WIRELESS
COMMUNICATION

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chapter 1

Present Scenario in Wireless Communication Systems

Key Topics

- Different types of communication systems (in general)
- Wired vs wireless communication
- Different types of wireless systems
- Present scenario and requirements
- Evolution of wireless systems
- 1G, 2G, 3G, and 4G wireless systems
- Licensed and unlicensed band communication

Chapter Outline

The book mainly covers wireless digital communication. Though it is assumed that the reader of the book is familiar with the basic theory of communication, many required concepts are revised as a ready reference, starting from this chapter. The students of this generation must be familiar with the wireless communication systems, both conventional and latest. This chapter discusses wireless systems. It explores the need for and scope of the best developments in wireless communications in India and other countries, which is possible only if the standards used today for wireless systems are known. Evolution of a system is linked with the previous systems and the new system is designed by looking into the problems of the previous systems and eliminating them. Hence, the development scenario of 1G to 4G is also necessary to be known. Once this background is created and students start studying these from the root level of the wireless link, considering each and every stage of the wireless link, every part of the theory and its application to the system can be correlated and best solutions can be found out for the 'anywhere, anytime' communication scenario.

1.1 INTRODUCTION

There are dual possibilities in all of the following while dealing with communications with the two hardware ends, a *transmitter* and a *receiver*.

- The input (or baseband) signals may be analog or digital.
- The channels may be wired (guided) or wireless (unguided).
- The transmissions may be analog or digital.
- The number of bits sent at a time may be serial (one bit at a time) or parallel (more bits at a time, i.e. symbols).

- The communication may be baseband or passband (general word for broadband/wideband).
- The mode of communication may be synchronous or asynchronous.
- The information may be real-time or non-real-time (stored data).
- The direction of transmission may be unidirectional or bidirectional.

Out of the two possibilities, only one can exist at a time. To have the combination of both possibilities, either conversion or convergence in the system is required. Because of the two possibilities in the input signals and the two possibilities in the transmissions, according to the theory of binary, four combinations of communication systems are possible, as described in Section 1.1.1. The analysis of the systems may be done by using a qualitative approach first and then a quantitative approach and analysing first the ideal system and then the actual system, with noise.

For studying wireless digital communication, some basic knowledge of other fields of electronics is also required. They are mentioned in Fig. 1.1.

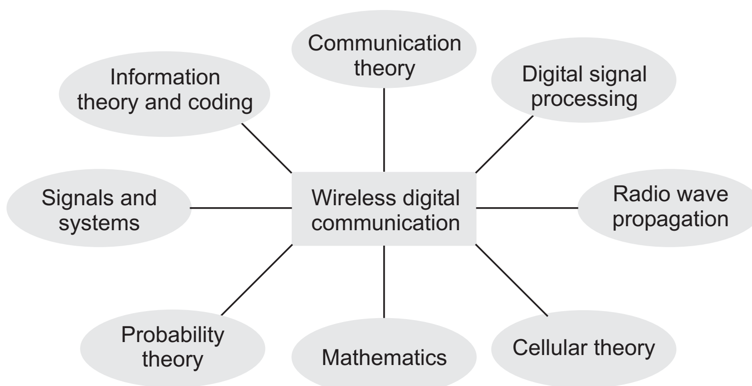

Fig. 1.1 Required knowledge of other fields for understanding wireless digital communication

1.1.1 Different Types of Communication Systems

The communication systems can be of four different types in general as mentioned previously (they may be wired or wireless) and are explained below. Digital input analog transmission type of system is mainly categorized as wireless digital system (except wired line communication through MOdulator+DEModulator (MODEM)). Pulse code modulation (PCM) scheme, which exists for analog-to-digital conversion (ADC), is considered in the source coding stage of wireless communication link, though it is the method for analog input-digital transmission. Here different types of systems and the corresponding modulation schemes are described for a proper visualization.

Analog Input-Analog Transmission

These types of systems were designed for the very first time. Wireless communication commercially started with AM (amplitude modulation) radio broadcasting in the 550 to 1600 kHz range. Thereafter, FM (frequency modulation) transmissions also started commercially in the band from 88 to 108 MHz. In both these systems, the input was in the analog form of audio signal. These broadcast systems still exist. When the analog television standards were framed, AM was selected for video information and FM for audio information, for combined audio and video transmission. These standards are still followed to maintain the compatibility with the older televisions and follow the VHF and UHF ranges. In cable TV also, analog transmission method is used. In local loops of wired telephone lines, analog baseband signal is transmitted without modification in the signal.

The recent age is revolutionary and it seems that in the near future, the analog input-analog transmission systems will be obsolete. Transient period of revolution has already started with digital broadcast systems employing A-D-A conversion stages with the standards, digital audio broadcasting (DAB) and digital video broadcasting (DVB). High definition radio (HD Radio) and digital radio mondiale (DRM) systems are also coming up. All these systems follow orthogonal frequency division multiplexing (OFDM) modulation scheme, which is suitable for long-distance communication and hence for broadcasting.

Analog Input-Digital Transmission

Digital transmission in its baseband form is suitable for transmission only on the wired lines. To achieve this, analog-to-digital conversion is required and the PCM scheme can achieve this. Over the telephone trunk lines or over the integrated services digital network (ISDN) or broadband ISDN (B-ISDN) B channels, PCM signals of 64 kbps bit rate are transmitted. Another method for analog input digital transmission is delta modulation (DM), but because of its practical limitations related to slope overload and sampling rate, it is not standardized in commercial systems. PCM signals can also be converted into frames for transmissions over wired links of computer networks. Differential pulse code modulation (DPCM) and adaptive DPCM (ADPCM) are the modified and efficient versions of PCM.

Thus, PCM is the important scheme in the present scenario. It forms the basis for the source coding stage of the wireless link for digital communication by providing A to D conversion of the real-time input signals, like voice, image, and video. It is described in detail in Chapter 3.

Digital Input-Digital Transmission

When it is necessary to send the digital information in its baseband form, the binary form of transmission may not be always suitable, as it may not be compatible with the transmission channel or because it adds the DC level in the final transmission, which causes more energy in the signal. We need to convert the form of transmission by changing the bit representation format/voltage levels for shaping of signal power and also incorporating the synchronization points in the signal. In short, we can shape the signal for the desired spectrum characteristics for digital baseband communication. *Non-return-to-zero* (NRZ), *return-to-zero* (RZ), Manchester, differential Manchester, bipolar, etc., are the methods that have a final digital form of transmission. These methods are normally suitable for the wired line or mostly in computer networks; however, they are sometimes incorporated in wireless links. These methods are also called *digital signalling*; they are a suitable form for ISDN lines. It is also called *line coding* and can be applied to digital baseband.

Line coding can be applied to digital baseband in wireless communication before the modulation stage. It is described in Chapter 2.

Digital Input-Analog Transmission

This type of transmission is mainly used in the systems that use the MODEMs either over wired line or wireless links. Here modulation scheme converts the input digital signal into an analog form for the transmission. Final Wireless communication is always possible in the analog form only. If the wireless transmission is required and the frequency after modulation does not fall into the RF range, it is necessary to use an RF upconversion stage. If the wired communication is used, only data modem is required without upconversion stage. Amplitude shift keying (ASK), frequency shift keying (FSK), M-ary phase shift keying (M-PSK), M-ary quadrature amplitude modulation (M-QAM), minimum shift keying (MSK), spread-spectrum modulation (SSM), orthogonal frequency division multiplexing (OFDM), etc., fall into this category. The details of each modulation scheme are covered in Chapters 7, 8, and 9.

1.1.2 Wired vs Wireless Communication

The existing systems are not all wireless; a few are wired. Fundamentals of both types of media are described here, so that the questions like 'how both the communications differ' and 'what kind of conversions are required for the converged system' may be answered.

The electrical signals on an open wired line, such as a twisted pair, travel at a velocity of light, which is determined by the expression

$$v = \frac{1}{\sqrt{\varepsilon\mu}} \tag{1.1}$$

where ε and μ are the permittivity of free space (capacitance per unit length measured in farads/metre) and the permeability of free space (inductance per unit length measured in henries/metre), respectively. In free space $v = 3 \times 10^8$ m/sec, given that $\varepsilon = 9.854 \times 10^{-12}$ F/m and $\mu = 4\pi \times 10^{-7}$ H/m. The signal travels as an electromagnetic (EM) wave just outside the wires (radiation). It differs from a free space EM wave (such as the one launched by a TV, radio, or mobile antenna, which spreads out in all directions) only in that it is bound to and guided by the wires of the transmission line.

When do two connecting wires become a transmission line? It is when the capacitance and inductance of the wires act as 'distributed' instead of 'lumped'. This begins to happen when the wire approaches dimensions of a wavelength (wavelength λ and frequency f are related by $\lambda = v/f$). At sufficiently high frequencies, when the length of connecting wires between any two devices, such as two computers, is in the order of a wavelength or larger, the voltages and currents between these two devices act as waves that can travel back and forth on the wires. Hence, a signal sent out by one device, propagates as a wave towards the receiving device and the wave is reflected unless the receiving device is properly terminated or matched. Of course, if we have a mismatch, the reflected wave can interfere with the incident wave, making communication unreliable or even impossible. Proper termination of a wired link is important when networking computers, printers, and other peripherals, which must be properly matched to avoid reflections.

Three different wired media are mainly popular:

1. Twisted pair wirelines, unshielded twisted pair (UTP) and shielded twisted pair (STP), for conventional landline telephone system, 10BaseT Ethernet cabling, etc.
2. Coaxial cable for closed circuit TV (CCTV) and cable TV Network, Ethernet 10Base2, 10Base5 cabling, etc.
3. Optical fibres for long distance communications, B-ISDN, fibre distributed data interface (FDDI), local area network (LAN), synchronous optical network (SONET), etc.

The first two wired media provide a reliable, guided link that conducts an electric signal associated with the transmission of information from one fixed terminal to another. Wires act as filters (due to lumped resistance and capacitance) that limit the maximum transmitted data rate of the channel because of band limiting frequency response characteristics. Twisted pair wireline can support typically 250 kbps bit rate while a coaxial cable may support typically 300 Mbps. The signal passing through a wire also radiates EM waves outside of the wire to some extent that can cause interference to nearby radio signals or to other wired transmissions as a noise. These characteristics may differ from one to another wired medium. Laying additional cables in general can double the bandwidth of wired medium and in no any other way.

Optical fibre is a dielectric guided medium which passes the information through itself in the form of a light wave. The carrier frequency range is of the order of 10^{14} Hz. Ideally optical fibres have infinite bandwidth but in practice, due to limitations of sources and detectors and dispersion effect, the bit rate up to Tbps (terabits per second) is achieved over high-grade optical fibres. It exhibits pulse spreading effect due to the dispersion and hence bit errors may occur. Dielectric medium supports more than one frequency to pass through it and such is the case in optical fibres in form of *wavelength division multiplexing* (WDM). Wireless medium (which is also dielectric in nature) supports more than one frequency at a time. All the links undergo the effect of white noise.

Compared to wired media, the wireless medium is unreliable, though ideally infinite, it has a low bandwidth, effectively due to delay spread and ISI effects described in Chapter 5. However, it supports mobility due to its tetherless nature. Different signals through wired media are physically conducted through different wires, but all wireless transmissions share the same medium, air, in form of unguided electromagnetic wave released through an antenna of supporting bandwidth. Thus, it is the frequency of operation and the legality of access to the band that differentiates the variety of wireless services. Wireless networks operate around 1GHz (cellular), 2.4 GHz [personal communication systems (PCS) and wireless LANs], 5 GHz (wireless LANs), 28–60 GHz [local multipoint distribution service (LMDS) and point-to-point base station connections], and 300 GHz satellite ranges and IR frequencies for optical line-of-sight communication/laser communication. These bands are either licensed, like cellular and PCS bands, or unlicensed, like the ISM (**I**ndustrial, **S**cientific and **M**edical) bands or U-NII bands. As the frequency of operation and data rates increase, the hardware implementation cost also increases and the ability of a radio signal to penetrate walls decreases. The electronic cost has become less significant with time. For frequencies up to few GHz, the signal penetrates through the walls, allowing indoor applications with minimal wireless infrastructure inside a building. At higher frequencies, a signal generated outdoors does not penetrate into buildings and a signal generated indoors stays confined to a room. This phenomenon imposes restrictions on the selection of a suitable band for wireless application.

Capacity improvement is a continuous issue for the scientists to combat for wireless systems. Wired media provide an easy means to increase capacity; we can use more wires, where and when required, if it is affordable. With the wireless medium, we are restricted to a limited available band for operation, and we cannot obtain new bands or easily duplicate the medium to accommodate more number of users in a system. As a result, researchers have developed a number of techniques to increase the capacity of that wireless system to support more users with a fixed bandwidth. A method for wireless cellular systems, like frequency reuse, is comparable to laying new wires in wired systems. If the two cells of same frequency are at a sufficient distance, the same frequency can be reused for interferenceless communication in both the cells. The theory is described in Chapter 11. Even one may reduce the size of the cells to overcome the demand of the population. In a wireless system, reducing the size of the cells by half allows twice as many users as in one cell. Reduction of the size of the cell increases the cost and complexity of the infrastructure that interconnects the cells. Capacity issues are highlighted in Chapter 11 for the various technologies implemented over cellular infrastructure. Multiple access schemes also help to accommodate more users.

There appears to be a tremendous potential for improving capacity by using smart antenna systems. Single input-multi output (SIMO), multi input-single output (MISO), and multi input-multi output (MIMO) systems are described in Chapter 15. Capacity increment by 300 to 400 per cent is possible in cellular environments with such techniques; compared to single input single output (single antennas at transmitter and also at receiver) system. Even OFDM can support multiple users with multi carrier communication in the cellular environment.

1.1.3 Types of Wireless Systems

Basically there are two types of wireless communication systems:

1. Wireless broadcast systems, in which the user is always at the receiver end.
2. Wireless networks, where multiple users can exchange their information, being a transmitter or a receiver independently.

Hence, accordingly, the wireless link requirements will be different. The modulation schemes are also selected according to the suitability of the system.

Wireless Broadcast Systems

These kinds of systems do not require the cellular structure or device identification numbers except some special systems. The transmissions are with a single transmitter and of sufficiently high power amplification. Within the predefined range anybody can receive the transmissions with the help of user receiver set. They are mainly frequency tuning based communications. The examples of such systems are AM/FM radio, television, direct-to-home (DTH), DAB, DVB systems.

Wireless Networks

These types of systems are mainly based on cellular infrastructure or ad hoc connections, e.g. mobile telephone network and universal mobile telecommunication system (UMTS), wireless LAN, and mobile Internet, based on personal domain/cell support. For cell-based systems, at least one transmitter per cell is required. They are low power transmitters as compared to the broadcast systems. The transmitters (or transceivers) of different cells may be interlinked to form a path between the destination and source devices. They are frequency tuning plus identification number or address-based communications. Ad hoc networks do not require cellular infrastructure.

With this fundamental understanding, one can start the study of wireless digital communication to have the proper visualization of the system. We shall start our study with a comprehensive presentation on existing scenario of the wireless systems because the readers may be familiar with these applications as they might be the users.

1.2 EXISTING TECHNOLOGIES

There is an increasing demand for broadband/wideband wireless communication systems due to requirement of high-speed communications (mobile Internet, wireless video transmissions, etc.). At the same time, the telecommunications industry faces the problem of providing telephone services to rural areas, where the customer base is small, but the cost of installing a wired phone network is very high. One method of reducing the high infrastructure cost due to a wired system is to use a fixed wireless radio network. The problem with this is that to enable the rural and urban areas to communicate, large cell sizes are required to obtain sufficient coverage. It results in problems caused by the large signal path loss and long delay times in multipath signal propagation due to long distances. If we design more number of cells for the rural area, it would be an inefficient, costly affair due to low population density. Hence, a modulation technique should be introduced in the systems, which covers longer distance eliminating the problems of wireless channel.

However, researchers in wireless digital communication still face problems, such as multipath delay compensation, speed of communication or high bit rate communication, and efficient use of available spectrum and spectrum efficiency improvement for accommodating more users and applications.

Currently, *global system for mobile telecommunications* (GSM) technology is being applied to wireless telephone systems even in rural areas. However, GSM uses frequency division multiple access/time division multiple access (FDMA/TDMA) with frequency reuse, which has limited frequency channels to communicate and with a high symbol rate, leading to problems with multipath causing intersymbol interference (ISI). Hence, there is a need for a scheme that can give no ISI effects at high-speed communications. Even afterwards, the enhanced data rate for GSM evolution (EDGE) technology is also introduced for higher bit rate. Many service providers compete with each other providing maximum possible coverage for mobile telephony. They also try to introduce the latest services to the subscribers to acquire the market. General packet radio service (GPRS) is the protocol by which packet radio is made possible and hence data services are added to the GSM system. It is designed to have wireless Web access through mobile telephony service providers.

All basic methods are tried by the scientists and engineers. Several techniques are under consideration for the fourth generation of digital phone systems—land mobile communication as well as wireless ATM, with the aim of improving cell capacity, multipath immunity, security, and flexibility. These include wideband code division multiple access (WCDMA) and the latest development is the emergence of a new multicarrier modulation (MCM)/multiple access technique, namely orthogonal frequency division multiplexing or multiple access (OFDM or OFDMA). Both these techniques could be applied to provide a fixed wireless system for rural areas. However, each technique has different properties, making it more suited for specific applications. The combinations of both these schemes are also considered to overcome the limitations of both the systems.

With CDMA systems, all users transmit in the same frequency band using specialized separate orthogonal codes as a basis of channelization (described in Chapter 10). The transmitted information is spread over the spectrum by multiplying it with a wide bandwidth pseudo-random sequence. Both the base station and the mobile station know these random codes, which are used to modulate the data sent, allowing it to de-scramble the received signal.

The OFDM is for multiple-user access and allows many users to transmit in an allocated band simultaneously, by subdividing the available bandwidth into many narrow bandwidth carriers (described in Chapter 9). Information is allocated to several carriers in which to transmit their data, so that the bits on each subcarrier are much longer, drastically reducing ISI. Thus, it provides the concept of multicarrier modulation (multiple carriers for one digital baseband signal) rather than the conventional single-carrier modulation. The transmission is generated in such a way that the carriers used are orthogonal to one another, non-interfering with each other and thus allowing them to be packed together much closer than standard frequency division multiplexing (FDM). This leads to OFDM providing a high spectral efficiency. Presently, OFDM is used as a physical layer standard in IEEE 802.11a/g and 802.16x protocols, HIPERLAN protocols (Japan), DAB, and DVB. HDradio is a new concept developed based on OFDM to have CD-like quality of audio reception.

It is the requirement of time that all the existing systems should be converged and total wireless scenario is expected to cover the entire world. It will bring in a new era in communication. Using these technologies, wireless connections with mobility can be maintained directly to the people and information can be made available whenever they want it. Newly designed mobile devices can support many technologies in one device along with conventional mobile telephony. Essential wireless technologies that are coexisting are ultra-wideband (UWB), Wi-Fi, Bluetooth, and various 3G technologies like WCDMA and wireless access protocol (WAP). These technologies are working synergistically to meet unique users' needs. It is likely that no single broadband wireless technology will achieve dominance over another.

It is necessary to know about the suitability of a particular technology in a particular application. The UWB is most suitable for very small networks supporting a very high bit rate. Wireless personal area networks (WPANs) are very small networks within a confined space, such as an office workspace or a room within the home and using Bluetooth standard. The UWB technology offers to WPAN users a much faster service, short-distance connection and are currently under development. WLANs have a broader range than WPANs, typically confined within office buildings, stores, homes, etc. Intel has developed Intel Centrino Mobile Technology for Wi-Fi, which is gaining popularity. Wireless metropolitan area networks (WMANs) cover a much greater distance than WLANs, connecting buildings to one another over a broader geographic area. The emerging WiMAX technology (802.16d today and 802.16e in the near future) will further enable mobility and reduce dependence on wired connections. Wireless wide area networks (WWANs) are the broadest range wireless networks and they are most widely deployed today in the cellular voice infrastructure although they have the ability to transmit data. Next generation cellular services based on various 3G technologies will significantly improve WWAN communications.

It is now a challenge to cover the global wireless communication and for that universal mobile telecommunication system (UMTS) project is undertaken by engineers for ten years. It is the standard for universal telecommunications standardized by IMT 2000. Using WCDMA, the standards are developed for the system even for indoor and outdoor communication. Table 1.1 summarizes some of the present wireless digital communication-based systems that are already in practice. Table 1.2 gives a comparison chart for existing and upcoming technologies for wireless networking.

Table 1.1 Summary of existing wireless digital communication-based applications

Application	Existing Standard/Technology Used
Mobile telephony (digital cellular telephony)	GSM, CDMA (IS-95 to CDMA 2000), WCDMA-UMTS
Wireless LAN/MAN/WAN	IEEE 802.11(Wi-Fi), 802.16(WiMAX), etc.
Personal area communication	Bluetooth
Digital audio broadcast, HD radio, DRM	DAB
Digital video broadcast, DTH through Satellite	DVB
Mobile satellite communication, Global communication	Iridium, UMTS, GPS
Mobile Internet access	GPRS, Mobile IPv6, WAP
Wireless local loops	DECT, CorDECT, CDMA, GSM
Mobile adhoc networks	All WLAN/WMAN standards and Bluetooth, sensor N/w

Table 1.2 Comparison of most recent wireless networking technologies

	EDGE	CDMA 2000/1 x EVDO	Blue-tooth	Wi-Fi	Wi-Fi	Wi-Fi	WiMAX	WiMAX	WCDMA/ UMTS	UWB
Standard usage	2.5G WWAN	3G WWAN	802.15.1 WPAN	802.11a WLAN	802.11b WLAN	802.11g WLAN	802.16d WMAN Fixed	802.16e WMAN Portable	3G WWAN	802.15.3a WPAN
Throughput	Up to 384 kbps	Up to 2.4 Mbps (typical 300–600 Kbps)	Up to 720 kpbs	Up to 54 Mbps	Up to 11 Mbps	Up to 54 Mbps	Up to 75 Mbps (20MHz BW)	Up to 30 Mbps (10MHz BW)	Up to 2 Mbps (Up to 10 Mbps with HSDPA techno-logy)	110 – 480 Mbps
Range	Typical 1–5 miles	Typical 1–5 miles	Up to 30 feet	Up to 300 feet	Up to 300 feet	Up to 300 feet	Typical 4–6 miles	Typical 1–3 miles	Typical 1–5 miles	Up to 30 feet
Frequency	1900 MHz	400, 800, 900, 1700, 1800, 1900, 2100 MHz	2.4 GHz	5 GHz	2.4 GHz	2.4 GHz	2–11 GHz	2–6 GHz	1800, 1900, 2100 MHz	7.5 GHz

1.3 EVOLUTION IN WIRELESS SYSTEMS: TOWARDS WIRELESS EVERYWHERE

The communication link requires a transmitter, a channel, and a receiver to transfer the information—maybe in unidirectional or bidirectional manner. Here the real-time signals and data must be modified in accordance with the channel characteristics and also in the suitable detectable format so that they can be communicated reliably through the media. For the transmission, wired or wireless media can be chosen. As the wireless systems are more portable and easy to carry, it is becoming more and more popular. In the present scenario, we have combination systems that may have wired infrastructure with an extensive wireless support, e.g., mobile telephony integrated with the landline public switched telephone network (PSTN) and also with the Internet. In future, it is expected that every system will be totally mobile. In Fig. 1.2, it is shown that the highest mobility is achieved with UMTS with a little

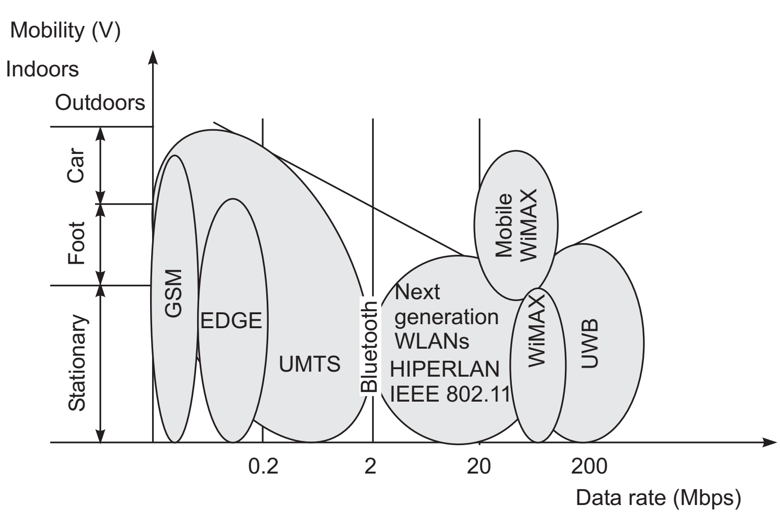

Fig. 1.2 Mobility and bit rate both are increasing with the generations

compromise on the bit rate. However, in IEEE 802.16e mobile wireless broadband access system, the solutions are found to have vehicular mobility with higher bit rate.

At the same time, digital systems are more advantageous in terms of performance compared to analog systems. It is easy to use processor or computer support, have digital signal processing, handle the bit errors, and store the data. It is the age when the concept of ‘digital everywhere’ is adopted by the masses. The people have experienced the excellent performance of digital systems and they demand such a quality even in wireless applications. In short, wireless digital communication based systems are in great demand.

Basically, by *wireless digital communication,* we mean that the focus is on the main link (transmitter+channel+receiver) and its fundamentals for communication, including various blocks of processing the information signal, which are introduced in Chapter 2 onwards. Here it is necessary to know the various methods of modifying the data or real signals, modulation schemes, channel characteristics, receiving methods, etc. Cellular theory forms the systematic platform to have the infrastructure to develop the wireless digital communication based multiple users’ links without interference. (i.e., a system development can be possible). Due to cell concept, users can be identified uniquely even in the mobility mode. In *mobile communications*, the main focus is on the cell-based wireless multiuser telecommunication systems, for which the standards and protocols are developed to get them communicated. Here the user is assumed to be either in steady or in mobility mode. The aim of wireless communication is to optimize the physical link while that of mobile communication is to optimize the whole system, including higher layers.

Actually, wireless communications were started specially for military purpose. Gradually, the development is observed in computers, *digital signal processing* (DSP), VLSI etc., which made possible the development of portable, sophisticated wireless units, such as decent mobile phones, Centrino technology based laptops, and palmtops. Digital signal processing has become the unavoidable part of the existing wireless systems. wireless communication systems of present age are mostly based on DSP processors, VLSI/ASIC/FPGA chips, microstrip RF circuits, and PC interface. In Fig. 1.3, it is mentioned that the faster DSP processors (compared in terms of MIPS) are incorporated with the systems to make the higher bit rate support. Sophisticated software products are developed and hence the amazing applications have been possible in multimedia. People enjoy the services like local/STD/ISD mobile calls, SMS/MMS, chat, wireless FAX and e-mail, and mobile Internet access.

Wireless systems are now popular worldwide to help people and machines to communicate with each other irrespective of their location. Cellular system is the most common platform even for the future systems. Using that, in near future, we shall have the numerous options to set up an unwired connection over radio interface. One of the slogans of the wireless communication systems (4G) is ‘always best connected’ meaning that wireless equipment should connect to network or system that at the moment is ‘best’.

It is necessary to have the frequency planning for various wireless systems to coexist. Wireless channel is an unguided dielectric media and hence the frequency ranges it can support are ideally infinite. Still due to many reasons, full available spectrum cannot be

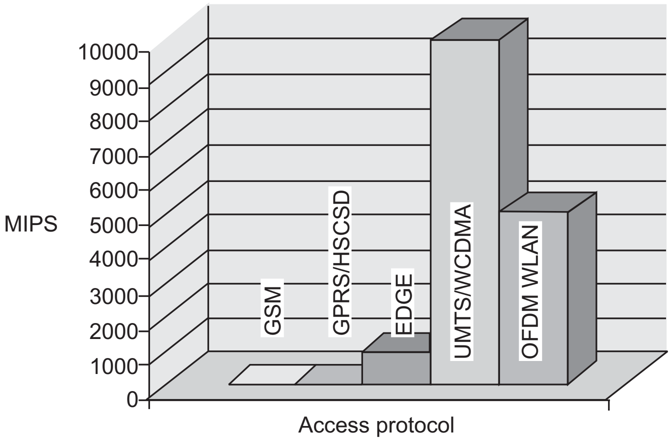

Fig. 1.3 Processing power requirement for wireless protocols and standards according to complexity of hardware MIPS=million instructions per second (It is the measure to compute the speed of DSP processor.)

utilized. The RF and the above range utilized for wireless communication are systematically shared; different ranges are used for different applications. Various connection ranges from the satellites provide a low bit rate but global coverage and cellular system based mobile satellite communication provides connections with a high bit rate. Contradictorily local area network and personal area network provide maximum range of few to hundred metres. If the systems have to coexist, they would obtain a crowded frequency spectrum, since there are many factors that want their share of the limited frequency resource. To use the signal strategies that are spectrally efficient is thus of utmost importance. The current trend to achieve high spectral efficiency is by using the adaptivity on all four dimensions: time, frequency, power, and phase.

The requirements of wireless communication in short are as follows:

- High speed/high bit rate
- High spectral efficiency
- Zero ISI/ICI
- Converged
- Anywhere, anytime
- Global coverage
- Multimedia supported
- Wireless
- Digital communication systems.

Latest techniques like WCDMA, OFDM, hybrid OFDM, and MIMO will fulfill most of the requirements mentioned above. Also a new approach, software defined radio, is coming up with the same set of hardware but different programs used to have the different channel coding or modulation schemes.

1.3.1 1G, 2G, 3G, AND 4G WIRELESS SYSTEMS

There is no specific measure to calculate the years of generation. Rather than that, the generations are measured on the basis of the considerable innovations in the standards and applications. Analog systems are considered as the start-up and hence they are known as first-generation systems. The systems of other generations are illustrated in Fig. 1.4.

Again it is very difficult to distinguish the systems on the basis of generations. For simplicity, complete analog systems mainly dealing with audio (except television with analog video) are classified as first-generation systems, also analog mobile phone systems (AMPS). Partially analog and digital systems are classified as 2G systems, where audio and images were communicated. Bit rate was very low around 10 to 50

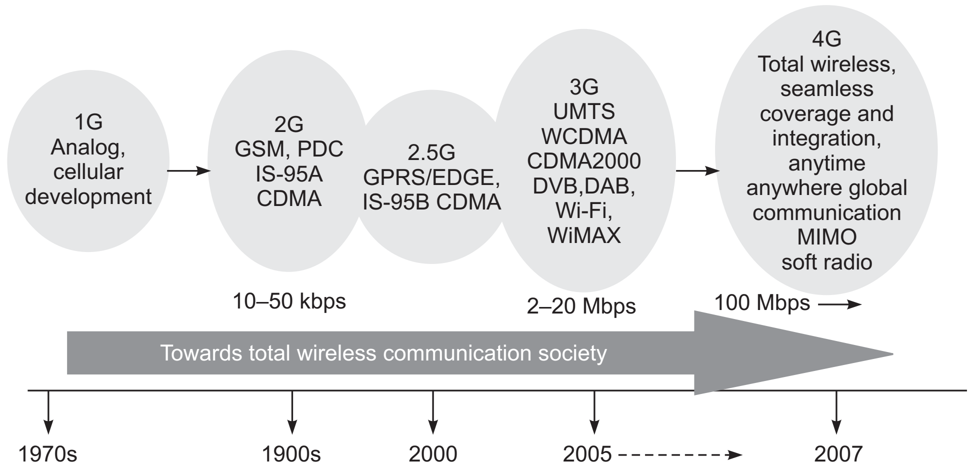

Fig. 1.4 Generations in wireless digital communication: moving towards high bit rate and mobile IP

kbps. Fully digital systems with audio, image, and video are classified as 3G with tremendous rise in the bit rate, of the order of 2 to 20 Mbps, in Wi-Fi and WiMAX even up to 54 Mbps. In 4G high-speed, fully digital, anywhere, anytime, and converged, wireless communication is expected with total multimedia. The expected bit rate may reach up to 100 Mbps or more in wireless manner. With evolution in WiMAX standards and UWB, development in the 4G systems has been started.

Why does a wireless channel face the problem of high bit rate? The channel faces the problem of delay spread due to multipath fading, meaning that the channels are time dispersive; it is discussed in detail in chapter 5**.** Spreading results in merging of two consecutive pulses. If the bit rate is too high, the bit duration is less and hence due to merging of two consecutive pulses, it is very difficult to identify two separate pulses. This limits the bit rate of the system. Higher order M-PSK and diversity mitigation techniques like MIMO or multicarrier technique like OFDM can eliminate the problem of higher bit rate.

The 2G technology for mobile communication originated during 1990s. Before that the conventional telephony was based on wired line. A few military wireless applications, AM, FM, television, radar, and satellite communication systems were the only implemented and known systems to the people. The revolution started with two new systems—the Internet based on wired lines and cellular-based GSM based on wireless channel mainly for voice communication. In the year 2000, GSM had data-transmission enhancement called GPRS, which could use any number of time slots among the total eight slots for sending the data. The technology exists with a data rate of 14.4 kbps to 64 kbps. People found another high-speed data enhancement in GSM, called EDGE, in which modulation scheme is changed from *Gaussian minimum shift keying* (GMSK) to 8-PSK and the transmission data rate can be up to 500 kbps. The GSM system initially was focused on voice services with circuit switching, whereas current 2.5G technology is focused on circuit-switched voice service and packed switched data services.

Major challenges before the implementation of 3G were as follows:

1. Slow production of mobile phones and services.
2. Wireless Internet for exponentially growing users was difficult to implement until IPv6 is implemented. (Refer to any book on computer networks for IPv6. It is the protocol for IP layer and includes IP addresses for mobile networks also.)
3. Global roaming with a single number as proposed was yet to be standardized.
4. Low-cost flexible mobile devices with all desirable features were yet to evolve.

All the challenges were accepted by the scientists and engineers and they developed 3G systems successfully solving major problems and now we are very near to the 4G technologies.

The 3G technology is optimally focused on using a single interface number and an advanced core network. It aims at developing the following features:

1. Anywhere and any time mobile communication with low-cost and flexible hand-held devices.
2. Wireless data access, particularly with wireless Internet connection. This was motivated by exponential growth of the Internet access.
3. High data rate of 2 Mbps or more compared to the previous 2G systems offering 10 to 50 kbps.
4. High-speed multimedia or broadband services causing shift from voice-oriented services to the Internet access (both data and voice) video, graphics, and other multimedia services.
5. Global roaming support and global communication.
6. Use of spectrum around 2 GHz and higher, whereas spectrum allocation for 2G was 800/900 MHz.

The 2G technology offered a quite satisfactory voice communication, but with growing data traffic, the 3G technology has mainly targeted data services, particularly the Internet traffic. The main service component of the 3G technology is quality and reliable data traffic. The journey from 2G to 3G started with intermediate halt on 2.5G providing reliable services with minimal investment. The UMTS is the typical 3G system that uses WCDMA technology as mentioned previously. It has the following aims:

- Data services up to 2 Mbps in rural or urban environment
- Voice over packet switched IP based network
- Good spectral efficiency and low delay
- Complete mobility to the user
- Typical applications:
    - Speech—Teleconferencing and voice mail
    - Message—SMS, e-mail, etc.
    - Switched data—Low-speed LAN, Internet, etc.

Table 1.3 Important UMTS applications and their requirements

Applications or Services	Data Rate Required	Quality of Service Required	Time Critical Data
Messaging (e-mail, etc.)	Low (1–10 kbps)	High	No
Voice	Low (4–20 kpbs)	Low (BER < 1e-3)	Yes
Web browsing	As high as possible (>10–100 kbps)	High (BER < 1e-9)	Depends on the material; generally not time critical.
Video conferencing	High (100 kbps –2 Mbps)	Medium	Yes
Video surveillance	Medium (50–300 kbps)	Medium	No
High quality audio	High (100–300 kbps)	Medium	Yes
Database access	High (>30 kbps)	Very High	No

- Medium multimedia—E-commerce, LAN, and Internet public messaging
- High multimedia—Video clips, on-line shopping, and fast LAN and Internet
- High interactive multimedia—Video telephony and video conferencing

Some important UMTS applications and their requirements are listed in Table 1.3.

1.3.2 Beyond 3G

During the past 20 years, wireless networks have evolved from analog, single-medium (voice), and low data rate (few kbps) system to digital, multimedia, and high data rate (10 to 100 Mbps) system of today.

The International Telecommunication Union (ITU) in July 2003 had made the following requirements for 4G system:

1. At a standstill condition, the transmission data rate should be 1 Gbps.
2. At a moving condition, the transmission data rate should be 100 Mbps.

With these high-speed data systems, many advanced applications for the users can be realized like video streaming. A potential 4G system could be used in the family of OFDM, because OFDM can have a transmission data rate of 54 to 70 Mbps, which is much higher than what the CDMA system can provide. Comprehensive, broadband, integrated mobile communication will step forward into all-mobile 4G service and communication. The 4G technology is developed to provide high-speed transmission, next generation Internet support (IPv6, VOIP and Mobile IP), high capacity, seamless integrated services and coverage, utilization of higher frequency, low mobile cost, efficient spectrum use, quality of service and end-to-end IP system. In short, the 4G requirements are as follows:

- High-speed data communication
- Best quality voice
- Multimedia on mobile
- LAN and intranet/Internet on mobile

1.4 LICENSED AND UNLICENSED BANDS FOR PRESENT-DAY WIRELESS SYSTEMS

The wireless channel is shared by a number of users and frequency ranges are provided systematically to the users or to the services or applications for reliable communication (refer to Chapters 10 and 11). Suppose if a few frequencies are allocated to some cellular mobile operators like Airtel, Hutch, or Idea, they have to pay heavy charges for the allocated ranges. Even satellite channels also are paid channels because of this. Mobile operators cannot have huge private infrastructures, like satellites, and moreover they have to follow government rules. Hence, they have to get the licensed bands for communication. The GSM, CDMA based mobile telecommunications are made over licensed bands.

Presently, few technologies, limited to the user's area without the need for a huge or global infrastructure are developed. Some applications of these technologies are PAN, based on Bluetooth, UWB, and WLAN, based on WiFi, which are the small-area communication systems. The frequency range of operation is 2.4 GHz–5.6 GHz. Actually these bands are the international bands for the scientists and medical officers. Because the systems are not concerned with other such systems at far distances, independent communication is possible. For example, in Bluetooth application, one device with Bluetooth support will search other active Bluetooth devices within a 10 metres area. The list will be displayed on the screen and the device will be selected from the list for the communication. Beyond this range, if any other *Bluetooth device is active*, it will not be concerned with the devices of the previous 10 metre area. These communications are called *unlicensed band communications*. Since they are based on spread spectrum or OFDM technology, secure communication is possible. In spread spectrum techniques, orthogonal codes are present while in OFDM, orthogonal carriers are present.

Summary

- Study of wireless digital communications requires basic knowledge of many other fields.
- Final RF transmission form is always analog but baseband signal inputted to modulation stage decides whether the wireless communication link is analog or digital.
- Wireless digital communication systems are demanded everywhere because of advantages of digital communication with mobility.
- With different combinations of coding and modulation schemes, different response of the wireless systems can be observed. Hence, selection of an optimum set-up of the protocols and standards is a matter of compromise.
- Wireless systems can be categorized on the basis of generations and the generations are formed on the basis of major changes in the communication systems.
- Many different systems and standards are existing presently, which will converge in future and we shall have 'all in one' type mobile devices.
- The expected trends are 'anywhere, anytime' mobile communication.
- Presently, the 3G systems are coming up and also the UMTS system is under development. Development of 4G system has also started.
- Unlicensed (ISM) band communications are allowed only for personal area communica-

tion systems like Bluetooth and operate at 2.4 and 5.6 GHz. For infrastructure-based mobile networks, licensed bands are utilized, in which frequencies are planned out for coexistence of the systems.

- CDMA, OFDM, and their combination along with MIMO will solve most of the problems of the next generation. These will be the technologies of 4G.

Review Questions

1. How are the communication systems classified in general?
2. How are the wireless systems classified? Find out the major changes in the classified wireless systems.
3. What are the systems at present in which partly wired links and partly wireless communication is incorporated? Can you find out the types of cables used in different wired systems?
4. Prepare the list of all the existing communication systems used in everyday life. Out of these, find out which are wired and which are wireless and then prepare a list of the existing wireless systems and the associated standards along with their modulation schemes, bit rate, frequency range of communication, special features, etc.
5. Represent the electromagnetic wave equation with its amplitude, frequency, and phase assuming that the wave is travelling in any one direction.
6. When will a signal be scalar or vector? How can scalars and vectors be represented in mathematical form?
7. Compare AM, FM, and PM techniques of modulation. What are the drawbacks of these techniques that are eliminated in digital modulation techniques?
8. Why is line coding more important for wired line communication?
9. List out the requirements of 4G and from the analysis of the existing standards, find out the points at which we are lacking.

   or

   Which are the areas that should be concentrated upon by the scientists and engineers to have the reliable ‘anywhere anytime’ communication scenario?
10. Develop the wireless digital communication transmitter and receiver requirements in the form of blocks and link them to form basic link diagram.
11. List out the basic requirements of the UMTS system.
12. Compare wired and wireless communication and find out why a higher bit rate is the problem of wireless link and not of the wired link. When does a wired link have the problem of higher bit rate?
13. How can we increase the users’ accommodation capacity on the wired and wireless links?
14. How does licensed and unlicensed band communication differ?
15. Discuss the major changes that took place in the communication systems from first to fourth generation in general. Also discuss separately the changes in the 1G to 4G wireless systems.
16. How can you say that wireless digital communication exhibits interdisciplinary approach?

Multiple Choice Questions

1. Which of the following is the communication system mainly suitable for wireless digital communication?
(a) Analog input-analog transmission
(b) Anlog data-digital transmission
(c) Digital data-digital transmission
(d) Digital data-analog transmission

2. Which of the following is the scheme for creating digital database of real signals?
(a) Pulse code modulation
(b) Manchester coding
(c) Binary conversion
(d) Pulse amplitude modulation

3. Which of the following systems is a 3G system?
(a) Analog cellular system
(b) EDGE
(c) FM
(d) UMTS

4. The capacity of the wireline system can be increased
(a) by TDMA
(b) by random access
(c) by increasing the number of wires
(d) by all of the above methods

5. The protocol for Wi-Fi system is
(a) IEEE 802. 16d
(b) IEEE 802.15.3
(c) IEEE 802.11a
(d) IEEE 802.15.1

6. Which of the following is a system in which long-haul communication is involved?
(a) Mobile satellite communication system
(b) GSM system
(c) WiMAX system
(d) Bluetooth system

7. The systems that utilize ISM band for communication are
(a) GPRS and EDGE
(b) Bluetooth and Wi-Fi
(c) GPRS and Bluetooth
(d) Bluetooth and WiMAX