 meters. In time, at 1 Mbps a bit will be 1 µs long. If the delay spread is 250 ns then each bit will be spread out to a length of 1.25 µs and will overlap with the following bit by a quarter of its length.

This is called Inter-Symbol Interference (ISI) and has the effect of limiting the maximum data rate possible. ISI is present in most communications channels and there are good techniques for combating it (such as Adaptive Equalization). It is most severe in the radio environment.

Most people are familiar with this effect since it is the cause of “ghosts” in television reception - especially with indoor antennae.

3. When people move about the room, the characteristics of the room (as far as radio propagation is concerned) change.

Overcoming multi-path effects is the most significant challenge in the design of indoor radio systems.

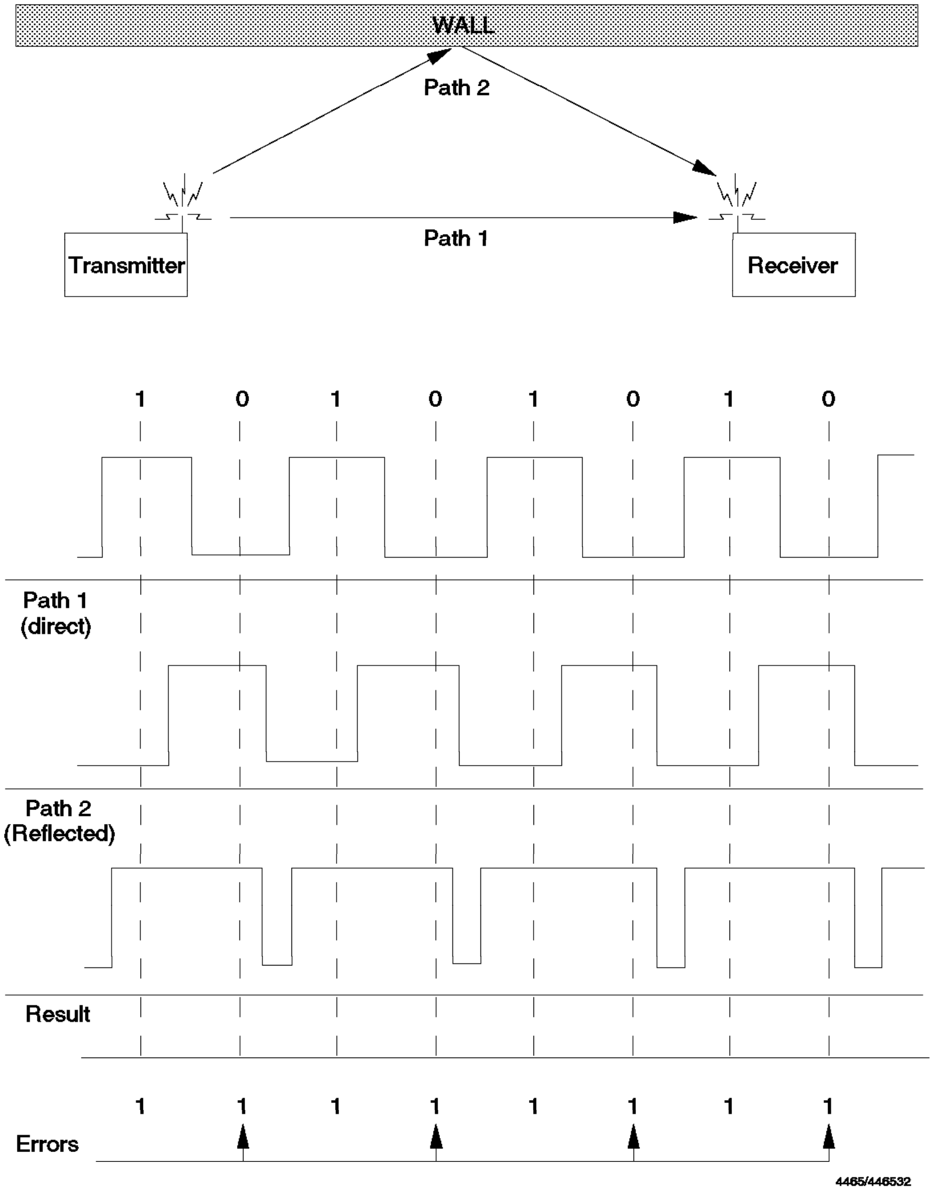

Figure 40. Inter Symbol Interference. Path 1 shows the bit stream received by the direct path from the transmitter to the receiver. Path 2 shows the same bit stream delayed slightly by being reflected and thus taking longer to reach the receiver. The receiver cannot differentiate between the two signals and sees a bit stream with some bits that are incorrect.

- Intermittent Operation

  In an office or factory environment people move about the area and occasionally move large objects about. This can cause intermittent interruption to the signal, rapid fading, and the like.

- Security

  Because there are no boundaries for a radio signal, it is possible for unauthorized people to receive it. This is not as serious a problem as would first appear since the signal strength decreases with the fourth power of the distance from the transmitter (for systems where the antenna is close to the ground - such as indoor systems). This is known as the inverse square law in free space. Nevertheless, spectrum is a problem which must be addressed by any radio LAN proposal.

- Bandwidth

  Radio waves at frequencies above a few GHz do not bend much in the atmosphere (they travel in straight lines) and are reflected from most solid objects. Thus, radio signals at this frequency will not normally penetrate a building. Inside the building this means there is a wide range of frequencies available which may be used for local applications with very few restrictions.

- Direction

  In general radio waves will radiate from a transmitting antenna in all directions. With a smart antenna design it is possible to direct the signal into specific directions or even into beams. In the indoor environment, however, this doesn′t make a lot of difference due to the signal reflections at the wavelengths commonly used.

- Polarization

  Radio signals are naturally polarized and in free space will maintain their polarization over long distances. However, polarization changes when a signal is reflected. Side-effects that flow from this must be taken into consideration in the design of an indoor radio system.

- Interference

  Depending on which frequency band is in use there are many sources of possible interference with the signal. Some of these are from other transmitters in the same band (such as radar sets and microwave installations nearby). The most likely source of interference within the 2.4 GHz frequency band is the microwave oven. Potential leakage can be as high as 200 mW, which is twice the IBM Wireless LAN′s transmit power. Electric motors, switches, and stray radiation from electronic devices are other sources of interference.

5.1.2 Sharing the Bandwidth

With many workstations in the same area wanting to communicate a method is needed to share the bandwidth. Different LAN designs use quite different methods of operation and of bandwidth sharing. However, most use a combination of the methods outlined below:

Frequency Division Multiplexing (FDM)

The principle of FDM is described in 3.2.1, “Frequency Division Multiplexing (FDM)” on page 72.

Time Division Multiplexing (TDM)

The principle of TDM is described in 3.2.2, “Time Division Multiplexing (TDM)” on page 73.

Polarization Division Multiplexing (PDM)

Provided that polarization can be maintained, we could potentially use the direction of polarization as a multiplexing technique. In the presence of multiple reflections, however, polarization changes and is essentially unpredictable. Thus, polarization is not usable as a multiplexing technique in the indoor radio environment. (In the outdoor environment, polarization is widely used as a way of doubling capacity on high-speed digital microwave links.)

Space Division Multiplexing (SDM)

Using directional antennae and reflectors we can (roughly) shape radio signals into beams. Signals can be beamed from one location to another and the same frequency can be used for many beams between different locations. Typical outdoor microwave systems operate this way.

Channel separation is far from perfect but a radio LAN system could be built with carefully selected frequencies and directional antennae such that the same frequency is reused for many connections.

Structuring the network in a cellular fashion is also a form of SDM. This is described in 1.2.1, “Voice Communication” on page 5.

Code Division Multiplexing (CDMA)

In a spread spectrum system (with some special techniques) it is possible to transmit multiple signals at the same frequency at the same time and still separate them in the receiver. This is called CDMA and is discussed in 5.2, “Spread Spectrum and Code Division Multiple Access (CDMA).”

5.1.3 Conventional Narrowband Radio (Microwave)

It is perfectly sensible to build a radio LAN using conventional narrowband microwave radio. The Motorola Altair product is an example of such a system.

There are a number of issues, however, that pose interesting design dilemmas:

1. The use of microwave radio even at low power usually requires licensing of the equipment to a specific user and allocation of a unique frequency.
2. The ISM bands are unlicensed. Some are available worldwide (but can only be used by spread spectrum systems). In addition, they are less sensitive to interference and noise.

5.2 Spread Spectrum and Code Division Multiple Access (CDMA)

The concepts of spread spectrum and of CDMA seem to contradict normal intuition. In most communications systems we try to maximize the amount of useful signals we can fit into a minimal bandwidth. In spread spectrum we try to artificially spread a signal over a bandwidth much wider than necessary. In CDMA we transmit multiple signals over the same frequency band, using the same modulation techniques at the same time. There are very good reasons for doing this. In a spread spectrum system we use some artificial technique to broaden the amount of bandwidth used. This has the following effects:

Capacity Gain

When you use the Shannon-Hartly law for the capacity of a bandwidth-limited channel, it is easy to see that for a given signal power the wider the bandwidth used, the greater the channel capacity. So if we broaden the spectrum of a given signal we get an increase in channel capacity and/or an improvement in the signal-to-noise ratio.

This is true and easy to demonstrate for some systems but not for others. “Ordinary” frequency modulation (FM) systems spread the signal above the minimum theoretically needed and they get a demonstrable increase in capacity. Some techniques for spreading the spectrum achieve a significant capacity gain but others do not.

The Shannon-Hartly Law

The Shannon-Hartly law gives the capacity of a bandwidth-limited communications channel in the presence of “Gaussian” noise. (Every communications channel has Gaussian noise.)

$$Capacity = B \log_2 (1 + \frac{P_S}{2 N_0 B})$$

Where P represents signal power, N noise power and B available bandwidth.

It is easy to see that with P and N held constant capacity increases as bandwidth increases (though not quite as fast). So, for a given channel capacity, the required power decreases as utilized bandwidth increases. The wider the bandwidth the lower the power required for a given capacity.

Security

The use of spread spectrum in the commercial sector was historically restricted in the U.S. by the Department of Defense for the purpose (among others) of ensuring secure battlefield communications. Spread spectrum signals have an excellent rejection of intentional jamming (any jamming signal must have significant power to be successful). In addition, the Direct Sequence (DS) technique results in a signal which is very hard to distinguish from background noise unless you know the particular random code sequence used to generate the signal. Thus, not only are DS signals hard to jam, they are extremely difficult to decode (unless you have the key) and quite hard to detect anyway, even if all you want to know is when something is being transmitted.

Immunity to Multipath Distortion

Some spectrum spreading techniques have a significantly better performance in the presence of multi-path fading than any available narrowband technique.

Interference Rejection

Spread spectrum signals can be received even in the presence of very strong narrowband interfering signals (up to perhaps 30 dB above the desired signal).

Multiplexing Technique (CDMA)

Some techniques of frequency spreading enable the transmission of many completely separate and unrelated channels *on the same frequency and at the same time as other, similar signals*.

There are two major techniques for generating SS signals:

1. Direct Sequence (DS) - also called pseudo noise (PN)
2. Frequency Hopping (FH)

5.2.1 Direct Sequence Spread Spectrum (DSSS)

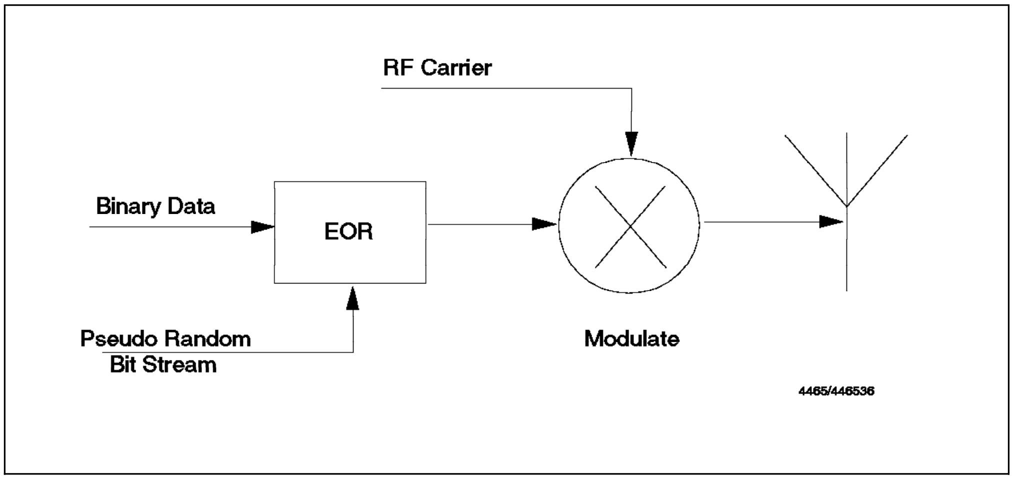

Figure 41. Direct Sequence Spread Spectrum Modulation - Transmitter

Also called “pseudo noise” (PN), DSSS is a popular technique for spreading the spectrum. Figure 41 shows how the signal is generated.

1. The binary data stream (user data) is used to “modulate” a pseudo-random bit stream. The rate of this pseudo-random bit stream is much faster (from nine to 100 times) than the user data rate. The bits of the pseudo-random stream are called *chips*. The ratio between the speed of the chip stream and the data stream is called the *spread ratio*.
2. The form of “modulation” used is typically just an exclusive OR (EOR) operation performed between the two bit streams.
3. The output of the faster bit stream is used to modulate a radio frequency (RF) carrier.
4. Any suitable modulation technique can be used but in practice many systems use a very simple bipolar phase shift keying (BPSK) approach.

Whenever a carrier is modulated, the result is a spread signal with two “sidebands” above and below the carrier frequency. These sidebands are spread over a range (+ or -) the modulating frequency. The sidebands carry the information and it is common to suppress the transmission of the carrier (and sometimes one of the sidebands). It can be easily seen that the width (spread) of each sideband has been multiplied by the spread ratio.

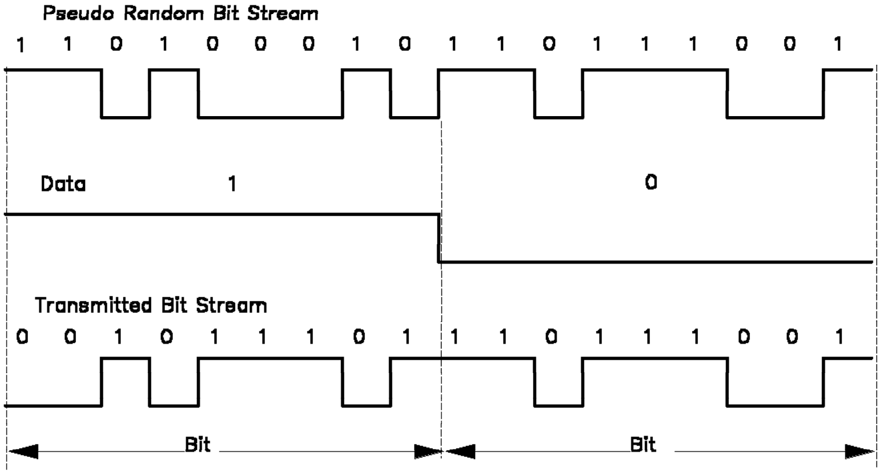

Figure 42. Direct Sequence Spread Spectrum Modulation. A pseudo-random bit stream much faster (here nine times the speed) than the data rate is EORed with the data. The resulting bit stream is then used to modulate a carrier signal. This results in a much broader signal.

At first sight this can be quite difficult to understand. We have spread the spectrum *but in order to do it we have increased the bit rate by exactly the signal spread ratio.* Surely the benefits of spreading the spectrum (such as the capacity gain hypothesized above) are negated by the higher bit rate?

The secret of DSSS is in the way the signal is received. The receiver knows the pseudo-random bit stream (because it has the same random number generator). Incoming signals (after synchronization) are correlated with the known pseudo-random stream. Thus the chip stream performs the function of a known waveform against which we correlate the input. (There are many ways to do this but they are outside the scope of this discussion.)

DSSS has the following characteristics:

Capacity Gain

The capacity gain predicted by the Shannon-Hartly law is achieved. This means that for the same system characteristics, you can use a lower transmit power or a higher data rate (without increasing the transmitter power).

Improved Resistance to Multi-Path Effects

It was mentioned above that the length of a data bit at 1 Mbps is about 300 meters. We can think of this as a notional “data wavelength”. ISI is most difficult to suppress when the delay spread is less than this data wavelength. Because we have introduced “chipping” we can perform equalization at the chip wavelength. This chip wavelength is significantly less than the data wavelength (by the spread ratio).

It turns out that we can remove delayed signals (where the delay is longer than a chip time) very effectively using adaptive equalization. This gives extremely good compensation for ISI.

Rayleigh fading is reduced with DSSS. The location of radio fades within an area is critically dependent on the wavelength. Since the wavelength at one side of the band is different (slightly) from the wavelength at the other side, the location of radio fades is also different. The wider the bandwidth used, the less the problem with fading. This mitigates the Rayleigh fading problem somewhat but does not entirely eliminate it.

Immunity to Narrowband Interference

Because the energy of the data signal is spread over a wide range, the presence of a narrowband signal (even a very strong one) within the wideband range has little effect on the DSSS receiver (all it sees is a small increase in the signal-to-noise ratio).

It is even possible to transmit a DSSS signal “over the top” of a group of narrowband signals (using the same frequency space). This is shown in Figure 43.

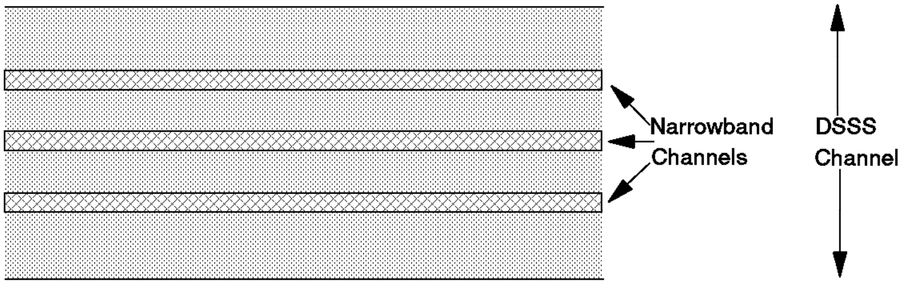

Figure 43. DSSS over Narrowband Channels

The narrowband channels see the DSSS signal as an increase in noise level (which, if kept within reason will have little effect). For metropolitan area cellular radio systems, DSSS has been seriously suggested for use “overlaying” existing analog FDM cellular radio channel space.

Security

Because the signal is generated by a pseudo-random sequence a receiver must know the sequence or it can′t receive the data. Typically such sequences are generated with shift registers with some kind of feedback applied. Unless the receiver knows the key to the random number generator it can′t receive the signal.

The biggest problem with DSSS is synchronizing the receiver to the transmitter pseudo-random sequence. Acquisition of synchronization can take quite a long time. Radio LAN systems are not as sensitive (from a security point of view) as a military communication system and it is feasible to use a short, predictable, bit sequence instead of a pseudo-random one. Security is not as good (to receive it you still need a DSSS receiver but you no longer need the key, but synchronization can be achieved very quickly and the correlation in the receiver doesn′t have to be as precise.

Near-Far Problem

While DSSS is extremely resistant to narrowband interference it is not very resistant to the effects of being swamped by a nearby transmitter on the same band as itself (using the whole bandwidth). A signal from a far-away transmitter can be blanketed out by a nearby transmitter if the difference in signal strength at the receiver is only about 20 dB.

5.2.2 Code Division Multiple Access (CDMA)

The DSSS technique gives rise to a novel way of sharing the bandwidth. Multiple transmitters and receivers are able to use the same frequencies at the same time *without* interfering with each other. This is a by-product of the DSSS technique. The receiver correlates its received signal with a known (only to it) random sequence: all other signals are filtered out.

This is interesting because it is really the same process as FDM. When we receive an ordinary radio station (channels are separated by FDM), we tune in to that station. The tuning process involves adjusting a resonant circuit to the frequency we want to receive. That circuit allows the selected frequency to pass and rejects all other frequencies. What we are actually doing is selecting a sinusoidal wave from among many other sinusoidal waves by selective filtering.

If we consider a DSSS signal as a modulated waveform, when there are many overlapping DSSS signals the filtering process needed to select one of them from among many is exactly the same thing as FDM frequency selection except that the waveforms are not sinusoidal in shape. However, the DSSS “chipping sequences” (pseudo-random number sequences) *must be orthogonal (unrelated)*. Fortunately there are several good simple ways of generating orthogonal pseudo-random sequences.

For this to work, a receiving filter is needed that can discriminate a single DSSS signal from among all the intermixed ones. In principle, you need a filter that can correlate the complex signal with a known chipping sequence (and reject all others). There are several available filtering techniques which will do just this. The usual device used for this filtering process is called a Surface Acoustic Wave (SAW) filter.

CDMA has a number of very important characteristics:

“Statistical” Allocation of Capacity

Any particular DSSS receiver experiences other DSSS signals as noise. This means that you can just go on adding channels until the signal-to-noise ratio gets too great and you start getting bit errors. The effect is like multiplexing packets on a link. You can have many active connections and so long as the total (data traffic) stays below the channel capacity, everything will work well. For example, in a voice system, only about 35% of the time does a channel actually have sound (the rest of the time is gaps and listening to speech in the other direction). If you have a few hundred channels of voice over CDMA what happens is the average power is the channel limit - so you can handle many more voice connections than are possible by FDM or TDM methods.

This also applies to data traffic where the traffic is inherently bursty in nature. However, it has particular application in voice transmission because when the system is overcommitted there is no loss in service, only a degradation in voice quality. Degradation in quality (dropping a few bits) is a serious problem for data but not for voice.

No Guard Time or Guard Bands

In a TDM system when multiple users share the same channel there must be a way to ensure that they don′t transmit at the same time and destroy each other′s signal. Since there is no really accurate way of synchronizing clocks (in the light of propagation delay) a length of time must be allowed between the end of one user′s transmission and the beginning of the next. This is called "Guard Time". At slow data rates it is not too important but as speed gets higher it comes to dominate the system throughput. CDMA, of course, does not require a guard time - stations simply transmit whenever they are ready.

In FDM systems, unused frequency space is allocated between bands because it is impossible to ensure precise control of frequency. These guard bands represent wasted frequency space. Again, in CDMA they are not needed at all.

Smooth Handoff

In the mobile environment perhaps the key problem is "handoff" where one user is passed from one cell to another. In an FDM system this is performed by switching frequency. In CDMA, all you do is pass the key (random sequence generator) to the next cell and you can get a very smooth handoff.

IBM has developed a radio LAN system which will allow users to be fully mobile within the area covered by a number of access points all joined together with an Ethernet connection. The Ethernet wired LAN can also connect a terminal to other fixed LAN devices. When a station is moved it makes a new connection with a new base station. There are many applications in factories (large plant areas) and warehouses which need continuous connection to the system. Any system which aims to provide this requires a method for smooth handoff.

Requirement for Power Control

As mentioned earlier (the near-far problem), DSSS receivers can′t distinguish a signal if its strength is more than about 20 dB below other similar signals. Thus if many transmitters are simultaneously active a transmitter close to the receiver (near) will blanket out a signal from a transmitter which is further away.

The answer to this is controlling the transmit power of all the stations so that they have roughly equal signal strength at the receiver. It should be noted that this implies a "base-station-to-user" topology, since in an any-to-any topology power control cannot solve the problem.

Easier System Management

With FDM and TDM systems users must have frequencies and/or time slots assigned to them through some central administration process. All you need with CDMA is for communicating stations to have the same key.

5.2.3 Frequency Hopping (FH)

In a frequency hopping spread spectrum system, the available bandwidth is divided up into a number of narrowband[4] channels. The transmitter and the receiver "hop" from one channel to another using a predetermined (pseudo-random) hopping sequence. The time spent in each channel is called a "hop". The rate at which hopping is performed is called the "hopping rate". This is illustrated in Figure 44.

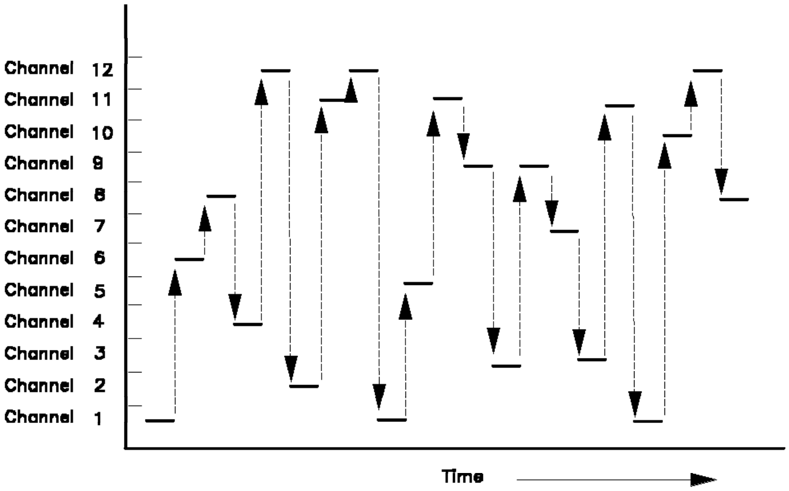

Figure 44. Frequency Hopping

Fast Frequency Hopping

A fast frequency hopping system is one where frequency-hopping takes place faster than the data (bit) rate. FFH demonstrates exactly the capacity gain suggested by the Shannon-Hartly law.

Unfortunately, while FFH systems work well at low data rates they are difficult and expensive to implement at data rates of 1 Mbps and above; thus, while they are theoretically important there are no high-speed (user data rate above 1 Mbps) FFH systems available.

Slow Frequency Hopping

Slow Frequency Hopping is where hopping takes place at a lower rate than the user data (bit) rate. To be considered an SFH system (from a regulatory point of view) hopping must take place at least once every 400 ms and it must statistically cover all of the available channels.

There are many advantages to SFH. However, the capacity gain achieved by other spectrum spreading methods is *not* demonstrated in SFH systems.

When encoding data for transmission over an SFH system the same requirements apply as for regular narrowband transmission. That is, the data stream must contain frequent transitions and should average the same amount of time each symbol state. These characteristics are usually inherent in the data encoding scheme. If the encoded data is not

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[4] Really they have to be "narrower" (than the available frequency band) rather than "narrowband" as such. That is, it is possible (and very reasonable) to frequency hop among a number of DSSS channels.

in this form then it is necessary to randomize (scramble) the data before transmission and to descramble it on reception.

5.2.3.1 CDMA in FH Systems

Sharing the wideband channel between multiple FH systems is possible and can be considered a form of CDMA. With two or more systems hopping over the same bandwidth collisions do occur. When there is a collision data is corrupted and lost.

In an FFH system (say 10-100 hops per bit) corrupted chips will have little effect on user data. However, in an SFH system user data will be lost and higher layer error recoveries will be needed. One way of avoiding the problem in the SFH environment is to arrange the hopping patterns so that each system uses a *different* set of channels so that collisions cannot occur.

5.2.4 DSSS and SFH Systems Compared

There is some discussion in the industry over which system of spread spectrum operation is the most cost effective. The technology is not at all mature yet and researchers are still trying to settle the matter but there are some early indications.

1. In a paper presented to the IEEE, Chen and Wu (1992) report a performance comparison between the two systems. The study uses two kinds of mathematical channel models and studied two speeds of operation. Systems were compared *without* equalization or error correction techniques being applied.

   Their conclusion was that at speeds of 1 Mbps the SFH system was superior to DSSS in almost every respect and significantly so in most. At speeds of 10 Mbps their conclusion is the opposite. That is, DSSS is better, again under simulated conditions.

   As manufacturers bring their systems to market, experience will show the difference.

2. An assessment of manufacturing cost shows that SFH “should” cost less to manufacture and operate at lower power than DSSS. (This all depends on the system design.)

   It should be noted that there are many ways to implement either system. For example, you can have a DSSS system which uses only a very short pseudo-random sequence. This saves significant cost in the adapter but limits the potential for CDMA operation and removes much of the security advantage.

3. An SFH system can easily avoid local sources of strong narrowband interference. All it needs to do is to modify the hopping pattern to avoid the particular frequency band. The ISM bands have many uses and sources of narrowband interference are relatively common. While, in general, a narrowband interferer will not bother DSSS, a strong local interferer (such as a nearby microwave system) will. An SFH system can detect and avoid the frequency bands involved.

4. There is a great variation in the ability of RF-LAN equipment available in the market today to reject spurious interference. The laws of physics set the limit of what can be achieved; the design and engineering of the equipment will determine what is actually achieved. The choice of components involved will have a strong influence on the ultimate outcome. It is possible to build a

DSSS system that is minimally impacted by strong sources of radio frequency interference; it is generally agreed that by its very nature SFH is more immune and secure from this phenomenon.

5.3 Building a Radio LAN System

A radio LAN will consist of a number of stations which can be configured into a LAN in various ways. These configurations or "topologies" are described below:

5.3.1 Topologies

There are many possible radio LAN topologies the main three type are as follows:

- Peer-to-peer
- Base-to-remote
- Base-to-remote with wired LAN

Peer-to-Peer

This is where there is no base station and traffic is directly transmitted from user to user.

This mode of operation is considered essential because many users will want to set up ad hoc connections between small numbers of stations on an as-needed basis. This is shown in Figure 45.

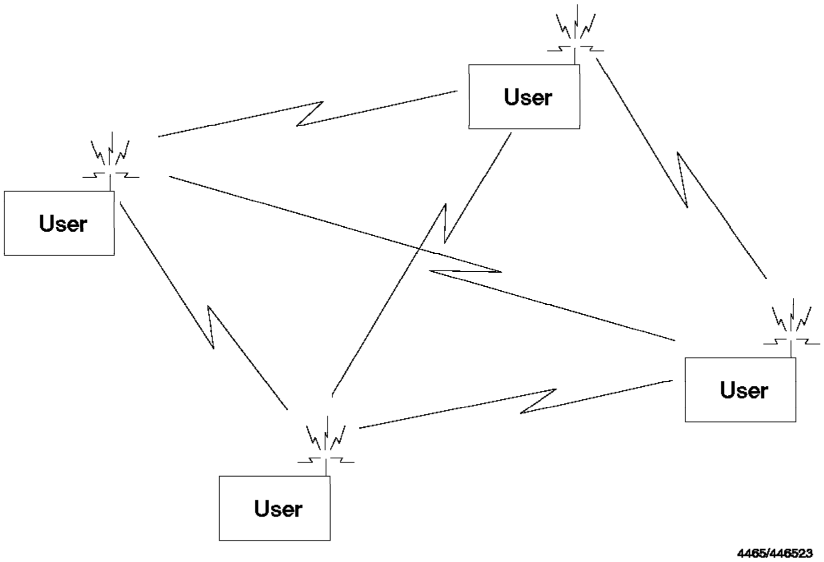

Figure 45. Peer-to-Peer Wireless LAN

LANs such as these might be set up, used, and dispersed again within the space of an hour.

Such a system could use multiple channels (FDM or CDMA) between pairs of users or a single channel with TDM or CSMA operation to share the available capacity between users.

Use of a Base Station

When a base station is used, all transmissions from workstations are routed to or from the base station. This is shown in Figure 46 on page 107.

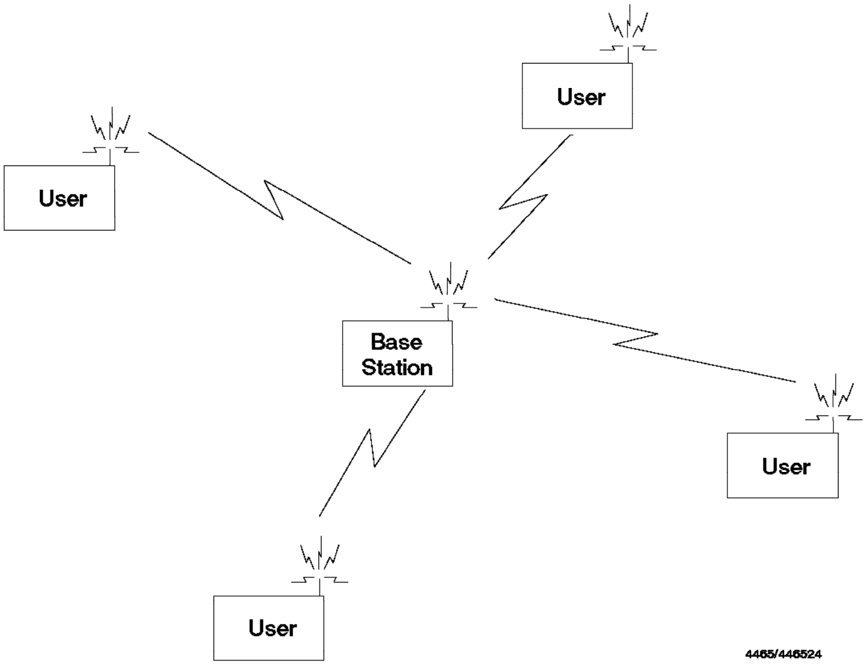

Figure 46. Base-to-Remote Wireless LAN

The base station performs the function of a bridge (optionally) connecting the radio LAN segment to a wired LAN.

Connection to a Wired LAN

Most often a radio LAN will require a connection to a wired LAN. In this case the base station should perform the function of a bridge connecting the radio LAN segment to the wired LAN segment. This is shown in Figure 47 on page 108.

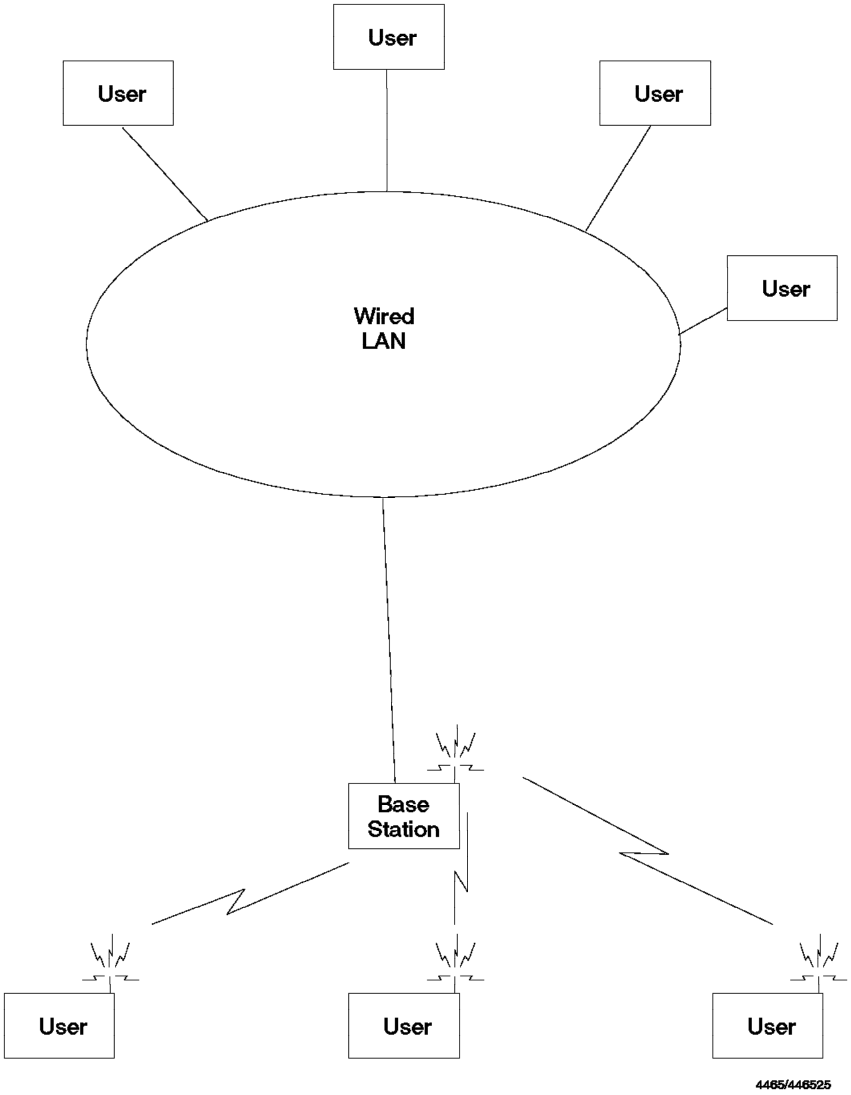

Figure 47. Base-to-Remote with Wired LAN

It is now possible to have multiple base stations connected together by a wired LAN with a mobile user moving around and being passed from one base station to another much like a cellular telephone user. There are many applications in large plant environments where this is very useful. The IBM Entry Level WLAN system is capable of supporting this function.

5.3.1.1 Topologies Compared

In comparing a peer-to-peer (ad hoc) configuration to a base-station configuration the following points should be considered:

1. In a peer-to-peer configuration the maximum size of a LAN is the area which encompasses the radii of the maximum transmission ranges of all the terminals. (This assumes that each terminal is within the transmission range of *all* the other terminals.) Figure 48 on page 109 explains this.

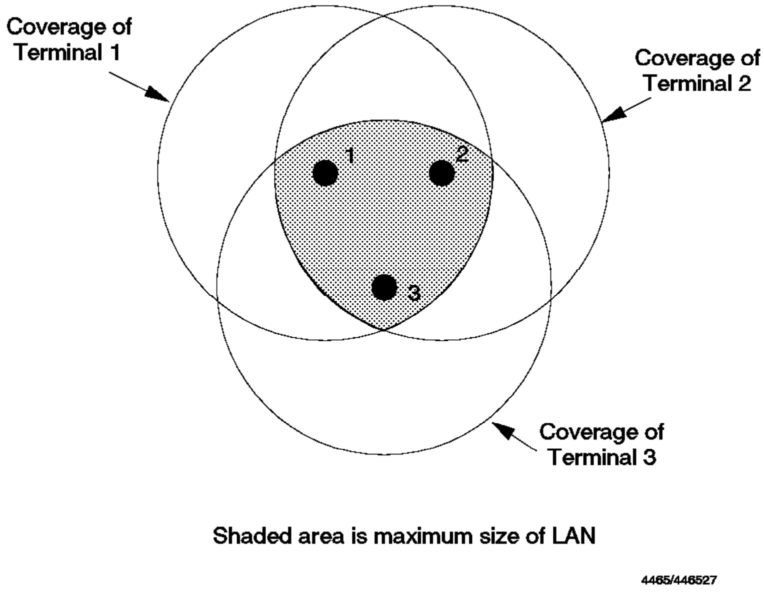

Figure 48. Peer-to-Peer LAN Size

In the base-station approach the maximum size of the LAN is the area of a circle whose *diameter* is equal to the maximum range of the transmission. See Figure 49 to help with understanding this.

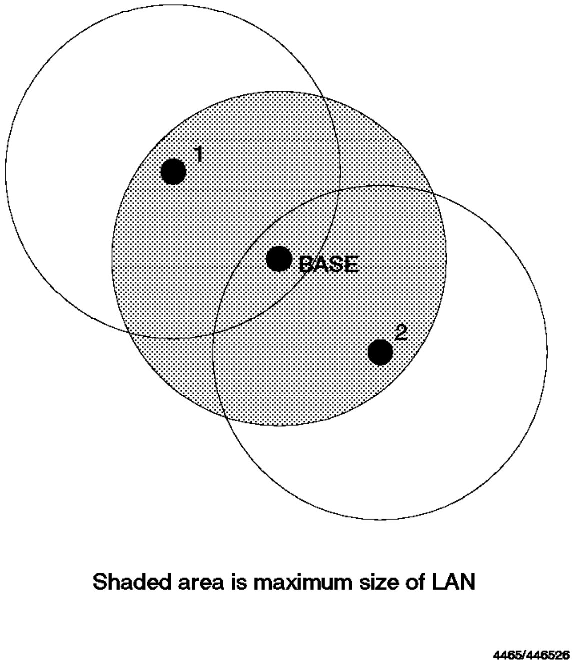

Figure 49. Base-Station LAN Size

Thus, the base-station approach allows a single radio LAN to be geographically much larger than the peer-to-peer approach (all other considerations being equal).

2. If the traffic pattern is genuinely peer-to-peer and evenly distributed, the peer-to-peer approach offers much greater capacity and efficiency. If you go through a base station, the data must be transmitted over the air twice - reducing the system′s capacity by half.

   However, in practical LANs this is almost never the case. Communication is usually from workstation to server or from workstation to gateway. With radio frequencies where there is a bridge to a wired LAN, a significant proportion of the traffic will probably need to go between the radio users and wired LAN users.

   Thus, systems with a base station will usually be a better approach. In some cases it makes sense in this configuration to put the base station and the bridging function in the same machine. Other configurations have a separate base station that can be positioned remotely to provide the best radio coverage.

Table 5. Comparison of Peer-to-Peer versus Base-to-Remote Operation

	Peer-to-Peer	**Base-to-Remote**
Coverage	Unpredictable (Hidden Terminals)	Predictable (Base to Remote)
Area Covered	Transmission Range = Network Diameter	Transmission Range = Network Radius
Access Points (to Network)	Multiple	1 per Cell
Security	Single Level (Network O/S Only)	Multi-Level Base, MAC and Physical Control
Management	Unpredictable (Hidden Terminals)	Predictable (Mgmt function through Base)
Expansion	Limited - Difficult	Multi-Cell Design
Future Upgrades	Manual Distribution	Automated (through Base)

The IBM Wireless LAN product uses a base-to-remote configuration, while the IBM Entry Level Wireless LAN can use either peer-to-peer or base-to-remote. For wireless peer-to-peer LANs, connections can be made between remote workstations without contacting a central base station. Those connections may be out of range of a cell leader station, although within the physical cell area. The station designated as cell-leader controls the frequency hopping pattern (in the case of SFH or FFH) or the psuedo-random code for CDMA systems. This station must be able to contact all stations in the LAN for the system to work successfully.

There may be an obstacle blocking the transmission path to the cell leader, even though the remote stations can communicate successfully. This makes management of peer-to-peer WLANs difficult since access control cannot be effectively monitored from a central control point.

5.4 Compression / Throughput Issues

The theoretical maximum throughput for a given radio frequency, design implementation and product, and the effective data transmission rate for the same seldom coincide. This is because throughput is a function of several factors:

- Signal rate
- Signal/Noise ratio
- Rejection of and immunity to signal interference
- Protocol overhead
- Redundant data transmissions
- Error detection and/or correction codes
- Latency
- Environmental factors
- Compression techniques

The signaling rate (for example, 2 Mbps for direct-sequence spread spectrum in the ISM bands) is often mistakenly referred to as the data transmission rate. The signaling rate is the clock frequency of the radio itself. The IBM Wireless LAN frequency-hopping spread spectrum system signals at 1 Mbps. In conjunction with an IBM-unique hardware data compression feature, it can achieve higher effective data throughput rates than DSSS systems that proclaim their higher clock signaling rate as equivalent to increased throughput.

5.5 Security Aspects

One of the main concerns often expressed when installing wireless LANs is the question of data security. These concerns are valid and may be addressed as follows:

There are three types of security risks:

- Attack by casual listener
- Attack by professional hacker
- Attack by insiders

5.5.1 Attack by Casual Listener

A casual listener might be someone in a neighboring building using the same type of equipment. Each WLAN system must be capable of identifying those workstations authorized to participate in that LAN, and deny unauthorized workstations to access the WLAN. It should not be possible for unauthorized workstations to overhear and interpret data traffic on a WLAN.

5.5.2 Attack by Professional Hacker

A *passive* attack could come from someone receiving the WLAN radio signal and using sophisticated tools to try to interpret the data content of the radio signal heard. An *active* attack could originate within transmission range of the WLAN but outside the facility. Eavesdropping by attempting to insert an unauthorized wireless workstation into an existing WLAN is one example.

5.5.3 Attack by Insiders

Insider attacks are attempts by employees, who are authorized for limited data access, to try to access data to which they are not authorized. One form of this is attempting to log on to a server or a WLAN in a different department.

One method successfully used to combat both casual listener and professional hacker attacks is data encryption. Data is passed to software or hardware encryption systems before transmission. Encrypting data online using software algorithms during transmission can significantly reduce the effective data capacity of a link since processing resources are spent on behalf of the encryption program. Using a hardware chip to encrypt data on the WLAN adapter is more efficient since the workstation processor is not being put under any load.

Wireless station registration is a method used to prevent unauthorized workstations from connecting to a WLAN. Each WLAN workstation is registered by a unique address or name to the base station. Only registered workstations are permitted to log on to the WLAN base station. This method is used to combat many different kinds of attacks.

A third method to prevent an unauthorized access to a wireless LAN is that of authentication. Authentication can be a simple coded response from a workstation to a query from the base station or access point. Other methods could include sophisticated dynamic profiles of individual users such as keyboard techniques and response times. Authentication need not be a single process at registration time but may be a continuous check on both workstation and user.

Both spread spectrum techniques (DSSS and FHSS) make it extremely difficult for unauthorized stations to determine the content of WLAN traffic. DSSS signal power levels are frequently below the general level of background noise, which makes them very difficult to detect. FHSS signals change frequency so often that it is almost impossible for a receiver to follow the sequence if the hopping pattern is not known. Spread spectrum is one of the preferred techniques used by military organizations for these reasons. Military versions are credited with key roles in many battlefield successes by providing secure communication channels.

Additional security is often provided by the Network Operating System (NOS) used in the LAN. Usually, the LAN server requires user identification and passwords during the logon procedure. This prevents unauthorized users, who may have access to an authorized workstation from accessing sensitive data.

5.6 Scalability

The ability to expand an installed WLAN network to meet business needs is a vital factor in designing a WLAN system. When the number of workstations connected to a base-station approaches the maximum for that cell, another base station can be installed to reduce the load on the first base station. Base stations are typically connected to an Ethernet or token-ring backbone network. When multiple overlapping cells are installed, interference can affect performance. DSSS cells can be sensitive to interference from adjacent cells since all frequencies are used simultaneously. FHSS systems tend to be less sensitive to interference since each cell uses a different hopping sequence and a large number of frequencies are used sequentially.

The integration of a WLAN into an existing network is an important factor in providing seamless connectivity. Typically a WLAN is connected to a wired Ethernet or token-ring network by a bridge or router. Many WLANs support protocols commonly used in the wired LAN environment (typically 802.2, NetBIOS, TCP/IP and IPX). This allows existing applications to be used without modification in a wireless environment.

5.7 Interoperability

The current state of standards for WLANs will make direct interoperability between WLAN stations from different manufacturers difficult. Connectivity is generally enabled by joining different base stations together through a backbone Ethernet or token ring. Publication of the final 802.11 standard and implementation in available WLAN products should improve the ability to interconnect WLAN products. However, adherence to 802.11 standards will only ensure interoperability when the same PHY and MAC layer models are used by each product.

5.8 Health Issues

The power levels used in wireless LANs must be low enough not to affect user health. There have been conflicting expert reports on the effects of various levels of frequency spectrum exposure on the human body. Occasionally reports have been misused or quoted out of context, which has led to misunderstanding and public apprehension in some instances. Some high-frequency sources which have come under scrutiny include high tension power lines, radio telephones and cellular telephones. While there have been reports of higher cancer rates among people exposed to high-tension power lines, these reports have been rebutted by other experts who claim that this has not been statistically proven.

There was considerable controversy over the safety of cellular telephones after a consumer in Florida claimed that his wife had died of a brain tumor caused by a cellular phone. He brought a legal suit against the manufacturer of the phone but the lawsuit was dismissed. A recent study sponsored by the National Institutes of Health measured how much radiation a user′s shoulders, head, neck and upper torso absorbed. The study found that the level of radiation absorbed by the body is four to five times lower than levels generally accepted by scientists as safe.

The IEEE is also working on health-related aspects of wireless LANs and has published the IEEE standard C95.1-1991. The findings are that eight hours of exposure to WLANs is equivalent to three seconds of cordless phone operation. The National Cancer Institute is investigating the results of radiation on the human body. As a result of these different investigations, it is possible that the regulations on transmission power may be tightened in some areas.

In the ISM bands, there is a U.S. limitation of 1 W transmitted power when using spread spectrum techniques. The IBM Wireless LAN transmits at less than 100 mW of power in this band. This compares favorably with the 0.6 W transmitted by handheld or 3 W by mobile cellular phones which have been agreed on as safe power levels. Microwave ovens also operate in the 2.4 GHz ISM band and are not seen as a health hazard.

5.9 Wireless LAN Applications

There are many existing applications where a wireless LAN could improve the flexibility of the existing system. There are also new applications which could not exist without the use of a wireless LAN.

5.9.1 Point of Sale (POS) Terminals

In supermarkets and department stores the layout of the display stands is frequently changed to allow new articles to be displayed or to rearrange the position of existing articles. One of the limiting factors is the position of POS terminals. These terminals cannot be easily relocated or new ones installed, as both a data connection (typically a LAN connection to a server) and a power connection are required. The data connection is required as the server may hold the price database and log each POS transaction. These transactions can be fed to a warehouse application to maintain inventories by automatic reordering. Power connections are generally available throughout a building, but the data connections are found only at the locations which have been planned at the initial installation. Laying new cables for an additional POS terminal is expensive and sometimes not possible where cables would be running across the floor or the building structure does not allow it. Installing a WLAN connection between the POS terminal and the server can allow the terminal to be placed anywhere on the shop floor that a power connection is available. For example, during a sale this would enable a temporary POS terminal to be installed very quickly. Temporary POS terminals could also be set up outside the store in the summer selling seasonal goods such as sunglasses.

POS data connections are quite suited to wireless transmission since as each article is scanned, only a short key data record is sent to the server and the item and price information returned is also contained in a short data record. The transaction record then sent to the server is also a small amount of data. Bandwidth considerations are not a problem as data rates are low. The reliability of the wireless connection is of great importance so that customers are not kept waiting and that they have confidence that their receipts are correct.

5.9.2 Replacement for Wired LAN

Another major application for WLANs is as an alternative to traditional wired LANs. There may be a number of reasons why a traditional wired LAN is unsuitable or too costly for installation in a particular building. The building could be old and of historic significance, and the occupier may not be allowed to modify the interior, cut holes, or install cable ducting. The building could also have thick solid walls and interior partitions which would make it difficult to install LAN cables. Some older buildings may also have materials such as asbestos used in their construction, where it could pose a health hazard to make holes to install LAN cables.

Even for newer buildings, there may be a cost saving by installing a wireless LAN for new LAN installations.

5.9.3 Healthcare

Wireless LANS will find many applications in healthcare, especially in the hospital environment. Medical teams will be able to call up medical data on each patient as they visit them on their daily rounds using a mobile workstation. Nursing staff can check the required medication for each patient at the bedside and update records of medication given and records of temperature, blood pressure and other routinely measured parameters. In emergency situations, a mobile workstation connected via wireless LAN could provide instant access to patient history and provide a link to senior medical staff for remote diagnosis.

The advent of wireless LANS will make a significant impact on the quality and immediacy of patient care in the future.

5.9.4 Other Applications

Many new applications in different industries will be developed using WLAN technology. These will include:

- Mobile airport check-in desks
- Warehouse stock control
- Process control on production lines
- Ad hoc networks for conferences
- Education system access for students
- Flexible office accommodation

5.10 Wireless Standard IEEE 802.11

IEEE LAN standards have enjoyed wide acceptance in industry. This is because publication of standards such as the IEEE 802.2 standard for MAC-layer protocols, the IEEE 802.3 Ethernet standard and the IEEE 802.5 Token-Ring standard have ensured compatibility between equipment manufactured by many different companies. Customer acceptance of these standards was based on the ability to build networks of equipment bought from competing companies, and competition has worked to push prices down. Industry acceptance of these standards is in part based on the fact that the committees proposing these standards are made up of representatives of many of the companies developing or planning products for the LAN market.

Many users are worried about investing in systems when no accepted standards are available to ensure interoperability between different manufacturers. Towards this end, the IEEE 802.11 WLAN committee has been trying to create a unified Media Access Control (MAC) standard that will enable interoperability between WLAN equipment from various vendors. The MAC protocol implements the lower half of Layer 2 of the OSI (Open Systems Interconnection) reference model that governs access to the transmission media. Several different physical (PHY) layer types will also be defined within this proposal, one for every technology used (for example, IR or ISM-RF). Since 1991 the 802.11 committee has been working on a set of standards, but so far no agreement has been finalized.

The main purpose of the 802.11 standard is to provide a minimum subset of standards to ensure that WLANs from different manufacturers can interoperate. However, it may take some time before all details of the emerging IEEE 802.11

standard are agreed upon, and until that time there will be a number of different access protocols being used in products on the market. It has proven difficult to find agreement since the radio environment is quite different from the traditional LAN environment in the areas of reliability and security. The move to smaller portable equipment has made it necessary for the 802.11 committee to define standards for roaming and power management in order to conserve battery power.

IBM has launched wireless products prior to the final agreement on the 802.11 standard because of delays in finalizing this standard. The IEEE 802.11 subcommittee is working on a draft standard scheduled for approval by the Executive Committee by year-end 1995. The IBM Wireless LAN product complies with ETSI standard 300-328.

5.10.1 Description

The declared purpose of the IEEE 802.11 committee, as stated in a draft document, is to "develop a medium access control (MAC) and Physical Layer (PHY) specification for wireless connectivity for fixed, portable and moving stations". Specifically, the 802.11 standards will:

- Describe the functions and services required by an 802.11 compliant device to operate within ad hoc and infrastructure networks as well as aspects of station mobility (transition) within those networks.
- Describe the medium access (MAC) procedures to support asynchronous and time-bounded MAC service data unit (MSDU) delivery services.
- Support the operation of an 802.11 compliant device within a wireless LAN which may coexist with multiple overlapping wireless LANs.
- Describe the requirements and services necessary to provide security, privacy and authentication of 802.11 compliant devices.

The IEEE 802.11 proposal describes the physical level and the MAC level; see Figure 50.

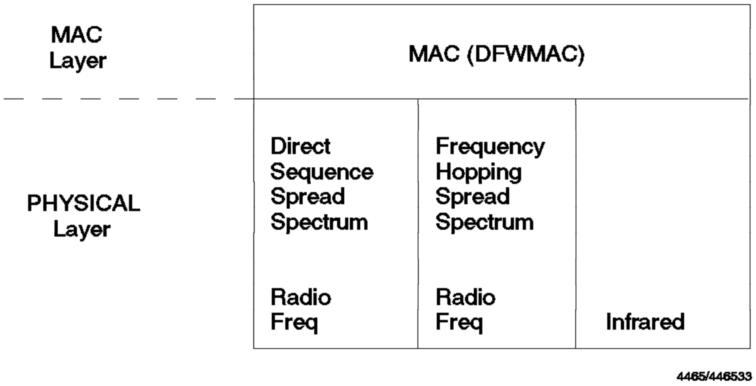

Figure 50. IEEE 802.11 Layers Reference Model

The IEEE 802.11 standard will support several different physical layer standards, so users need to be aware that the statement that a product conforms to the IEEE 802.11 standard does not necessarily make it compatible with similar products from other manufacturers.

Initial work in the 802.11 committee was focussed on the 2.4 GHz ISM frequency band which is available in most countries. Since the MAC layer is being defined so that it is independent of the PHY layer, other frequency bands can be added when available without changing the MAC layer.

5.10.2 Physical Layer (PHY)

There are three distinct working groups within the IEEE 802.11 committee working towards three distinct PHY environments:

- Direct Sequence Spread Spectrum (DSSS) group
- Frequency Hopping Spread Spectrum (FHSS) group
- Infrared (IR) group

5.10.2.1 Direct Sequence Spread Spectrum

This is one of the two radio frequency physical layers defined in the 802.11 model. Two data rates have been defined:

- 1 Mbps
- 2 Mbps

For 1 Mbps the modulation method is Differential Binary Shift Keying (BSK); for 2 Mbps Differential Quaternary Phase Shift Keying (QPSK) is specified. In addition to data rate, modulation technique, and channel definitions, the 802.11 DS physical layer definitions specify transmitter turn-on and turn-off times, receiver sensitivity, training sequence, and synchronization.

5.10.2.2 Frequency Hopping

Two data rates are also defined for this physical layer:

- 1 Mbps
- 2 Mbps

The modulation schemes defined are two-level Gaussian Frequency Shift Keying (GFSK) for 1 Mbps and four-level GFSK for 2 Mbps.

Transmitter turn-on and turn-off times, receiver sensitivity and hopping frequencies are also defined. Receiver training and synchronization have not been defined at the time of writing. Frequency-hopping is controlled by a MAC function, not in the PHY layer.

5.10.2.3 Infrared Physical Layer

In this physical layer, there are also two different definitions:

- Baseband modulation
- Carrier modulation

The baseband modulation definition specifies 1 Mbps and 2 Mbps transmission rates. The modulation methods are 16 or 4 Pulse Position Modulation (PPM) and the light frequency specified is from 850 nm to 950 nm with a spectrum of DC to 5 MHz.

The carrier modulation definition specifies data rates of 4 Mbps and 10 Mbps within a spectrum of 15 MHz to 30 MHz. The modulation method has not been defined at the time of writing.

5.10.3 MAC Layer (MAC)

The definitions in this 802.11 layer are described by the Distributed Foundation Wireless Media Access Control (DFWMAC). The DFWMAC describes how wireless stations communicate and includes definitions of collision detection, frame size, frame priority and access control. It is independent of the underlying PHY specifications and should enable communications programs to be written independently of the PHY layer.

5.11 Other WLAN Standards

The European Telecommunication Standards Institute (ETSI) Technical Committee RES-2 is also working on WLAN standards complementary to the work of the IEEE. This committee is also working on a HIPERLAN (High Performance Radio LAN) standard to provide 10/20 Mbps data rates to workstations. One group within this committee will define the PHY and MAC functions while a second is working on the overall architecture.

ETSI has developed a minimum set of operating standards rather than interoperability definitions. The ETSI standard, ETS 300 328, defines the requirements and technical characteristics of wideband data systems operating in the 2.4 GHz ISM band using spread spectrum techniques. It is similar to the Part 15 rules of the FCC, is less stringent in the frequency spreading requirements and specifies a maximum power of 100 mW compared to 1 W specified by the FCC.

In Japan, there are two organizations working on wireless LAN:

- The Research and Development Center for Radio Systems (RCR)
- The Telecommunication Technology Council (TTC)

The RCR concentrates on the PHY standards. At 2.4 GHz a data rate of 10 Mbps within a 20 meter range is under discussion, while at 19 GHz the integration of video, voice and data within a 15-meter range is being looked at. The TTC concentrates on connections between WLANs and wired networks such as LANs, ISDN and PSTN.

Regulations may make WLAN operation impossible in some environments. For example, many European countries do not allow radio signals to be transmitted across public areas. In this case, two buildings may not be connected across a public street. A solution may be to use an infrared beam or use a PTT connection.

5.12 Radio LAN Systems

Two aspects of a radio LAN communication system have been described above: the Physical Transmission and the MAC. Of course, to build a usable system you need much more than this:

1. A management scheme is needed to control which stations are allowed to become members of a particular LAN.
2. Network management is needed so that errors can be found and fixed quickly and so that time people spend in administrative tasks is minimized.
3. If the users are to be mobile, then you need to build a cellular structure. Within each cell there is a base station (access point) and the base stations

are interconnected by a wired LAN infrastructure (distribution system). The objective is to allow continuous and transparent operation for users who are moving around. This means that a user must be able to continue a session (connection) to a server *without* interruption as the user moves between access points.

To do this the access points must communicate with each other and there must be some method to determine when handoff is to occur, to which cell the user is to be handed and to synchronize the necessary system changes in order to do it smoothly.

5.13 Summary

In this chapter we have seen some of the problems associated with designing and setting up an indoor radio LAN. Many of the problems are common to other radio systems, but the indoor environment produces some additional factors that need to be considered. The main consideration is to determine how a number of WLAN stations in a small space are able to communicate to a base station and each other, without causing interference to other stations in the network. This is achieved using spread spectrum techniques which fall into on or other of two categories:

- Direct sequence spread spectrum (CDMA)
- Slow or fast frequency hopping

Both of these techniques allow many transmissions to occur simultaneously in a wide bandwidth channel without causing interference.

The chapter also discusses the various topologies of WLANs and compares them for performance and coverage. The topologies covered are:

- Peer-to-peer
- Base-to-remote
- Base station to wired LAN

The final section covers some other aspects of WLANs including, health, security, applications and standards.

Chapter 6. Wireless Communication in WANS

There are many different types of wireless wide area networks, both public and private. This chapter discusses some of the characteristics of these networks which are common for both voice and data applications. The use of data communications on voice networks is compared with packet-switched data networks and the interconnectivity of the major networks is discussed.

6.1 Characteristics of the Wireless Wide Area Network

Many of the characteristics of a wireless LAN have their equivalents in the wireless WAN environment. There are additional problems associated with wide area communications, and many of these problems can result from a combination of some of the following:

- Use of data communications on networks designed for voice
- Use of public access networks
- Effects of data transmission to/from moving vehicles
- Environmental considerations
- External interference
- Security

6.1.1 Multi-Path Effects

In the same manner as a wireless LAN, wireless WANs can suffer from a number of problems associated with multi-path effects. It is a common experience for users of cellular phones to find that they cannot make or receive a call from a particular location; the received signal strength indicator (RSSI) on their phone shows that they are not in communication with a base station. With modern cellular phone coverage, this is unlikely to be caused by poor cellular planning by the network operator, but much more likely to be either of the following:

- Rayleigh Fading
- Radio shadow

6.1.1.1 Rayleigh Fading

Rayleigh fading is described in 5.1.1.1, “Multi-Path Effects” on page 93, and is similar for wide area networks. The wavelength of radio frequency signals at 900 MHz is one third of a meter; changing one′s location by this distance could make the difference between being able to make a cellular phone call or being in a “blackspot” or “hole”.

Most cellular phones have some kind of signal strength meter, properly known as a Received Signal Strength Indicator (RSSI). The indicator shows the relative signal strength that the mobile phone is receiving from the control channel of the base station on which it has registered. The indicator is not normally calibrated and in its usual form consists of a number of discrete levels shown on the phone display. It is normal to check the RSSI before attempting to make a call, to ensure that there is sufficient signal strength in the area for good communications. However, the attempt to make a call may fail due to insufficient signal strength, even though the RSSI may be showing a good signal. There may be two reasons for this:

1. The RSSI is showing the signal strength received from the base station, but the mobile phone will be transmitting on a channel that is 45 MHz offset from this channel. This difference in frequency may be sufficient to put the phone′s transmitter in a blackspot due to Rayleigh fading.
2. The call setup is normally performed on a control channel. As soon as the call is connected, the base station will instruct the phone to switch to a working channel. This will be a different frequency and may cause the phone to be in a blackspot. (NMT systems use a different method of channel allocation and this may not apply.)

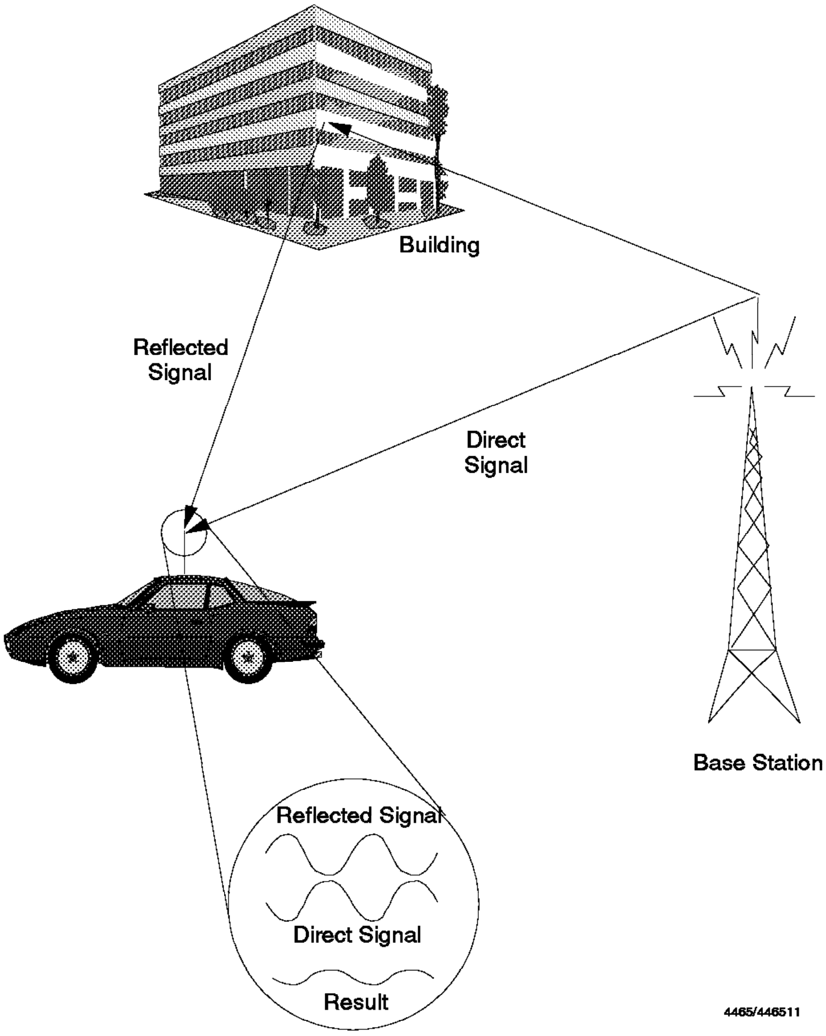

Figure 51. Rayleigh Fading

When the mobile radio terminal is in a moving vehicle, Rayleigh fading can be experienced as a regular fluctuation in signal strength dependent on the vehicle speed. In cases where the mobile terminal is stationary, but is close to moving vehicles such as trucks or aircraft, then a similar effect will be experienced caused, in this case, by a moving reflected signal.

6.1.1.2 Inter-Symbol Interference (ISI)

Inter-symbol interference in wireless wide area networks can have similar effects to that in WLANs, but for slightly different reasons. See 5.1.1.1, “Multi-Path Effects” on page 93 for more information. In general, WWAN data rates are lower, especially when using networks designed for voice. Consequently, the duration of a single bit of data will be longer. However, due to the longer distances between base stations, reflecting objects and mobile terminals, (kilometers rather than meters), the delay spread can be much longer and the opportunity for ISI to occur is still significant.

6.1.2 Radio Shadow

Another common problem, especially in cities and hilly countryside is known as “radio shadow” where a receiving station is shielded from a direct “line of sight” view of the radio base station. In practice this problem is often minimized in cities because reflected signals can find their way to the antenna, even though the direct signal is blocked. Hilly country may be difficult as signals are not reflected in the same way.

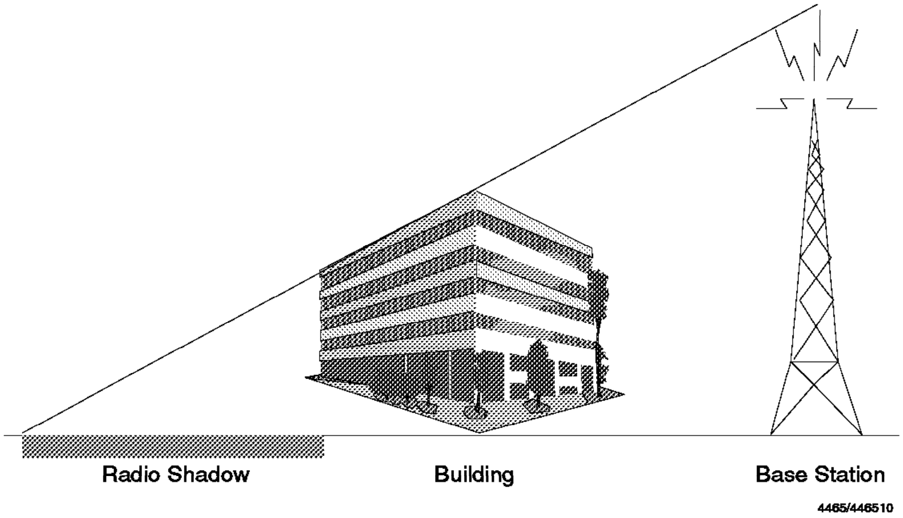

Figure 52. Radio Shadow

6.1.3 Adaptive Equalization

Adaptive equalization is a method of pre-processing a signal based on the characteristics of the transmission medium. For wireline communications the characteristics of the wired connection can be established at the start of communications by sending a pre-determined sequence of information that the receiving end already knows. The receiving end can then establish how the signal must be changed before it is transmitted in order for it to be received as recognizable information. This information is communicated to the transmitting end at a low data rate, to avoid corruption. The process is repeated in the opposite direction so that both stations have knowledge of the characteristics of the connection. This system works very well in wired connections and allows for data rates much faster than could be expected using low bandwidth voice grade circuits. Similar techniques can be used for radio communication, but it must be remembered that the characteristics of the radio link will be constantly changing, and the equalization must be continually changed to match the conditions.

6.1.4 Moving Vehicles

Cellular phones work well in vehicles moving at relatively high speeds and hands-free operation allows some voice systems to be used with safety.

Note: Most countries now have legislation limiting the use of cellular phones by drivers of moving vehicles, unless they have hands-free operation.

Data applications present additional problems. It is not easy for the driver of a vehicle to operate a data communications device while it is moving, except for simple messaging, such as taxi applications. Even with hands-free voice recognition a data device would probably provide too much distraction to enable safe operation. Data communications will therefore be limited to *passengers* in moving vehicles. The effect of Rayleigh fading in moving vehicles has already been discussed in 6.1.1.1, "Rayleigh Fading" on page 121.

An additional problem will be a highly fluctuating inter-symbol interference effect. This will result from continuously changing reflected signals from other vehicles.

Data communication can be effected by Doppler Shift. This is the effect that can be heard when a motor vehicle sounds its horn when passing a fixed observer. The sound of the horn changes in pitch to a lower frequency as the vehicle passes. This is because the source of the sound has moved towards the observer as each new cycle of the sound wave is generated. This has the effect of increasing the frequency of the sound as far as the observer is concerned. The opposite effect is apparent when the vehicle has moved past the observer. The frequency that is heard is now lower than the true frequency. The same effect can occur with radio waves. This is used by many police forces to measure the speed of vehicles. A microwave signal is transmitted in a tight beam at a vehicle moving towards the transmitter. The signal is reflected from the vehicle and received in the same device. The received signal will be at a higher frequency than the one that was transmitted, due to Doppler Shift. The speed of the vehicle can be calculated from this frequency difference. The police speed detectors are generally known as RADAR (Radio Detection And Ranging) devices.

It can be seen that a radio data communications system may suffer from errors if the mobile station is moving at high speed towards or away from a fixed base station.

6.1.5 Security

Whenever information is sent over a wide area, by radio frequency transmission or even over wireline, it must be remembered that there is always some security exposure if the information is of a sensitive nature. Much uninformed opinion has been aired on the subject of the lack of security in cellular phone communications, and it is true that it is very easy to eavesdrop. However, as discussed in 2.3, "Digital Cellular Telephony" on page 37, it would take a considerable amount of sophisticated technology in the hands of a professional "hacker" to target specific individuals and sources of information. It must be remembered that wired links to cellular and mobile data networks are not secure, and that any encryption that is provided by the network operator (such as GSM), will only be used on the air link and not on the wired connections to and through the network. Information on techniques for providing secure communications is provided in 8.7, "Security" on page 147.

6.1.6 Interference

In a wide area network environment there is more opportunity for radio signals to be interfered with or in the worst case jammed altogether. Most countries have legislation to control the emission of unwanted radio frequency signals and electrical products have to pass strict tests to ensure that they do not cause interference with radio communications. These tests are normally performed on examples of the initial production of products; changes in the manufacturing process, components used, or aging of the product may allow interfering radio frequency emissions to be generated after the product design has been approved. Normally, national agencies which are responsible for policing radio frequency interference are not pro-active in seeking out sources of interference. They rely on persons experiencing interference with radio communications to report the matter, and will investigate and, if necessary, prosecute the offenders. In most cases it is the *user* of the equipment who is legally responsible, rather than the manufacturer or supplier.

It would normally be the network operator who would take action by contacting the regulatory authority and working with them to track down the source of any interference and ensure that the problem is resolved.

6.1.7 Sharing the Bandwidth

The most common method of sharing bandwidth is Frequency Division Multiple Access (FDMA). This is used in analog cellular systems and in its most simple form consists of a narrow band radio frequency that is used exclusively by a pair of communicating stations. Other pairs of stations will communicate using adjacent channels, normally separated by a small “guard band”. Refer to 3.2.1, “Frequency Division Multiplexing (FDM)” on page 72 for more information. This can be a very inefficient use of radio spectrum as the number of users is restricted to the number of radio channels available.

A much more efficient way of sharing bandwidth is to use Time Division Multiplexing. In its most simple form it consists of a number of users taking turns to use a single radio channel “on demand”. An example of this is a Private Mobile Radio (PMR) installation which has a single channel which is shared by several users. A user will listen to see if the channel is being used, and then if clear, press the “push to talk” button on his handset. The radio channel is then used exclusively by a single user until the conversation is complete. More sophisticated systems have automatic allocation of use of the channel. When a mobile user activates the “push to talk” button, the radio transmits a request to the base station. The base station creates a queue of mobiles wishing to use the radio channel and as soon as it is free, the base station will open the channel to another user. Modern digital cellular phone systems use Time Division Multiple Access (TDMA), whereby a number of phones can use the same radio channel at the same time. Time on the channel is divided into frames (periods of time) which are further subdivided into time slots or burst periods. Each user is allocated a time slot in each frame and the communication is broken up into short bursts of information. For voice communication the slots or bursts are re-assembled into what appears to be a continuous transmission. TDMA is discussed in more detail in 3.2.2, “Time Division Multiplexing (TDM)” on page 73.

A version of TDMA is packetization, which is used for data communication. In this method, the radio channel is again broken up into time slots, but each burst of data contains information concerning its destination. There is no synchronized regular time at which a station transmits and the data packet may take different routes through the network at different times. This may cause packets to arrive at their destination out of sequence and the network must be able to re-assemble them into a meaningful data stream. Mobile Data Networks such as ARDIS and RAM use packetization. See 3.2.3, “Packetization” on page 74 for further information.

Code Division Multiple Access (CDMA) technology is used by Qualcomm in the US and a service has started in Korea. Apart from these two, there are no other CDMA networks known to the author at the time of writing. 2.3.3, “US Digital Cellular (Qualcomm)” on page 47 and 5.2, “Spread Spectrum and Code Division Multiple Access (CDMA)” on page 97 for further information.

6.2 Differences in Packet and Circuit Switched Networks

There has been much discussion concerning the relative merits of packet-switched wireless data network architectures such as Mobitex and RD-LAP and using circuit-switched networks such as AMPS and GSM for the transmission of data. Both types of networks have significant advantages for certain kinds of applications; other factors such as coverage, cost and availability can also influence choice. It is not our intention to discuss the merits of network operators in these pages, but rather to relate technology to applications.

One key factor in determining whether to use packet-switched or circuit-switched networks is the need for voice communications. Although voice support was available on the early VHF Mobitex system in Sweden, it is no longer used, and any requirement to have voice communications in the same terminal device as data communications will require the use of circuit-switched operation. The only exception to this is CDPD where the data service is packetized and overlayed on a circuit-switched network.

If the data application is required to be interactive in real time, then it is more likely that a circuit-switched network will be the best suited. Network delays on packet-switched networks can be of the order of several seconds and users, and sometimes software applications cannot tolerate this.

If the application involves sending large amounts of data across the link (file transfer), again a circuit switched connection is best. There are two reasons for this. First, a packet-switched network will take much longer for the transfer to complete. Secondly, packet-switched networks normally have tariffs which charge the user by the amount of data sent and not by connection time as in circuit-switched networks. The exception to this may be GSM where some operators may offer a data-only tariff which is charged by the byte.

Packet-switched networks operate in what is known as “disconnected mode”, which means that the network may hold on to the packets of data and send them to the mobile terminal at some later time. There may be a number of reasons for doing this, but one of the most common is when a mobile terminal is not in communication with the radio network. In this case the network will hold the data in a store and forward location until the mobile terminal is recognized as being in radio contact again. This can occur either when the host system is sending information to the mobile. If the data transfer is from mobile to host, then the mobile terminal will retain the data until it is again in contact with the network and then transmit the information without any intervention on the part of the user. This is an advantage of packet-switched networks, provided that the user does not require a “conversation” with the host system.

The same disconnected operation can prove advantageous when communication is required with the host system for short periods of time but many times during a working day. To establish a circuit-switched connection can take several tens of seconds while the call is routed by the network from the mobile terminal through the wireless network and into and through a Public Switched Telephone Network (PSTN). A second delay is incurred once the call to the host system has been established and a logon process is performed to verify and authenticate the access. With a packet wireless data access, once an initial call and authentication has been established, the mobile terminal can communicate with the host application without any call setup or logon delay. This, of course, assumes that a permanent connection exists from the host system to the wireless packet data network, or that the connection is made via a land-based PSS network. The host application will still have to provide some authentication to ensure that the mobile terminal currently accessed is the same as that which initially logged on to the system. This can be made transparent to the user depending on the level of security required.

A further advantage of packet wireless data networks is that they can use higher powered mobile radio transmitters to improve communications ability especially in buildings. This is because the transmitter is only turned on for a very short period of time when a packet of data is actually being sent. Continuous high power transmission would quickly drain the battery of a mobile data terminal, but short bursts of transmission allow for battery life that is comparable or better than an equivalent circuit switched device.

It can be seen from the above that some applications fit very neatly into either circuit-switched or packet data wireless network environments. A field service application which consists of call dispatch, call reporting and messaging would probably be best served by using a packet data network connection. Applications for field sales personnel, may be better suited to circuit-switched networks when large amounts of data need to be transferred. E-mail applications can fit in either network type, but may be better suited to a particular network depending on how they are used.

There are no hard and fast rules and each application should be examined in detail before a decision is made. For example, a field service application may require an interactive online database search to match symptoms to fixes. This may be better suited to a circuit-switched environment.

Many existing applications may need to be transferred to the mobile environment. If the application was designed to be accessed via PSTN from a fixed telephone site, then it may be difficult to use a wireless packet data network. It would be much easier to use a circuit-switched cellular access as this behaves in a very similar way to PSTN. The manufacturers of wireless packet data radio modems have addressed this problem by providing an emulation mode for their devices. This allows an existing application to use the same commands to the wireless modem as they would to a PSTN modem. However, the command structure is limited and does not allow the application to control and receive wireless network information in the same way as it could in “native” mode. This facility is useful to allow demonstrations and pilots for mobile data, but the application should really be rewritten to take advantage of the wireless environment.

Today′s fixed wire communications links operate at very high speeds; even ordinary PSTN dial up connections can have data rates up to 28.8 Kbps and higher using data compression. Consequently, applications designed for fixed wire communications do not have to restrict the amount of data sent to and from a mobile terminal. For example, a 3270 application will send a complete new screen of data whenever even a single character changes. The protocols that support these applications will also exchange large amounts of data in “handshaking” routines. When moving these applications into a wireless environment, these kinds of data transfers cause an unacceptable overhead in both time, cost and usability.

There are various techniques for overcoming these problems. The best solution is to rewrite the application to take into account the special requirements of wireless communications for a specific network type. The opportunity also exists to re-engineer the process behind the application to ensure that full use is made of the advantages that mobile wireless communications can bring. It is often very difficult and expensive to do this in reality, and it is more usual to try and tailor an existing application to fit. One way of minimizing the amount of communications traffic is to use a special software package that resides between the host application and the terminal application. The software is split into a host part and a mobile part, and is designed to manage the data transfer between the two. In the example of the 3270 screen transfer quoted above, the screen management software will only send changed data to the mobile terminal. In addition, frequently used screens will be held in the mobile terminal, and again, only changed information will be sent over the wireless link. The data to be sent over the wireless network can be translated into the unique protocols required and full advantage taken of the network management capabilities built in. The software can also provide special data compression and error handling to ensure that the wireless link does not require any rewriting of the application.

Another solution is to use a mobile gateway which provides a common interface for many applications wishing to communicate over a wireless network. The functions available are very similar to those described above, but are contained in a separate gateway server computer, with matching software for the mobile terminals. This is a much more flexible solution which allows multiple host computers to use the same gateway, and even attachment to several different wireless network types. A mobile terminal on one wireless network can even communicate with another mobile terminal on a completely different type of wireless network. The gateway can be installed on the same premises as the host computer, provided by a value-added network service, or provided by the wireless network operator. IBM has developed such a gateway product and it can support most of the major wireless network types.

6.3 Interconnectivity of Wireless WANs

6.3.1 Enterprise Connectivity

Initially, the only connection to analog cellular networks was via the PSTN, and the cellular phone networks were looked upon as an extension to the PSTN, even though they were operated by different companies. This is still the case in many countries, but as deregulation of telecommunications increases, cellular networks can be connected directly to other networks without using the PSTN. The first move in this direction was by connecting a cellular mobile switching center (MSC) to an enterprise private internal telephone network using a private set of leased lines. This allowed mobile phone users in that enterprise to make calls to their offices without using the PSTN and only having to pay for the cellular network use. The mobile phones thus appeared to the user to be an extension of the enterprise internal phone network.

Note: Charges for cellular phone calls are normally made up from two separate costs: the cost of using the cellular network, and the cost of connecting from the cellular network to the final destination using the PSTN.

A further development of this concept is being used in Europe with DCS1800 PCN phones. The enterprise internal network is a closed user group within the national PCN network. All telephone extensions are mobile PCN phones that employees can carry with them. The enterprise offices have their own cellular base station and telephone links between geographically separated offices are made using the PCN operators Mobile Land Network. The enterprise pays a fixed charge to use the PCN network for internal calls, but when a mobile worker takes his phone outside the office environment, normal tariffs will apply, except that no PSTN charge will be incurred when calling his office. The advantages of this are obvious:

- No wiring for telephones required
- Employees always contactable
- Minimal directory updating - employees keep the same phone number
- No reconfiguration required for office moves
- Low cost for mobile workers
- No special arrangements needed for employees working at home

6.3.2 Data Connectivity

When data was first sent over analog cellular networks, standard PSTN modems were used. It was soon realized that although the system worked, it was quite unreliable and the sessions established between the modems were often lost due to poor signal level, breaks in transmission and interference. The problems were mainly due to the fact that PSTN modems were designed to overcome problems that were common on wired networks but could not cope with the different conditions of a cellular network. Modems could be designed to work well with the conditions encountered in cellular networks, but they would also have to cope with conditions in the PSTN network as well. This made them more complex, more expensive and less efficient than either a PSTN modem or one designed for use on a cellular network.

One solution that was offered by some cellular network operators was to provide a cellular data service. The mobile terminal would have a special cellular modem attached to a standard cellular phone, and the network operator would provide a matching modem at the MSC. The network operator would then route the call via a second modem which was compatible with the host system PSTN or leased line modem.

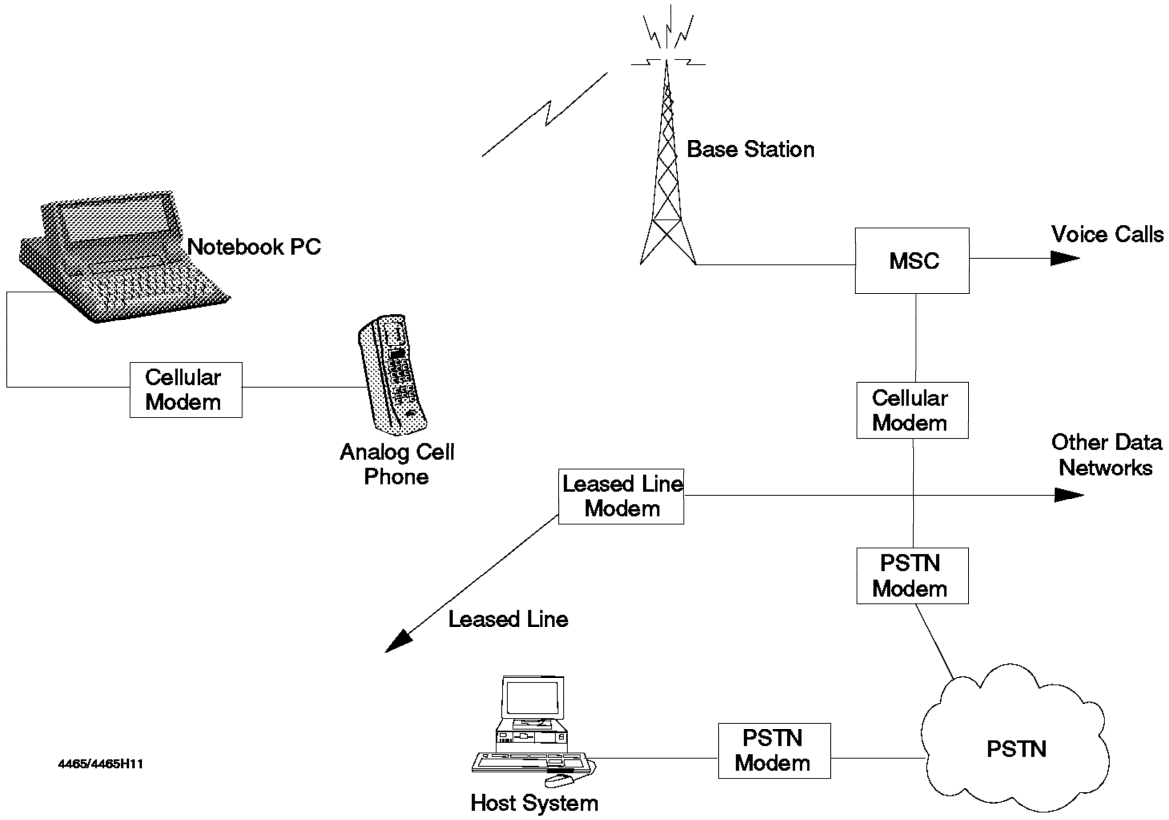

Figure 53. Cellular Data Service

A key feature of the cellular modem was its use of forward error correction. This meant that a special convolutional error correction code was added to the data that enabled the modem at the receiving end to correct blocks of data that had errors without having to resend the whole block. The host access could be either via the PSTN, by a private leased line to an enterprise system or into a value-added network. A special prefix to the telephone number would indicate to the cellular network that this was a data call and which network to route it to. This meant that the wireless part of the link could have modems that were optimized for wireless conditions and the land based link would have modems optimized for wired connections. The problem with this solution was that the user would have to buy a proprietary modem from the network operator for the mobile terminal and could only use it on that operator′s network. The solution works very well, but it has not been used in many networks. The advent of digital cellular with standard data services will soon make this type of service obsolete.

The second technique for sending data used modems that were set up to handle both wireless conditions and switched network conditions. The quality of a radio signal can vary considerably during a data transmission while wire line quality will normally remain much the same for any single call. PSTN modems will “train up” at the start of a data link and establish the optimum parameters for communication. If the line is good, then higher data rates and longer blocks are used. If the line is poor then the modems may decide to run at a slower speed to minimize the effect of errors. These parameters are normally fixed for the duration of a call. With radio communications an adaptive protocol is required. This means that if the link quality deteriorates, then the modems will “back off” and run at slower speeds or smaller blocks until things improve. One such protocol is MNP 10, which was developed by Microcom Systems Inc. for use in these conditions.

With digital cellular technology such as GSM, the air link is designed for data (digital telephony) and many of the problems associated with the transmission of data over analog networks disappear. See 2.3.1, “Global System for Mobile Communications (GSM)” on page 38 for a description of how data is sent of a digital cellular network. GSM uses a process of time division multiplexing which is very similar to the Integrated Switched Digital Network (ISDN) for fixed telecommunications. In fact, the GSM network could be considered as a mobile extension of ISDN running at a slower speed. Full-rate ISDN offers two 64 Kbps data channels plus a 16 Kbps control channel, (two B plus D channels), the data channels being shared between a number of PSTN voice circuits. Therefore using ISDN as the land-based network and GSM as the wireless network, an end-to-end digital communications link is possible with the benefits of built-in error correction and security. An alternative connection method would be to use a Public Switched Packet Data Network (PSPDN) for the land-based connection. This is shown in Figure 54.

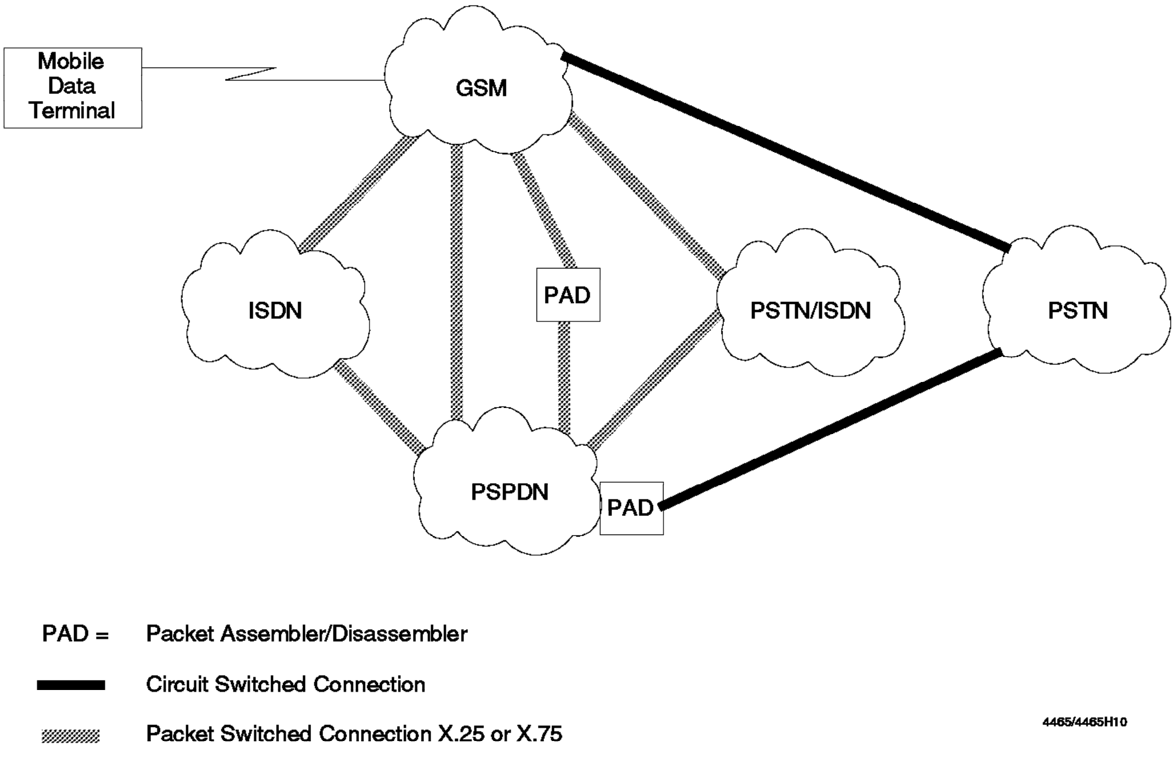

Figure 54. GSM to PSPDN Connectivity

The method of connection to PSPDN will vary according to the communications software in the mobile terminal and to which service(s) the user has subscribed.

6.4 Summary

In this chapter we have discussed how wide area wireless networks have very similar characteristics to those of local area networks, but have the effects of different conditions may be more pronounced in some cases and less in others. One of the main differences is that in the wide area network, there will be more dynamic changes to the environment, with moving vehicles, varying conditions and different network loading. A wireless LAN would normally be under control of a department within an enterprise and actions required to resolve problems could be easily enforced. In the case of a wireless WAN, however, the user will not normally have any control over the environment. Thus it is even more important to ensure that processes are in place to provide backup systems if required.

The selection of the type of wide area wireless network must be made by examining the application(s) to be used very carefully. Matching applications to networks is very important in the wireless arena and failure to do so may result in excessive costs, unacceptable delays, and in the worst case, total failure of the system.

The wide area wireless network must be regarded as an extension to the normal fixed networks. It is unusual for a wireless network to operate in isolation and connections to other networks and systems must be considered during the planning of a wireless application.

Chapter 7. Emerging Technologies

The preceding chapters have discussed the state of wireless communications today with an emphasis on data communications. The wireless industry is rapidly developing with significant changes in technology taking place every few months. The ability to make use of even larger parts of the electromagnetic spectrum for commercial applications is a direct result of the high levels of integration and miniaturization of electronics. These advances in technology have in turn generated new demands and expectations for applications that would have been considered impossible a few years ago.

A major change which is impacting people′s working lives is the need for mobility. Changes in working patterns mean that the traditional desk-bound job is being superseded by working from home and the mobile office. People expect to be able to access services from a number of different locations in order to be as effective as possible in their jobs. The wired infrastructure is expensive to maintain and even more expensive to install new services. Wireless communications will allow additional services to be supplied to existing and new locations. An example of this is seen in the new PCN services in Europe. Families who would normally only have a single phone line in the house are buying PCN phones to provide additional communications facilities at low cost. PCN network operators are offering free calls in off peak periods and customers are taking advantage of this to provide a second phone to the house (in some cases just to allow the children to make long calls without tying up the main phone, and without costing anything). In this situation, the mobility of a wireless communications device is a secondary advantage. The main reason is to provide alternative communications services at low cost. Working from home can cause problems when there is a single phone for work use and office use. A wireless device can solve this problem and ensure that someone may be contacted on a single phone number regardless if they are working in a traditional office or at home.

New applications are being developed which make use of technology which is not yet available, but is certain to be there when it is needed. An example of this is Intelligent Networking (see 7.5, “Intelligent Networks” on page 137). One of the main driving forces behind these advances is the use of computer technology and digital transmission techniques.

7.1 Digital Technology

We have seen how cellular telephony is being revolutionized by the use of digital transmission methods. This creates a significant step forward in the radio transmission of speech and ensures that there is no degradation of quality, no matter how many times the signal is processed (amplified or converted), providing that digital techniques are employed throughout the complete length of the communications link. Unfortunately, although much of our land-based network uses digital methods for trunking and long distance transmission, the telephone connection to individual telephones is almost always analog today. Large private corporations and public offices are slowly replacing their telephone switches with new digital exchanges and thus enabling the capability for an end-to-end digital connection. However, telephone switches are usually a long-term investment (installed for 20 years or more), and so it will be some time before digital communications will become ubiquitous in the commercial environment. Domestic telephone connections today are all analog, and there is no current move to change the situation. In the near future, customer demand for high-speed digital connections will drive the technological advances required for end-to-end digital connections. The domestic telephone is connected to exchanges using twisted pair copper wires which provide a voice grade circuit with a bandwidth of approximately 3.4 kHz, and is often referred to as POTS (Plain Old Telephone System). With sophisticated protocols and modulating techniques, these circuits can be used to send data at speeds up to 28.8 Kbps (V.34), providing the line quality is good enough. But with poor quality lines, the error rates may get so high that no useful data can be transmitted at this speed. For data communications, conversions from digital to analog and analog to digital could take place several times with a consequential delay and increased possibility of errors.

The problem facing network operators is how to deliver digital services to individual users over the last mile link from the exchange to the user′s premises.

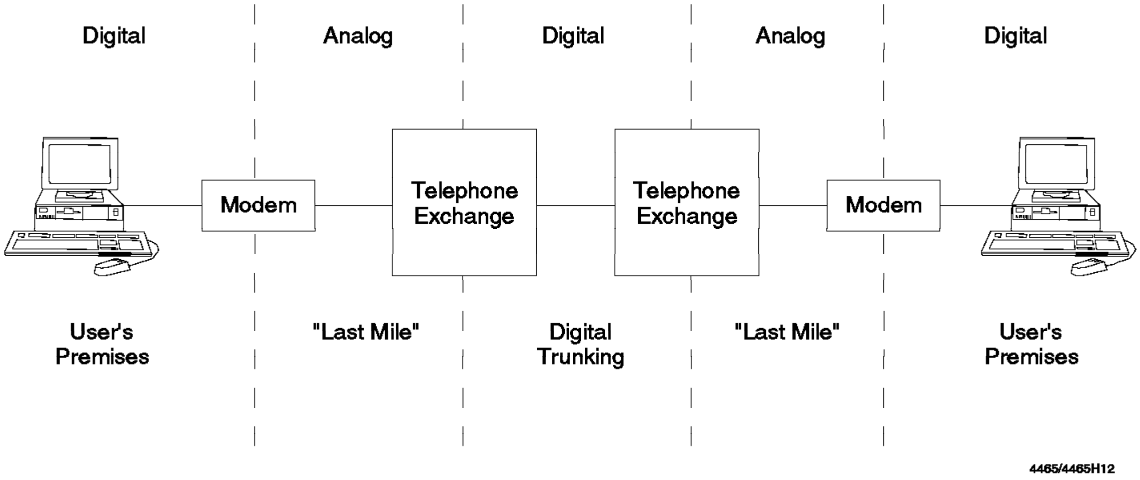

Figure 55. Analog and Digital Conversions

One way of overcoming this may be to use Integrated Switch Digital Network (ISDN) technology to provide end-to-end digital connections. ISDN uses adaptive equalization to send high speed digital information over an existing copper wire system. ISDN terminating equipment is expensive today, and network operators′ tariffs for ISDN service do not make it attractive for domestic use. The main advantage is that there is no need to replace the existing telephone connections to individual premises, which could be a very expensive and time-consuming operation for network operators.

A second way that is being implemented uses TV cable company connections to provide telephone and data services. This is normally achieved with fiber optic cables which provide two way voice and data links in addition to multiple TV channels. This works well for urban environments, but there are many places where it will be too difficult and expensive to provide cable connections. The alternative to Cable TV is Satellite TV for more remote areas. Today′s technology has concentrated on one-way communication for Direct Broadcast Satellites; although there is bandwidth available for voice and data communications, it is strictly one-way and the Satellite TV systems are only designed to deliver TV programs to subscribers.

The third alternative for providing high-speed and good-quality voice and data communications over the “last mile” is to use digital microcellular radio telephony. This is already starting to happen in Europe with the DCS1800 PCN networks. The PCN network operators are competing directly with the traditional POTS networks especially for additional or alternative telephone connections to existing PSTN subscribers. This provides total end-to-end digital connectivity, with the added advantage of mobility for data and voice users.

7.2 Roaming and Mobility

The telecommunications user of the future will require seamless mobility regardless of national boundaries and network restrictions. The technology to achieve this exists today, but a number of factors including affordability and regulatory considerations have prevented the implementation of these services in large numbers as yet. Digital technology will play a major role in making this possible.

Today′s communications are directed towards places, rather than people. One has to know where a person is located before one can communicate. The cellular phone is starting to change this, although you still have to direct a call to a phone rather than a person. The SIM card in a GSM phone is one step closer; the subscriber′s identity is the card not the phone. See 2.3.1, “Global System for Mobile Communications (GSM)” on page 38 for more information about SIM cards. Future developments will allow an individual user to have a personal phone number for use in whatever location and whichever network is available. This is described more fully in 7.5, “Intelligent Networks” on page 137.

The digital wireless technologies emerging today are starting to converge and future systems will use common techniques, even though the networks and frequencies used may be different. GSM has provided a base technology for a number of future networks. Already, PCN DCS1800 networks use exactly the same technology as GSM apart from the radio frequency. The cordless standard, DECT in Europe, is similar and future technologies will have much in common with GSM. This has several advantages including common digital integrated circuit technology leading to lower costs and faster development. The common technology will lead to the development of communicating devices that will be able to attach to more than one network and have intelligence built in to choose the most efficient network for communications at any particular time. The effect of this will be that a data communications user will be able to have a single device with built-in wireless communications capability that will connect to a wireless LAN while in an office environment, use a microcellular network for connection in an urban environment, a digital cellular network when traveling, and a cordless telephone connection when at home. In addition, the device may be able to use a mobile packet data network at any time for certain type of data transmission. It is unlikely that any communicating device will need all the attributes of the one described above, but subsets of the connectivity options will be common.

It is not just the wireless connectivity options of the communicating device which allow seamless roaming and mobility. The networks themselves must be able to determine where a subscriber is at any time and provide the most efficient connection. This is described in 7.5, “Intelligent Networks” on page 137.

7.3 PCN and PCS

The first step toward ubiquitous wireless communications will be the Personal Communications Network (PCN) or Personal Communications System (PCS). These networks are designed to provide access to a cellular communications service in locations where people live and work. They are digital cellular networks tailored for the urban and suburban environment, with good in-building coverage and highly portable devices. PCN/PCS networks are not designed for people traveling long distances or for vehicle installations, although the devices may be used in vehicles and may have adapters and connections to improve their in-vehicle usability. The networks will use microcells, which in an urban environment would cover an area of approximately one city block. They are designed to supplement, or even in some cases replace the existing wired telephone network.

PCN/PCS networks will be used for wireless data communications in new families of computing devices known as Personal Communicating Assistants (PCAs) or communicating Personal Digital Assistants (PDAs). These devices will provide various levels of functionality including Personal Information Management (PIM), E-mail, fax mail, and access to information services. The devices may be pen-based or have keyboards, and may or may not have voice capabilities. An example of the use of such a device would be to book a meeting. An entry for a meeting in the diary function of a PCA would generate a wireless message to all the attendees with compatible PCAs which could check for a free slot in their diaries and book a mutually acceptable time. Attendees who did not have compatible devices would be alerted to the meeting by means of a fax message or E-mail message. Diary management functions could reside in the PCA itself or in a host system. The key advantage is that a user will have only one diary and entries from any source will mean that it is automatically updated. This system only works satisfactorily using wireless technology. Any wired connection would have to rely on the user making a connection so that his host system can provide an update or be updated.

7.4 Global Communications

It is possible to use the telephone network to speak to anyone from almost anywhere in the world. In the last few years it has become accepted that it is possible to pick up a phone and dial directly to a subscriber almost anywhere. The same applies to data communications with a number of global networks available to provide interconnections for data users. The IBM Global Network (IGN) allows data users in many countries to connect to services and computing resource across the world.

Terrestrial long distance radio communication is limited to a few applications. For example:

- Ship to shore outside coastal waters
- Short wave amateur radio
- Remote telemetry
- Communications to remote communities (Australian Outback)
- Communications for scientific expeditions and military applications

These applications all use relatively low-frequency carriers to allow long distance propagation of radio waves. Low-frequency communications, however, do not provide sufficient bandwidth for anything other than low-grade voice communications, and sometimes only Morse code or equivalent can be used. Radio data communications can normally be used only for short distances and that base stations are connected together with wired circuits (trunked), to provide communications across long distances.

The exception to this is satellite communications. Satellites use carrier frequencies of 1.5 GHz and above. This has two major effects:

- Higher bandwidth
- Directional propagation

The high bandwidth allows multiple voice, video and data circuits, and the directional propagation allows signals to penetrate the ionosphere without significant losses. However, because of the very short wavelengths involved, signals from satellites can be more easily scattered by things such as leaves on trees and even precipitation.

As discussed in 1.3.7, "Satellite Applications" on page 16, global communications using satellites is becoming a reality. Cellular phones that have the capability of working on a regional cellular network and also accessing satellite communications will soon be available. It will always be more expensive to make a call using a satellite system (one dollar per minute), but when a subscriber is in a remote location, this will be the only way of staying in touch.

7.5 Intelligent Networks

The concept of "communications to people not places" only becomes a reality with the use of wireless communications. The ability to contact and be contacted anytime and anywhere also requires that a communications network has an intelligence that can keep track of subscribers. This works to a limited extent today with cellular phone networks. But what about the case when the subscriber does not have access to a compatible cellular network? There is no way in which the home network can route calls to the subscriber. GSM can do this within the GSM network, but still cannot know anything about other networks. What is needed is a method of keeping track of a subscriber, routing calls, storing calls when unavailable and alerting the subscriber when messages are waiting. The way in which a network can do this is by providing a virtual identity for a subscriber known as an alter-ego. The subscriber′s alter-ego handles all communication with the subscriber and will keep track of the physical location, the network, and the device which is available for communication. Anyone trying to contact the subscriber will be routed via the alter-ego which will then manage the communications. There may be more than one method of contacting a subscriber, and the alter-ego can ensure that an appropriate path is used. For example, if the alter-ego has been informed that the subscriber is in the office, then it may be more appropriate and less costly to route calls to the office phone rather than a mobile phone.

In addition to the alter-ego, a second entity can reside in the network. This is known as an agent. The purpose of the agent is to be aware of the subscriber′s preferences and deliver information and communications in a way that meets the subscriber′s requirements. For example, an agent can be instructed to only accept calls from specific destinations, or to translate E-mail message to speech and deliver them by means of a mobile phone.

If people are able to be contacted at anytime and anywhere, then the use of an agent in the network is essential to avoid unnecessary or nuisance calls. When a subscriber is roaming away from the home network, the cost of a call may involve additional charges that the initiator did not expect. For this reason, it is expected that the subscriber will be asked to pay for the additional cost to route the call to another network. If this is the case, then the subscriber must have a method of filtering unwanted calls. This will apply to data calls as well as voice calls.

When people are traveling, it may not be necessary for them to receive the same quantity of information as they would when they were at their home location. They may need to be alerted to a particular piece of information. An example would be when a share price on the stock exchange reached a certain threshold or even the score in a football match. An intelligent network could deliver this kind of information from an information provider according to the profile set up in the subscriber′s agent.

Many elements of the intelligent network are in place already. Wireless connectivity will ensure that the full potential is realized.

7.6 Summary

The most significant advance in technology today is the switch to digital communications techniques. This will open the door to a vast number of new services and applications. The distinction between different kinds of traffic on communications links will disappear, because all traffic will be data. The requirements in terms of bandwidth, network delay, and connectivity will still exist according to the source and destination of the traffic, but the communications channels themselves will only need to handle data. Wireless communications will benefit greatly from the use of digital techniques, as this will be far more efficient in using the available electromagnetic spectrum. This will result in improved and new services together with a dramatic lowering of costs.

A wireless revolution is underway, which will provide new opportunities for applications and services.

Chapter 8. Operational Considerations

The final chapter of this book brings together a number of unrelated, but important topics. Regulation, health issues, and security issues may all be seen as inhibitors to the growth of wireless communications, but these are being addressed and will be resolved satisfactorily.

There are many benefits from the use of wireless communications, including some that may not seem apparent at first. New applications will continue to be developed and new benefits will realized as a result.

8.1 Telecommunications Standards and Regulations

The wireless environment is heavily dependent on regulation and licensing to ensure that the most effective use is made of the electromagnetic spectrum. In the past, individual countries have made their own regulations on how radio systems can be used, without much consideration for their neighbors. With improvements in communications and technology, it has become very important to establish a global standard for the use of the elctromagnetic spectrum. This will enable communications equipment to be marketed and used world wide, without the need for country-unique devices and systems. Global markets will enable manufacturers to reduce costs and develop new wireless communication products more easily and quickly.

The process of moving to common standards will be very slow due to the considerable investment in existing technology, and we may never arrive at a total global solution.

8.1.1 Worldwide Standards and Regulations

Worldwide telecommunications standards usually come from the two Consultative Committees of the International Telecommunication Union (ITU), a sub-organization of the United Nations: the ITU-T (formerly the CCITT (Comité Consultatif International des Télégraphes et Téléphones) for aspects of international telecommunications networks, and the CCIR (Comité Consultatif des Radio Communications) for aspects of radio communications. A further body within the ITU is the International Frequency Registration Board (IFRB), which is responsible for advising and recording the worldwide usage of radio spectrum. In particular, it organizes the World Administration Radio Conference (WARC). In addition, telecommunication standards created by the International Standards Organization (ISO) are gaining in importance. The International Electrotechnical Commission (IEC) needs also to be mentioned. Its CISPR (Comité International Spécial Perturbations Radio) deals with radio interference created by or affecting all kinds of electrical systems.

Each country has control of the frequencies used within its own territory. Because mobile communication services in different countries have evolved differently in the past, there are presently few common available services worldwide. This will gradually change in the future due to international standardization. WARC ′92, a specially called meeting, resulted in a worldwide allocation of spectrum for new terrestrial and low-earth-orbit satellite (LEOS) mobile communications services in the category of Personal Communication Services/Personal Communication Networks (PCS/PCN). An agreement was made to designate worldwide the 1.70 - 2.69 GHz band to Future Public Land

Mobile Telecommunication Systems (FPLMTS). WARC decisions are binding for member states. The FPLMTS concept incorporates both terrestrial and satellite-delivered PCS/PCN systems. important specific allocations made by WARC ′92 are:

- Terrestrial PCS-type services: 1885 - 2025 MHz and 2110 - 2200 MHz.
- Low-earth-orbit satellite PCS-type services (“Big LEOS”): up-link 1610.0 - 1625.5 MHz, down-link 2483.5 - 2520.0 MHz (“Small LEOS” systems operate at frequencies below 1 GHz).

8.1.2 US Regulations and Environment

The FCC (Federal Communications Commission) regulates US communications. Standards are created by ANSI (American National Standards Institute), EIA/TIA (Electrical/Telecommunication Industry Association), and the IEEE. EIA/TIA has created a standard for a digital cellular telephony system: IS-54 (different from GSM). Qualcomm proposes another standard based on CDMA (Code Division Multiple Access). Various packet radio systems (ARDIS, MOBITEX, CDPD, CDI) are in operation or are being introduced.

In the US, and later in other countries, certain bands in the radio spectrum were made available for unlicensed use:

- *ISM (Industrial, Scientific and Medical) bands*: 902 - 928 MHz, 2400 - 2483.5 MHz, and 5.725 - 5.875 GHz. The 2400 MHz band is now available worldwide. Use of these bands is conditioned on the employment of direct-sequence or frequency-hopping spread spectrum modulation in order to avoid interference from other equipment such as cordless telephones, remote controls and security systems as well as microwave ovens.
- *User PCS band*: 1910 - 1930 MHz. In recently proposed bands for “Emerging Technologies”, the FCC has proposed that this 20MHz band be set aside for unlicensed operation of wireless LANs, cordless telephones and wireless PBXs.

In 1992, the FCC issued a Notice of Proposed Rule Making (NPRM) and tentative decision that outlined allocations and rules for PCS-type systems using both licensed and unlicensed spectrum. The FCC is also in the process of establishing allocations and rules for LEOS (low-earth orbit satellite), national SMR (shared mobile radio) and IVDS (interactive video and data services) systems.

WINForum is an industry advocacy group chartered to promote coordinated unlicensed use of the *User-PCS band*. IBM is a founding member along with other computer and PBX manufacturers. *Telocator* is an industry group representing companies interested in licensed and unlicensed use of frequencies in the 2 GHz region for PCS-type systems. Currently these frequencies are allocated to point-to-point microwave systems. There is no coordination for unlicensed operation in the ISM bands.

There will be dramatic changes in the competitive-regulatory environment during the 1990s in the form of a concentration of resources in the largest telephone companies. The purchase of McCaw Cellular by AT&T reestablishes its vertical market position, Sprint followed AT&T in vertical integration by merging with Centel and its cellular properties, and MCI has had discussions with other cellular companies. The auction of the PCS frequency bands to the highest bidder is establishing who the major players in PCS services will be. Cable TV companies are adding two-way capability to their video distribution systems and developing their own plans for PCS-type systems and services.

8.1.3 European Regulations and Environment

Important events in recent years have been the creation of the European Telecommunication Standards Institute (ETSI) in 1988, the opening of the terminal market to manufacturers (formerly terminal units were provided by the PTTs) and of national networks to international service providers (with few possible exceptions, such as basic voice telephony), and the establishment of a variety of European research programs in the field of radio communications: RACE, COST and ESPRIT. The ISO and IEC have as European counterparts the CEN (Comité Européen de Normalisation) and CENELEC (Comité Européen de Normalisation Electrotechnique).

The new environment has led to the rapid standardization and deployment of the first pan-European digital cellular telephone system: GSM. New cordless telephones for use in homes, offices, and for Telepoint services, are based on the digital CT-2 Interim ETSI standard that could become a de-facto world standard. Also completed are standards and frequency allocations for third-generation cordless systems: DECT. DCS-1800, the PCN/PCS system using GSM architecture are already implemented in Europe with similar systems planned in the US. Progress is also being made in the RACE projects UMTS (Universal Mobile Telecommunication System) and MBS (Mobile Broadband Services) with standards targeted for 1998.

The 2.4 GHz band is available for wireless LANs. The 900 MHz ISM band is not available because of its use for GSM and analog cellular in Europe. This has implications for manufacturers who sell products in the global marketplace.

8.1.4 Japanese Regulations and Environment

The Ministry of Posts and Telecommunications (MPT) plays a central role in regulations for telecommunications. The Research and Development Center (RCR) develops standards. Wireless systems must get Technical Standards Conformity Certification (type approval) from the MKK (Radio Equipment Inspection and Certification Institute).

As in Europe and the US, analog cellular telephony services are running out of capacity in some areas. Mobile phones have to be rented from cellular carriers. As of April 1994, the MPT permits vendors to sell these units directly to customers. For new digital cellular systems, frequencies were allocated in the 800 MHz and 1.5 GHz bands. The RCR has nearly completed the Japan Digital Cellular (JDC) standard, which is similar to IS-54.

Cordless telephones are called *Personal Handy Phones (PHPs)* in Japan. Technical specifications for a second-generation system were defined in 1992. The RCR has been working on a standard for which spectrum in the 1.9 GHz band has been allocated.

Until recently, radio-based LANs could not be used in Japan. In December 1992, the MPT amended the RF law to permit operation of medium speed wireless LANs in the 2.4 GHz ISM band, and operation of high speed LANs in the 19 GHz band. The MKK approval process for wireless LANs has also begun. The number of channels available for 2.4 GHz wireless LAN in Japan will be less than the number available in other countries. This may require more careful planning when different LANs are in close proximity.

8.2 Licenses

After Marconi demonstrated that wireless transmission was possible, there were many interest groups anxious to make use of, or control, this new communication medium. News organizations wanted to use wireless to convey the latest news more quickly, media organizations for public radio transmissions, and safety and rescue services for emergency calls. The military was also interested in making use of wireless for field communications. Governments were at first skeptical about allowing public access to radio. Legislation to control which services were permitted resulted. In many countries the job of allocating and coordinating scarce frequency bands to the service providers requesting them was given to the national PTT organization or a communications ministry. In the US this responsibility was given to the FCC. The PTT and/or communications ministries divided the frequency bands up into broadcast bands, amateur bands, utility bands and military bands. Each organization that wished to use a frequency in these bands could apply to the PTT, and was granted a license to use a frequency or a range of frequencies. Broadcast stations were allocated fixed frequencies. Organizations such as amateur radio operators were allowed use of the frequencies in a group of bands known as the “Amateur Bands”.

In order to minimize interference between transmitters, a set of regulations were introduced for signal strength, modulation technique and signal bandwidth. The licensing regulations were developed by national bodies and varied from country to country. The ITU-T (formerly the CCITT) helped to homogenize many of these regulations by issuing directives which were implemented in most countries.

As the technology advanced to allow use of frequency bands above 900 MHz, a number of bands were reserved for unlicensed use with new technologies. In 1985, the FCC in the US allocated the Industrial, Scientific and Medical (ISM) bands for LANs using spread-spectrum techniques without requiring a license. The transmitted power must be less than 1 W and the frequencies are 902-928 MHz, 2400-2483.5 MHz and 5725-5850 MHz. The FCC has also allocated an unlicensed narrow band 1910-1930 MHz for mobile users.

At the present time, only the 2.4 GHz band can be used for wireless LANs in some countries outside the US, although progress is being made in freeing up this area of the spectrum in most countries.

8.3 Available Spectrum

The propagation characteristics of radio waves depend on the frequency as described in 2.1, “Radio Frequency Characteristics” on page 21. The frequency ranges with the most suitable characteristics are very crowded and much of the frequency spectrum is reserved for dedicated services. The only bands in the US now available for unlicensed operation are the ISM bands.

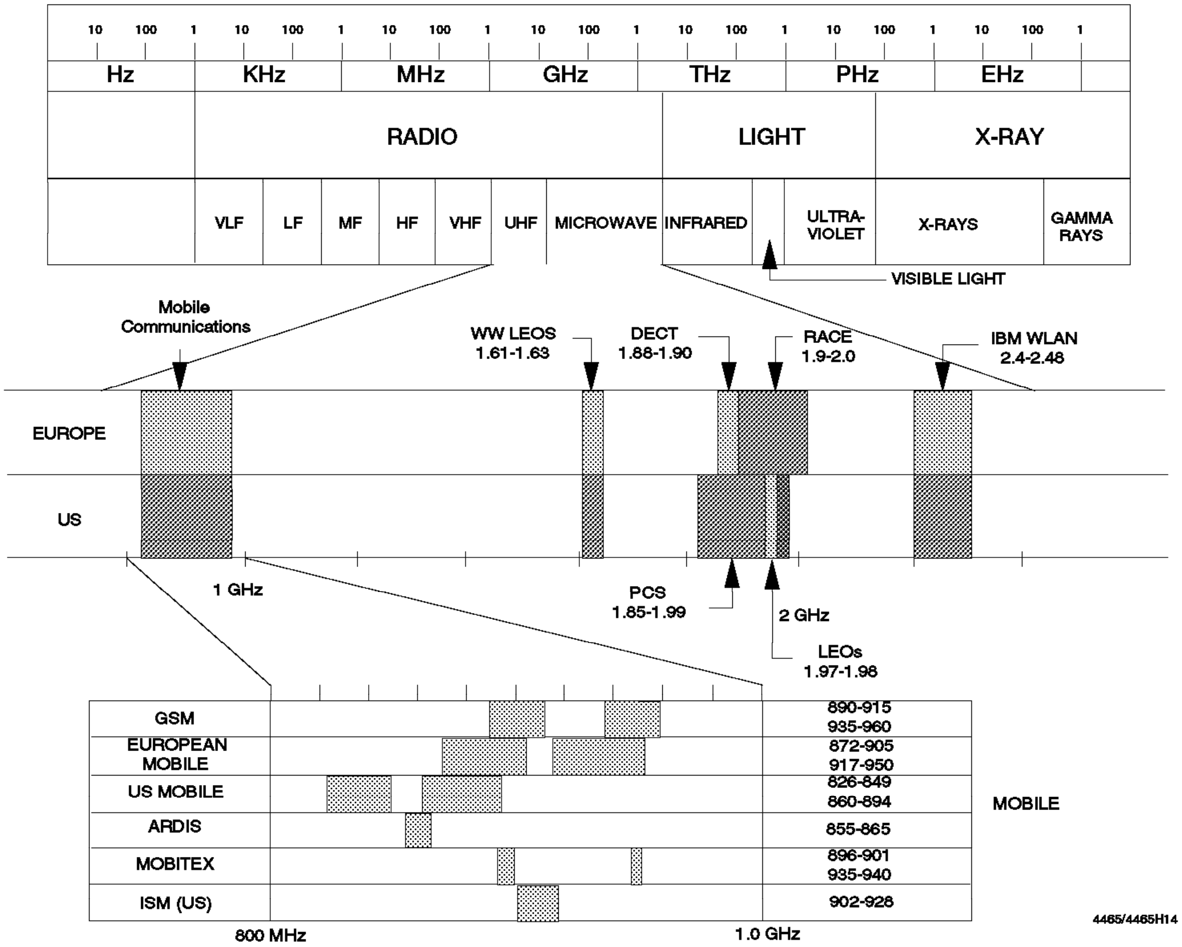

Figure 56. Frequency Spectrum. An overview of the frequency spectrum and some services using radio bands is shown.

8.4 PCS Auction in the US

In 1993 the U.S. Congress passed legislation to force the Department of Commerce (under which the FCC falls) to allocate 200 MHz of spectrum for private industry. The Department of Commerce (FCC) has selected the 2402-2417 MHz band as well as 2390-2400 MHz and 4660-4685 MHz bands. The right to use these frequencies was sold to the highest bidders at an auction in December 1994. Two 8 MHz sections of the 902-928 MHz band have also been chosen to be sold. Whichever company buys the rights to a part of the available frequency spectrum can provide any mobile or fixed wireless service they choose. Any other equipment operating on those frequencies and interfering with the authorized operator is unlicensed for use and subject to governmental action.

The reason for the interest in this auction is the effect it will have on the ability of the major telecommunications and cable TV companies to provide personal communications services (PCS). Bell Atlantic, Nynex and US West (three Bell company cellular carriers) have joined up with Airtouch Communications, a cellular spin-off from Pacific Telesis Group to bid for parts of the spectrum. Sprint has joined with the cable TV companies TeleCommunications Inc., Cox, and Comcast to bid also. AT&T will also be a major competitor. The ability to provide PCS services will require large investments in installing a wireless network infrastructure and developing the services to use it. Typical devices expected at first are small pocket phones, wrist pagers, personal digital assistants (PDAs) and wireless modems.

As this book is being written, the results of the PCS auction have been announced. A total of 18 companies have bid $17 billion for the licenses for 99 market areas in the US. According to the FCC, this will create 300,000 new jobs and add 1% to the gross domestic product of the US.

Table 6 (Page 1 of 2). Successful Bidders in the PCS Auction

Network Operator	**Market Area**
WirelessCo	New York, San Francisco, Detroit, Dallas/Ft Worth, Boston, Minneapolis, Miami, Denver, Seattle, New Orleans, St. Louis, Milwaukee, Pittsburgh, Louisville/Lexington/Evansville KY, Phoenix AL, Portland OR, Indianapolis, Des Moines IA, San Antonio, Kansas City, Buffalo/Rochester NY, Salt Lake City, Little Rock AR, Oklahoma City, Spokane WA, Nashville TN, Wichita KS, Tulsa OK
AT&T Wireless PCS	Chicago, Detroit, Charlotte/Greensboro/Greenville/Raleigh NC, Boston/Providence RI, Philadelphia, Washington/Baltimore, Atlanta, Cleveland, Cincinnati/Dayton OH, St. Louis, Richmond/Norfolk VA, Puerto Rico, Louisville/Lexington/Evansville, Buffalo/Rochester NY, Columbus OH, El Paso TX, Albuquerque NM, Nashville TN, Knoxville TN, Wichita
PCS Prime Co	Chicago, Dallas, Tampa, Houston, Miami, New Orleans, Milwaukee, Richmond, San Antonio, Jacksonville, Honolulu
American Portable Telecommunications	Minneapolis/St. Paul, Tampa/St. Pete, Houston, Pittsburgh, Kansas City, Columbus, Alaska, Guam
Powertel	Memphis TN, Jackson MS, Birmingham, Jacksonville,
GTE Macro Communications	Atlanta, Cincinnati/Dayton, Denver, Seattle
BellSouth Personal Communications	Charlotte/Greensboro/Greenville/Raleigh NC, Knoxville TN
Pacific Telesis Mobile Services	Los Angeles/San Diego, San Francisco/Oakland/San Jose
Western PCS	Portland, Des Moines, Salt Lake City, El Paso/Albuquerque, Oaklahoma City, Honolulu
Southwestern Bell Mobile Systems	Memphis/Jackson, Little Rock, Tulsa
Ameritech Wireless Communications	Cleveland, Indianapolis
Poka Lambro Telephone Cooperative	Spokane/Billings WA, Guam
PhillieCo	Philadelphia

Table 6 (Page 2 of 2). Successful Bidders in the PCS Auction

Network Operator	**Market Area**
Centennial Cellular	Puerto Rico
Cox Cable	Omaha
GCI Communications	Alaska
South Seas Satellite	American Samoa
Communications International	American Samoa

8.5 ISM Bands in the US

The ISM (Industrial, Scientific and Medical) bands in the US were allocated for indoor radio applications. Spread spectrum techniques *must* be used in these bands but provided transmitter power is very low (less than 1 watt) equipment does not need to be licensed in most countries. Note that there is some variation between countries on the boundaries of these bands.

Table 7. Indoor Radio Frequency Band Characteristics

	915 MHz	**2.4 GHz**	**5.8 GHz**
Frequency	902-928 MHz	2.4-2.48 GHz	5.73-5.85 GHz
Wavelength	32.8 cm	12.5 cm	5.2 cm
Width of Band	26 MHz	80 Mhz	120 MHz
Usage	ISM-SS	ISM-SS	ISM-SS
Range	Greatest	95%	80%
Status	Crowded	Low Use	V Low Use
Interference	High	Low	Low

Table 8. ISM Frequency Bands and Permitted Power Levels

Country	**Frequency Range**	**Power**
US and Latin America	2400-2483.5 MHz	1 W ERP
Canada	2400-2483.5 MHz	1 W ERP
ETSI countries except France	2400-2483.5 MHz	100 mW EIRP
France	2445-2483.5 MHz	100 mW EIRP
Australia	2400-2450 MHz	500 mW
Japan	2471-2497 MHz	10 mW/MHz EIRP

Note: ERP is the effective radiated power from a standard half-wave dipole antenna, while EIRP is the effective radiated power from an isotropic point, thus effective *isotropic* radiated power. ERP is equal to EIRP minus 2 dB.

In USA and Latin America, the bands 902-928 MHz with 1 W and 5750-5850 MHz with 1 W transmission power are also available. In Canada, 2400-2483.5 MHz with 1 W power can also be used.

The 2400 MHz band is divided into seven channels. Six of these channels are available in USA, five in Europe and a single channel in Japan.

8.6 Health

As discussed in 5.8, “Health Issues” on page 113, much uninformed reporting has been seen on the subject of the possibilities of a risk to health by the use of electrical and radio devices. Confusion may have arisen by the use of terms not properly understood or in the wrong context. For example, radio frequency, light, X-rays and Gamma rays are all part of the electromagnetic spectrum. Sources of all these electromagnetic waves are said to “radiate”. Unfortunately, the word “radiation” has become associated with the harmful effects that can be experienced by radiation from nuclear devices and X-rays. Radio transmitters radiate energy, but a look at Figure 3 on page 23 will show that radio waves are at the opposite end of the spectrum. Lying between radio frequencies and X-rays/Gamma rays is the region of visible and non-visible light. Visible light is not considered to have any harmful effects at all; only ultra-violet rays can cause sunburn. The energy levels of radio devices are also very different. Take the example of a 100 W domestic incandescent light bulb. This radiates most of its energy in the form of light, but it is hard to imagine that there could be health concerns over the electromagnetic radiation from light bulbs. Most portable radio transmitting devices radiate energy of only a few watts, and the trend is to produce lower-powered devices of only a few hundred milliwatts in order to make better use of the spectrum by frequency re-use.

In the latter part of the nineteenth century and early twentieth century, a great deal of scientific research was conducted into the effects of electricity and radio frequency emission upon the human body. Most of this research was directed towards the possible uses of electricity for medical purposes and many beneficial techniques were developed as a result. These include muscle stimulation using static electricity, DC currents, or extremely low frequency (ELF) alternating current, electrophoresis and electrolysis using DC current, and the heating effects of low frequency RF.

Radio frequency devices have been with us for nearly one hundred years now, and in the whole of that time there has not been single case proven where a correctly functioning radio transmitting device has caused damage to health.

In recent years, a significant amount of study has been directed towards determining any possible harmful effects of electromagnetic radiation in day-to-day use.

Possible effects of RF radiation on the human body may be divided into two types:

- Thermal
- Athermal

Thermal effects may be likened to the use of a microwave oven for warming food. A microwave oven heats food by producing small induced electric currents in the water content of food, which in turn produce a heating effect due to electrical resistance. Thermal effects at the power levels used by portable radio frequency devices are non-existent and there have been no reported cases or concerns about the thermal effects of portable radio.

Athermal effects are effects that are not caused directly by heating of the body. These effects have not yet been identified as a result of RF radiation.

The area where speculation on the effects of radio frequencies has been concentrated is that of athermal effects. There have been no studies where evidence of the athermal effects of RF on groups of people has been demonstrated.

The main concern that has been expressed is that exposure to RF radiation may increase susceptibility to cancer. There is no proven causal relationship between cancer and RF radiation.

All evidence gathered on the effects on health from RF radiation result from long term exposure to high powers and lead to the following conclusions:

- Most effects observed are thermal effects due to high power radiation.
- Nearly all effects are transient and reversible.
  - Conditions return to normal on removal of RF signal.

It may be concluded that the use of portable radio transmitting devices is totally safe and that one should not feel any concern for the future when radio communications will become an everyday experience.

There is continuing research into possible effects of electromagnetic radiation and with the growing use of radio transmitting devices a close watch will be kept for any evidence of risk to health.

8.7 Security

The security issues involved with the transmission of information using wireless technology has been mentioned before in 2.3, “Digital Cellular Telephony” on page 37, 5.5, “Security Aspects” on page 111, and 6.1.5, “Security” on page 124. However, it is worth summarizing some general principles here.

1. Any information sent by any method outside a physical location has a degree of security exposure greater than information that can be controlled internally.

   Sending can mean mailing or hand carrying hardcopy, or diskettes and tapes, as well as electronic transmission.

   Outside means anywhere external to a physically secure area.

2. The value of the information must be greater than the cost of protecting it and greater than the cost of stealing it.
3. Electronic eavesdropping may be the least cost effective and least successful method of industrial espionage.

   It is difficult to target individuals or specific pieces of information.

   Technology costs may be high.

   Incomplete information is likely to be obtained.

4. Traditional methods of bribery and corruption may be more successful and more cost effective.

   Information obtained is more accurate and complete.

   Information sources can be targeted.

   Long-term information feeds can be established.

5. Physical break-ins to offices may also be more effective.

In addition to these general principles regarding the protection of sensitive information, there are some additional factors which are only present in wireless communication security. The first consideration is that eavesdropping on a wireless communication can be performed without having to break into a secure location. Secondly, it is very difficult to determine if a wireless transmission is being received by an unauthorized person. And thirdly, it is very difficult to trace who may be receiving the transmission.

The factors discussed above, do not make wireless communication less secure, but there is less risk to those attempting to steal proprietary information of being caught and prosecuted. In some countries, it is seen as incumbent upon owners of information to take steps to provide adequate security to protect sensitive information. This means that a potential industrial spy must defeat some kind of security system and in doing so the act becomes illegal. If there is no security system, then information may be seen as public domain and no criminal act has occurred. In other legal systems it may not be illegal to listen or decode transmitted information, but using that information for personal gain or passing it on to a third party may be a criminal offense. The laws relating to the ownership of information is are varied and complex and become even more convoluted if information is transmitted across national boundaries.

The answer in all cases of sending sensitive information from one place to another, is to provide adequate protection. In the case of transmission of electronic information this will normally mean encryption. As discussed in 6.1.5, “Security” on page 124, encryption should be used on the whole length of data path, and not just on the wireless interface. Modulation techniques, compression, packetization and spread spectrum, all make it more difficult to decode a data transmission. However, these technologies are all commercially available and do not guarantee that the data cannot be retrieved by unauthorized persons.

In summary, the security aspects of wireless transmission are not fundamentally any different to other transmission methods. If sensitive information is sent outside a secure environment, it must be protected.

8.8 Benefits

Some of the more obvious benefits of using wireless communications have been mentioned in previous chapters. It is appropriate to bring these benefits and less obvious ones together in one section where those people who are considering using wireless to enhance business processes and improve everyday life can quantify the effect.

The benefit that probably comes to mind first of all is that of mobility. The user of wireless services is not tied to a single location and can travel around while still staying in touch with people and services as required. At first sight it may not be apparent that many people have need for this kind of mobility in their daily lives, but it is certain that every enterprise has a least some of its workers who are mobile. Mobility can be defined in many ways; from the needs of a world traveler in many different countries and remote regions, to the office worker who has stepped out of his office to converse with a colleague, and thus misses an important phone call. Wireless solutions can address both of these needs together with a vast range of voice and data requirements in between. Analog and digital cellular phone networks, PCN/PCS networks, cordless phones, satellite communications, RF or infrared LANs, paging systems, mobile data networks and infrared cordless connections can all satisfy the needs of mobile workers.

A subset of mobility is the requirement in some industries for flexibility. This can be in the form of the needs to reconfigure point of sale (POS) terminals for the retail industry or simple office moves without the need for rewiring a building.

With the advantages of mobility come the benefits of immediacy, or the competitiveness of time. In today′s commercial environment, a very high degree of competition is the norm and it is very unusual for find an industry where there is minimal competition. The traditional weapons in the battle for competitive advantage have been price, quality, and function (not necessarily in order of priority). A very fine balance has to be maintained between the competitive advantages of a given product or service and its profitability. A high quality, highly functional product sold at low price might be very attractive to the consumer, but unless it can be sold at a profit, the supplier may soon be out of business. The competitive value of time can be a new lever to gain advantage in a business. Some examples are:

> The insurance salesman who can provide an instantaneous quotation for a life policy and arrange for immediate cover has a distinct advantage over the salesman who has to wait for his office to mail a quotation and then return an application form.
>
> The sales representative from a supplier of electronic components who can check the stock levels of a given component and guarantee next-day delivery while on the customer′s premises.
>
> The white goods field service engineer who can verify a problem diagnosis and order a spare part without having to use the customer′s phone.
>
> The paramedic who can send medical data to a diagnostician while an accident victim is traveling to a hospital in an ambulance.
>
> The police officer who can check a licence plate for a suspect vehicle while following at a distance.

If mobile workers enter their own data, a number of other benefits are realized:

- Data is entered into the information system as it happens.
- Management information systems are in real time.
- Data is more accurate - no transcription errors.
- Workers take responsibility for their own input - third parties cannot be blamed for errors.

A major cost savings by using wireless communications for data entry is achieved by the reduction in use of printed forms. Hardcopy forms are expensive to produce, time consuming to fill in, and very expensive to process and store. In the past, information technology has been used to reduce these costs, but has not been able to provide an alternative for those workers who are not office based. With the use of wireless data terminals, another major step towards a paperless office can be achieved.

One of the most important benefits of wireless communications is the saving of travel time for mobile workers. A field service engineer may make a journey of an hour or more to a customer′s office only to find that a more important call has come in and he has to return. A salesman may have to travel to his office every day to ensure that he has up-to-date information on prices and stock levels. Both these trips can be eliminated by using wireless voice or data communications.

Additional benefits from avoiding unnecessary travel are less pollution, lower usage of fossil fuels, and a less stressful environment for the worker.

There are many advantages to using wireless technology and new ones will become apparent as new technology and applications are developed. These developments will make significant changes for the better, not only in people′s working environments, but in everyday life as well.

8.9 Summary

The initial impact that wireless technology made on people′s lives was due to radio and television broadcasting. The first public radio broadcasts were made within living memory and television only became popular by the middle of the century. In a very short time, the perception of broadcast reception moved from being a technological miracle to being a part of people′s everyday lives. We are at the start of a second wireless technology revolution. The era of wireless personal communications has begun and it will soon be a part of everyday life. This is evident in the massive take up of cellular phones and the increasing demands for personal communications. The impact of this technology on people′s lives is hard to predict but it is certain to happen and it is up to us all to ensure that wireless technology will be a major benefit to everyone.

Appendix A. Cellular Networks Worldwide

A.1 GSM Networks in Europe

Table 9. European GSM Networks

Country	**Operator**	**Network**
Austria	Austrian PTT	GSM
Belgium	Belgacom	GSM
Denmark	Tele Danmark Mobil	GSM
Denmark	Sonofon	GSM
Estonia	EMT	GSM
Finland	Telecom Finland	GSM
Finland	Radiolinja	GSM
France	SFR	GSM
France	France Telecom	GSM
Germany	DeTe Mobil	GSM
Germany	Mannesmann	GSM
Greece	STET	GSM
Greece	Panafon	GSM
Hungary	Pannon	GSM
Hungary	Westel	GSM
Ireland	Eircel	GSM
Italy	Telecom Italia	GSM
Luxembourg	Luxembourg PTT	GSM
The Netherlands	The Netherlands PTT	GSM
Norway	Tele-Mobil	GSM
Norway	Netcom	GSM
Portugal	TMN	GSM
Portugal	Telecel	GSM
Russia	Several	GSM
Sweden	Telia Mobitel	GSM
Sweden	Nordictel	GSM
Sweden	Comvik	GSM
Switzerland	Switzerland PTT	GSM
Turkey	Telsim	GSM
Turkey	Turkcel	GSM
United Kingdom	Cellnet	GSM
United Kingdom	Vodafone	GSM
United Kingdom	Orange	DCS1800
United Kingdom	One-2-One	DCS1800

A.2 Analog Cellular Networks in Europe

Table 10 (Page 1 of 2). European Analog Cellular Networks

Country	**Operator**	**Network**
Austria	Austrian PTT	C-Netz
Austria	Austrian PTT	D-Netz
Belarussia	Becel	NMT450
Belgium	Belgacom	MOB-II
Bulgaria	Mobifon	NMT450
Croatia	Croatian PTT	NMT450
Cyprus	CYTA	NMT900
Denmark	Tele Danmark Mobil	NMT450
Denmark	Tele Danmark Mobil	NMT900
Estonia	EMT	NMT450
Finland	Telecom Finland	NMT450
Finland	Telecom Finland	NMT900
France	SFR	NMT450+
France	France Telecom	Radiocom 2000
Germany	DeTe Mobil	C-Netz
Hungary	Westel	NMT450
Iceland	Iceland PTT	NMT450
Ireland	Eircell	TACS900
Italy	Telecom Italia	RTMS
Italy	Telecom Italia	TACS900
Latvia	LMT	NMT450
Lithuania	Comliet	NMT450
Luxembourg	Luxembourg PTT	NMT450
Malta	Telecel	ETACS
The Netherlands	PTT Telekom	NMT450
The Netherlands	PTT Telekom	NMT900
Norway	Tele-Mobil	NMT450
Norway	Tele-Mobil	NMT900
Poland	Centertel	NMT450
Portugal	TMN	C-NET
Romania	Telefonica Romania	NMT450i
Russia	Several	NMT450 & AMPS
Slovak & Czech Republics	Eurotel	NMT450
Slovenia	Mobitel	NMT450i
Sweden	Telia Mobitel	NMT450
Sweden	Telia Mobitel	NMT900
Switzerland	Switzerland PTT	Natel C
Turkey	PTT	NMT450

Table 10 (Page 2 of 2). European Analog Cellular Networks

Country	Operator	Network
Ukraine	UMC	NMT450
United Kingdom	Cellnet	TACS
United Kingdom	Vodafone	TACS

A.3 Analog Cellular Networks in Asia Pacific

Table 11 (Page 1 of 3). Asia Pacific Analog Cellular Networks

Country	**Operator**	**Network**
Australia	Telecom Mobilenet	AMPS
Australia	Optus	GSM
Australia	Vodafone	GSM
Australia	MobileNet Digital	GSM
Bangladesh	HBTL	AMPS
Brunei	JTB	AMPS
Brunei	JTB/Sultan	GSM
Cambodia	DPT/Camtel	AMPS
Cambodia	DPT	NMT900
Cambodia	DPT	NMT450i
Cambodia	DPT	ETACS
China	MPT	TACS
China	CESEC	AMPS
China	CESEC	TDMA
China	GMCC	GSM
China	Oil Co.	NMT450
China	China Unicom	GSM
Hong Kong	Hutchison	AMPS
Hong Kong	Hutchison	TACS
Hong Kong	CSL	TACS
Hong Kong	Pacific Link	ETACS
Hong Kong	Pacific Link	DAMPS
Hong Kong	SmarTone	GSM
Hong Kong	HKT-CSL	GSM
Indonesia	Telkom	NMT450
Indonesia	Telkom	AMPS
Indonesia	Telkom	GSM
Indonesia	Satelinda	GSM
Japan	NTT	NTT
Japan	NTT/IDO	PDC800
Japan	IDO	JTACS
Japan	IDO	NTT
Japan	DDI Corp	JTACS
Japan	Tu-Ka	PDC1500
Japan	Tokyo Digital Phone	PDC1500
Japan	Central Digital Phone	PDC1500
Japan	Kansai Digital Phone	PDC1500
Japan	Several	PHS

Table 11 (Page 2 of 3). Asia Pacific Analog Cellular Networks

Country	**Operator**	**Network**
Fiji	Vodafone	GSM
Korea	KMTC	AMPS
Korea	Shinsegi Mobile Coms	CDMA
Laos	CPTL	AMPS
Laos	Lao Shinawatra	GSM
Macau	CTM	TACS
Macau	CTM	GSM
Malaysia	Telekom Malaysia	NMT450
Malaysia	Mobikom	AMPS
Malaysia	Celcom	ETACS
Malaysia	Mobikom	DAMPS
Malaysia	Celcom	GSM
Malaysia	Binariang	GSM
Myanmar	Myanmar PTT	AMPS
New Zealand	Telecom NZ	AMPS
New Zealand	Telecom NZ	DAMPS
New Zealand	BellSouth	GSM
New Zealand	Telstra	GSM
Pakistan	Paktel	AMPS
Pakistan	Pakcom	AMPS
Pakistan	PMCL	GSM
Philipines	Extelcom	AMPS
Philipines	Extelcom	NAMPS
Philipines	Piltel	AMPS
Philipines	Piltel	DAMPS
Philipines	Smart Comms	TACS
Philipines	Globe Handyphone	GSM
Philipines	Islacom	GSM
Singapore	Singapore Telecom	AMPS
Singapore	Singapore Telecom	ETACS
Singapore	Singapore Telecom	GSM
Sri Lanka	Celltel	TACS
Sri Lanka	Mobitel	AMPS
Sri Lanka	Call Link	TACS
Sri Lanka	MTN	GSM
Taiwan	DGPT	AMPS
Taiwan	DGPT	GSM
Thailand	TOT	NMT450
Thailand	CAT	AMPS
Thailand	AIS	NMT900

Table 11 (Page 3 of 3). Asia Pacific Analog Cellular Networks

Country	**Operator**	**Network**
Thailand	TAC	AMPS
Thailand	AIS	GSM
Thailand	TAC	DCS1800
Vietnam	SMPC/HCM City	AMPS
Vietnam	VMS HCM City	GSM
Vietnam	VMS	GSM

A.4 Analog Cellular Networks in The USA

Table 12 (Page 1 of 7). US Analog Cellular Networks

Area	**Operator**	**Network**
New York	W Nynex Mobile	AMPS
New York	NW Metro One	AMPS
Los Angeles	W PacTel Cellular	AMPS
Los Angeles	NW Cellular One	AMPS
Chicago	W Ameritech Mobile	AMPS
Chicago	NW Cellular One	AMPS
Philadelphia	W Bell Atlantic Mobile	AMPS
Philadelphia	NW Metrophone	AMPS
Detroit	W Ameritech Mobile	AMPS
Detroit	NW Cellular One	AMPS
Boston	W Nynex Mobile	AMPS
Boston	NW Cellular One	AMPS
San Francisco	W GTE Mobilnet	AMPS
San Francisco	NW Cellular One	AMPS
Washington	W Bell Atlantic Mobile	AMPS
Washington	NW Cellular One	AMPS
Dallas	W SW Bell Mobile	AMPS
Dallas	NW MetroCel	AMPS
Houston	W GTE Mobilnet	AMPS
Houston	NW Houston Cellular	AMPS
St. Louis	W SW Bell Mobile	AMPS
St. Louis	NW Cyber Tel	AMPS
Miami	W BellSouth Mobility	AMPS
Miami	NW Cellular One	AMPS
Pittsburgh	W Bell Atlantic Mobile	AMPS
Pittsburgh	NW Cellular One	AMPS
Baltimore	W Bell Atlantic Mobile	AMPS
Baltimore	NW Cellular One	AMPS
Minneapolis	W US West	AMPS
Minneapolis	NW Cellular One	AMPS
Cleveland	W GTE Mobilnet	AMPS
Cleveland	NW Cellular One	AMPS
Atlanta	W BellSouth Mobility	AMPS
Atlanta	NW PacTel Mobile Access	AMPS
San Diego	W PacTel Cellular	AMPS
San Diego	NW Vector One	AMPS
Denver	W US West	AMPS
Denver	NW Cellular One	AMPS

Table 12 (Page 2 of 7). US Analog Cellular Networks

Area	**Operator**	**Network**
Seattle	W US West	AMPS
Milwaukee	W Ameritech Mobile	AMPS
Milwaukee	NW Cellular One	AMPS
Tampa	W GTE Mobilnet	AMPS
Tampa	NW Cellular One	AMPS
Cincinnati	W Ameritech Mobile	AMPS
Cincinnati	NW Cellular One	AMPS
Kansas City	W SW Bell Mobile	AMPS
Kansas City	NW Cellular One	AMPS
Buffalo	W Nynex Mobile	AMPS
Buffalo	NW Buffalo Telephone	AMPS
Phoenix	W US West	AMPS
Phoenix	NW Metro Mobile CTS	AMPS
San Jose	W GTE Mobilnet	AMPS
San Jose	NW Cellular One	AMPS
Indianapolis	W GTE Mobilnet	AMPS
Indianapolis	NW Cellular One	AMPS
New Orleans	W BellSouth Mobility	AMPS
New Orleans	NW Radiofone	AMPS
Portland OR	W GTE Mobilnet	AMPS
Portland OR	NW Cellular One	AMPS
Columbus OH	W Ameritech Mobile	AMPS
Columbus OH	NW Cellular One	AMPS
Hartford CT	W SNET	AMPS
Hartford CT	NW Metro Mobile	AMPS
San Antonio TX	W SW Bell Mobile	AMPS
San Antonio TX	NW Cellular One	AMPS
Rochester NY	W Rochester Telephone	AMPS
Rochester NY	NW Genesee Telephone	AMPS
Sacramento CY	W PacTel Cellular	AMPS
Sacramento CY	NW Cellular One	AMPS
Memphis TN	W BellSouth Mobility	AMPS
Louisville KY	W BellSouth Mobility	AMPS
Louisville KY	NW Louisville Telephone	AMPS
Providence RI	W Nynex Mobile	AMPS
Providence RI	NW Metro Mobile	AMPS
Salt Lake City UT	W US West	AMPS
Salt Lake City UT	NW Cellular One	AMPS
Dayton OH	W Ameritech Mobile	AMPS
Dayton OH	NW Cellular One	AMPS

Table 12 (Page 3 of 7). US Analog Cellular Networks

Area	**Operator**	**Network**
Birmingham AL	NW BellSouth Mobility	AMPS
Birmingham AL	NW Cellular One	AMPS
Bridgeport CT	W SNET	AMPS
Bridgeport CT	NW Metro Mobile	AMPS
Norfolk VA	W Contel Cellular	AMPS
Norfolk VA	NW Cellular One	AMPS
Albany NY	W Nynex Mobile	AMPS
Albany NY	NW Albany Telephone	AMPS
Oklahoma City OK	W SW Bell Mobile	AMPS
Oklahoma City OK	NW Cellular One	AMPS
Nashville TN	W BellSouth Mobility	AMPS
Nashville TN	NW Cellular One	AMPS
Greensboro NC	W Centel	AMPS
Greensboro NC	NW Cellular One	AMPS
Toledo OH	W United TeleSpectrum	AMPS
Toledo OH	NW Cellular One	AMPS
New Haven CT	W SNET	AMPS
New Haven CT	NW Metro Mobile	AMPS
Honolulu HI	W GTE Mobilnet	AMPS
Honolulu HI	NW Honolulu Cellular	AMPS
Jacksonville FL	W BellSouth Mobility	AMPS
Jacksonville FL	NW Cellular One	AMPS
Akron OH	W GTE Mobilnet	AMPS
Akron OH	NW Cellular One	AMPS
Syracuse NY	W Nynex Mobile	AMPS
Syracuse NY	NW Cellular One	AMPS
Gary IN	W Ameritech Mobile	AMPS
Gary IN	NW Cellular One	AMPS
Worcester MA	W Nynex Mobile	AMPS
Worcester MA	NW Cellular One	AMPS
Northeast Pennsylvania	W Commonwealth Mobile	AMPS
Northeast Pennsylvania	NW Cellular One	AMPS
Tulsa OK	W United States Cellular	AMPS
Tulsa OK	NW Cellular One	AMPS
Allentown PA	W Bell Atlantic Mobile	AMPS
Allentown PA	NW Cellular One	AMPS
Richmond VA	W Contel Cellular	AMPS
Richmond VA	NW Cellular One	AMPS
Orlando FL	W BellSouth Mobility	AMPS
Orlando FL	NW Orlando Cellular	AMPS

Table 12 (Page 4 of 7). US Analog Cellular Networks

Area	**Operator**	**Network**
Charlotte NC	W Alltel	AMPS
Charlotte NC	NW Metro Mobile CTS	AMPS
New Brunswick NJ	W Nynex Mobile	AMPS
New Brunswick NJ	NW Cellular One	AMPS
Springfield MA	W SNET	AMPS
Springfield MA	NW Metro Mobile CTS	AMPS
Grand Rapids MI	W Century Cellunet	AMPS
Grand Rapids MI	NW Cellular One	AMPS
Omaha NE	W Centel	AMPS
Omaha NE	NW Omaha Cellular	AMPS
Youngstown OH	W United TeleSpectrum	AMPS
Youngstown OH	NW Cellular One	AMPS
Greenville SC	W United TeleSpectrum	AMPS
Greenville SC	NW Metro Mobile	AMPS
Flint MI	W Ameritech Mobile	AMPS
Flint MI	NW Cellular One	AMPS
Wilmington DE	W Bell Atlantic Mobile	AMPS
Wilmington DE	NW Cellular One	AMPS
Long Branch NJ	W Nynex Mobile	AMPS
Long Branch NJ	NW Cellular One	AMPS
Raleigh-Durham NC	W United TeleSpectrum	AMPS
Raleigh-Durham NC	NW Cellular One	AMPS
W Palm Beach FL	W BellSouth Mobility	AMPS
W Palm Beach FL	NW Cellular One	AMPS
Oxnard CA	W PacTel Cellular	AMPS
Oxnard CA	NW Ventura Cellular	AMPS
Fresno CA	W Contel Cellular	AMPS
Fresno CA	NW Cellular One	AMPS
Austin TX	W GTE Mobilnet	AMPS
Austin TX	NW Cellular One	AMPS
New Bedford MA	W Nynex Mobile	AMPS
New Bedford MA	NW Metro Mobile CTS	AMPS
Tucson AZ	W US West	AMPS
Tucson AZ	NW Metro Mobile CTS	AMPS
Lansing MI	W Century Cellunet	AMPS
Lansing MI	NW Cellular One	AMPS
Knoxville TN	W United States Cellular	AMPS
Knoxville TN	NW McCaw	AMPS
Baton Rouge LA	W BellSouth Mobility	AMPS
Baton Rouge LA	NW Cellular One	AMPS

Table 12 (Page 5 of 7). US Analog Cellular Networks

Area	**Operator**	**Network**
El Paso TX	W Contel Cellular	AMPS
El Paso TX	NW Metro Mobile	AMPS
Tacoma WA	W US West	AMPS
Tacoma WA	NW Cellular One	AMPS
Mobile AL	W Contel Cellular	AMPS
Mobile AL	NW Gulf Coast Cellular	AMPS
Harrisburg PA	W United TeleSpectrum	AMPS
Harrisburg PA	NW Cellular One	AMPS
Johnson City TN	W United TeleSpectrum	AMPS
Johnson City TN	NW Cellular One	AMPS
Albuquerque NM	W US West	AMPS
Albuquerque NM	NW Metro Mobile	AMPS
Canton OH	W GTE Mobilnet	AMPS
Canton OH	NW Canton Cellular	AMPS
Chattanooga TN	W BellSouth Mobility	AMPS
Chattanooga TN	NW Cellular One	AMPS
Wichita KS	W SW Bell Mobile	AMPS
Wichita KS	NW Cellular One	AMPS
Charleston SC	W United TeleSpectrum	AMPS
Charleston SC	NW Cellular One	AMPS
San Juan PR	W Puerto Rico Telephone	AMPS
San Juan PR	NW San Juan CellTel Co.	AMPS
Little Rock AR	W Alltel Cellular	AMPS
Little Rock AR	NW Little Rock Cellular	AMPS
Las Vegas NV	W Centel Cellular	AMPS
Las Vegas NV	NW Amecell	AMPS
Saginaw Bay Midland MI	W Century Cellunet	AMPS
Saginaw Bay Midland MI	NW Intercontinental Comm.	AMPS
Columbia SC	W BellSouth Mobility	AMPS
Columbia SC	NW Metro Mobile	AMPS
Fort Wayne IN	W GTE Mobilnet	AMPS
Fort Wayne IN	NW Cellular One	AMPS
Bakersfield CA	W Contel Cellular	AMPS
Bakersfield CA	NW Metro Cellular	AMPS
Davenport Moline IL/IA	W Contel Cellular	AMPS
Davenport Moline IL/IA	NW US Cellular	AMPS
York PA	W United TeleSpectrum	AMPS
York PA	NW York CellTelCo	AMPS
Shreveport LA	W Century Cellunet	AMPS

Table 12 (Page 6 of 7). US Analog Cellular Networks		
Area	**Operator**	**Network**
Shreveport LA	NW Cellular One	AMPS
Beaumont TX	W GTE Mobilnet	AMPS
Beaumont TX	NW Defray Cellular	AMPS
Des Moines IA	W US West	AMPS
Des Moines IA	NW US Cellular	AMPS
Preoria IL	W Centel Cellular	AMPS
Preoria IL	NW US Cellular	AMPS
Newport News VA	W Contel Cellular	AMPS
Newport News VA	NW Cellular One	AMPS
Lancaster PA	W United TeleSpectrum	AMPS
Lancaster PA	NW Abell Cellular	AMPS
Jackson MS	W Alltel Cellular Assoc.	AMPS
Jackson MS	NW Jackson CellTel Co.	AMPS
Stockton CA	W PacTel Cellular	AMPS
Stockton CA	NW Stockton Cellular	AMPS
Augusta GA	W Cellular Phone	AMPS
Augusta GA	NW Cellular One	AMPS
Spokane WA	W US West	AMPS
Spokane WA	NW McCaw Cellular	AMPS
Huntington-Ashland WV	W Independent Cellular Network	AMPS
Huntington-Ashland WV	NW Huntington Cellular	AMPS
Vallejo CA	W GTE Mobilnet	AMPS
Vallejo CA	NW Cellular One	AMPS
Corpus Christi TX	W SW Bell Mobile	AMPS
Corpus Christi TX	NW McCaw	AMPS
Madison WI	W Ameritech Mobile	AMPS
Madison WI	NW Cellular One	AMPS
Lakeland FL	W GTE Mobilnet	AMPS
Lakeland FL	NW Cellular One	AMPS
Utica, Rome NY	W Utica/Rome Cellular	AMPS
Utica, Rome NY	NW Cellular One	AMPS
Lexington-Fayette KY	W BellSouth Mobility	AMPS
Lexington-Fayette KY	NW Cellular One	AMPS
Colorado Springs CO	W US West	AMPS
Colorado Springs CO	NW Providence Cellular	AMPS
Reading PA	W Bell Atlantic Mobile	AMPS
Reading PA	NW Cell Radio Corp.	AMPS
Evansville IN	W Contel Cellular	AMPS
Evansville IN	NW Cellular One	AMPS

Table 12 (Page 7 of 7). US Analog Cellular Networks

Area	**Operator**	**Network**
Huntsville AL	W BellSouth Mobility	AMPS
Huntsville AL	NW Cellular One	AMPS

Appendix B. Mobile Data Networks Worldwide

B.1 Mobile Wireless Data Networks of the World

Table 13. Mobile Data Networks Worldwide

Country	**Operator**	**Network**
Australia	BellSouth	Mobitex 400
Australia	Telecom DataTAC	RD-LAP 800
Belgium	RAM	Mobitex 400
Canada	RAM	Mobitex 900
Canada	ARDIS	RD-LAP & MDC4800 800
Chile	RAM	Mobitex 800
Finland	PTT	Mobitex VHF & 400
France	FTMD	Mobitex 400
France	TDR	Mobitex 400
Germany	De Te Mobile	Mobitex 400
Germany	De Te Mobile Modacom	RDLAP 400
Hong Kong	Pilot	Mobitex
Hong Kong		Datatac
Japan	Nippon City Media	Mobitex
Malaysia		Datatac
The Netherlands	RAM	Mobitex 400
Norway	PTT	Mobitex VHF & 400
Singapore		Mobitex
Singapore		Datatac
Sweden	PTT	Mobitex VHF & 400
Thailand	Pilot	Mobitex
Thailand		Datatac
Thaiwan	GE	EDACS
UK	RAM	Mobitex 450
UK	Hutchison/Motorola	RD-LAP 450
UK	Vodfone Paknet	X.25 VHF
UK	Cognito	Proprietary VHF
USA	RAM	Mobitex 900
USA	ARDIS	RD-LAP & MDC4800 800
Venezuela	RAM	Mobitex 800

List of Abbreviations

ADC	American Digital Cellular
AM	Amplitude Modulation
AMPS	Advanced Mobile Telephone System
ANSI	American National Standards Institute
APA	All Points Addressable
ARQ	Automatic Repeat Request
ASK	Amplitude Shift Keying
ARDIS	Advanced Radio Data Information System
ATIS	Advanced Traveler Information System
AUC	Authentication Centre
AWGN	Additive White Gaussian Noise
BPSK	Bi-polar Phase Shift Keying
BRS	Base Radio Station
BSC	Base Station Controller, also Binary Synchronous Communication
BSK	Binary Shift Keying
BTS	Base Transceiver Station
CA	Collision Avoidance
CB	Citizens Band
CCIR	Comite Consultatif International des Radio Communications
CCITT (now ITU-T)	Comite Consultatif International des Telegraphes et Telephones
CD	Compact Disk, also Collision Detection
CDMA	Code Division Multiple Access
CDPD	Cellular Digital Packet Data
CEN	Comite Europeen de Normalisation
CENELEC	Comite Europeen de Normalisation Electrotechnique
CEPT	Conference du Post et Telecommunications
CISPR	Comite International Special Perturbations Radio
COST	Cooperation Europeen dans la domaine de la recherche Scientifique et Technique
CSMA/CA	Carrier Sense Multiple Access / Collision Avoidance
CSMA/CD	Carrier Sense Multiple Access / Collision Detection
CT	Cordless Telephony
D-AMPS	Digital AMPS
DBS	Direct Broadcast Satellite
DC	Direct Current
DCS	Digital Communications System, also Data Communications System
DECT	Digital European Cordless Telecommunications
DFWMAC	Distributed Foundation Wireless Media Access Control
DQPSK	Differential Phase Shift Keying
DSSS	Direct Sequence Spread Spectrum
EIA	Electrical Industry Association
EIR	Equipment Identity Register
EIRP	Effective Isotropic Radiated Power
ELF	Extremely Low Frequency
ERP	Effective Radiated Power
ERMES	European Radio Messaging System
ESN	Electronic Serial Number
ESPRIT	European Strategic Programmes for Research and development in Information Technology
E-TACS	Extended Total Access Communication System
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FCS	Frame Check Sequence
FDM	Frequency Division Multiplexing

FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FFH	Fast Frequency Hopping
FH	Frequency Hopping
FM	Frequency Modulation
FPLMTS	Future Public Land Mobile Telecommunication Systems
FSK	Frequency Shift Keying
GMSC	Gateway Mobile Switching Center
GMSK	Gaussian Minimum Shift Keying
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HIPERLAN	High Performance Radio Local Area Network
HLR	Home Location Register
IBM	International Business Machines Corporation
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFRB	International Frequency Registration Board
IGN	IBM Global Network
IMSI	International Mobile Subscriber Identity
IMTS	Improved Mobile Telephone Service
IPX	Internet Packet Exchange
IR	Infrared
ISDN	Integrated Switched Digital Network
ISI	Inter-Symbol Interference
ISM	Industrial Scientific and Medical
ISO	International Standards Organization
ITS	Intelligent Transportation System
ITSO	International Technical Support Organization
ITU-T (formerly CCITT)	International Telecommunication Union - Telecommunication
IVDS	Interactive Video and Data Services
IVHS	Intelligent Vehicle Highway System
JDC	Japanese Digital Cellular
LAN	Local Area Network
LCD	Liquid Crystal Display
LD	Laser Diode
LED	Light Emitting Diode
LEO(S)	Low Earth Orbit (Satellite)
LU	Logical Unit
MAC	Media Access Control
MBS	Mobile Broadband Services
MEO(S)	Medium Earth Orbit (Satellite)
MKK	Radio Equipment Inspection and Certification Institute (Japan)
MPT	Ministry of Posts and Telecommunications (Japan)
MSC	Mobile Switching Center
MSISDN	Mobile Station International ISDN
MSRN	Mobile Station Roaming Number
NA-TDMA	North American TDMA
NMC	Network Management Centre
NMT	Nordic Mobile Telephone
NOS	Network Operating Center
NPRM	Notice of Proposed Rule Making
NRZ	Non Return to Zero
NRZI	Non Return to Zero Inverted
NT	Non Transparent
NTT	Nippon Telegraph and Telephone Corporation
OMC	Operations Management Centre
OOK	On-Off Keying
OSI	Open Systems Interconnection
PAMR	Private Access Mobile Radio
PBX	Private Branch Exchange
PC	Personal Computer
PCM	Pulse Code Modulation
PCMCIA	Personal Computer Memory Card International Association

PCN	Personal Communications Network
PCS	Personal Communications Services
PDA	Personal Digital Assistant
PDM	Polarization Division Multiplexing
PHP	Personal Handy Phone
PHY	Physical Layer
PIC	Personal Intelligent Communicator
PLMN	Public Land Mobile Network
PM	Phase Modulation
PMR	Private Mobile Radio
PN	Pseudo Noise
POS	Point Of Sale
POTS	Plain Old Telephone System
PPM	Pulse Position Modulation
PRM	Private Mobile Radio
PSK	Phase Shift Keying
PSPDN	Packet Switched Public Data Network
PSS	Packet Switched Stream (UK)
PSTN	Public Switched Telephone Network
PTT	Post Telegraph Telephone
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature (Quaternary) Phase Shift Keying
RACE	Research and Development in Advanced Communications Technology in Europe
RADAR	Radio Detection And Ranging
RCR	Research and Development Center for Radio Systems
RDS	Radio Data System
RF	Radio Frequency
RF/NCP	Radio Frequency/Network Control Processor
RSSI	Received Signal Strength Indicator
SDLC	Serial Data Link Control
SDM	Space Division Multiplexing
SFH	Slow Frequency Hopping
SIM	Subscriber Identity Module
SLIP	Serial Line Internet Protocol
SMR	Shared Mobile Radio
SMS	Short Message Service
S/N Ratio	Signal to Noise Ratio
SNA	Systems Network Architecture
SSB	Single Sideband
T	Transparent
TACS	Total Access Control System
TCP/IP	Transmission Control Protocol/Internet Protocol
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TETRA	Trans-European Trunked Radio
TIA	Telecommunication Industry Association
TIMSI	Temporary International Mobile Subscriber Identity
TTC	Telecommunication Technology Council
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunications System
UV	Ultraviolet
VAN	Value Added Network
VCR	Video Cassette Recorder
VHF	Very High Frequency
VLR	Visitor Location Register
WARC	World Administration Radio Conference
WLAN	Wireless Local Area Network

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