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Overview of Wireless Communication Systems 1

1.1 Introduction

Communication industry is one of the fastest growing industries with several researchers contributing to make it more efficient with every passing day. Guglielmo Marconi's demonstration of radio telegraphy in 1897 can be regarded as the beginning of the wireless revolution. Since then, wireless systems have been advancing at a very high rate. Owing to the multiple advantages provided by these systems, the customer base is increasing exponentially.

Wireless communication can be implemented using different technologies. Some of the popular choices are infrared and radio frequency. Infrared technology is implemented by transmitting infrared light as a diffused beam or direct beam. For high data rate and effective performance, direct Line Of Sight (LOS) transmission is desirable. Although, this technology is simple, relatively secure and cheap, it is suitable for short-range wireless solutions. Radio frequency technology, on the other hand, is frequently employed for large-range solutions. Popular examples of systems using this technology are mobile communication standards like GSM, cordless phone standards like DECT, satellite communication and so on. Although, radio signals can cover a larger distance, penetrate through obstacles like walls to provide indoor solutions, they suffer from the major problem of security and interference.

In the following sections, the advantages and challenges of wireless communication will be highlighted. The functional blocks that make up the transmitter and receiver entities will be explained. Since, wireless communication entities attached to different systems can

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co-exist, frequency allotment must be done carefully to prevent excessive interference. Different frequency allotment techniques will be explained and finally, popularly employed wireless communication systems will be introduced with their standards.

1.2 Advantages and Challenges

Wireless communication systems have witnessed rapid increase in customer base with more and more subscribers shifting their service from wired counterparts. In this section, the advantages offered by wireless communication are highlighted. The latter part of the section, will focus on the challenges which are faced while designing any wireless system.

Advantages offered by wireless systems

- *Mobility*: One of the most important benefits gained from wireless networks is user mobility support. Any user with portable handsets can move freely within the coverage area and avail uninterrupted service. Consider the case of cellular mobile telephone systems in which the entire coverage area is divided into several non-overlapping cells. Each cell is served by a Base Station and these Base Stations are further connected by wired medium to the backend core network. Any user can move freely within the cell while being served by the same Base Station. If the user moves between cells, control information is handed over to the destination cell Base Station without interrupting the on-going service.
- *Reduced cabling*: In wired networks, every system entity and user entity is physically connected by means of transmission media. Wireless systems can be of two types namely, infrastructure based and adhoc. They can be set up with minimized cabling in case of infrastructure based networks, while in the case of adhoc systems, no cabling is required at all.
- *Easy deployment*: As stated earlier, wireless systems can be set up as either infrastructure based or adhoc. In case of adhoc networks, the wireless nodes self configure to exchange information and data. These systems can be easily deployed which in turn reduces the time and cost of installation dramatically.
- *Flexibility*: Radio signals can penetrate through walls thus allowing both outdoor and indoor solutions, whereas in wired systems, these physical barriers impose restriction.

Design Challenges

The main design challenge in wireless communication is to overcome the adverse effects due to the following reasons:

- *Fading*: The signal in wireless systems carries information over the air interface. It may suffer reflection from obstacles in the propagation path resulting in multi-path propagation. This causes radio signals to reach the destination via a different path, in a different phase and in different time leading to fading. Fading causes random change in signal strength, echoes and frequency variations.

- *Interference*: A wireless entity working at a particular frequency range is prone to interference from any other entity working in the same frequency range. A quantity to measure this is the Signal to Interference Ratio (SIR). In order to have optimum performance, the SIR should be above the determined threshold value.
- *Security threats*: Unlike wired systems, entities in wireless systems are connected by air interface which is prone to eaves-dropping, jamming and unauthorized access attempts. Proper procedure must be maintained to prevent these from hampering a registered user's service.
- *System incompatibility*: Two system entities can communicate with each other only if they are compatible with each other. For instance, a mobile handset supporting frequency around 900 MHz is required for accessing GSM [2G cellular telephone system] service provided by the service operator.

1.3 Wireless System Network Architecture

A wireless communication system is made of several entities which work in close co-ordination in order to provide a desirable service to the registered subscribers. There can be two possible configurations of wireless networks, namely infrastructure-based and adhoc networks.

Infrastructure-based networks: In an infrastructure-based wireless network the backbone is wired and fixed. The subscriber device can access the service over air interface using this fixed backbone network. The authentication, control functions, call routing and so on are all handled by the backbone network. Cellular telephone communication systems and Wireless Local Area Network [WLAN] using Access Points [AP] fall under this category. Figure 1.1 illustrates these two systems. In case of WLAN, APs are installed at suitable locations. The user device communicates by forwarding and receiving packets to and from the AP. The AP acts as a bridge between wireless clients and the backend network. In case of cellular communication systems, the network entities like the Base Station, Base Station Controller, Mobile Switching Centre and other core elements are all connected by a wired transmission medium. The Mobile Station under the coverage of a particular Base Station can send information over the uplink channel and receive information on the downlink channel over the air interface.

Adhoc networks: In an adhoc network there is no fixed backbone network. The wireless devices self configure to form a network where each device can communicate in peer-to-peer mode. The control functions and routing information are distributed amongst all devices. As this type of network configuration needs no fixed network, it avoids the cost and time required for installation. This ease of deployment makes it a popular choice in military and low-cost commercial applications. Figure 1.2 illustrates an adhoc network. Devices in adhoc networks may leave or join the network randomly, Moreover, the Signal to Noise Ratio (SNR) of wireless links between the devices varies with time and distance. This requires updating of the routing table periodically according to the requirement.

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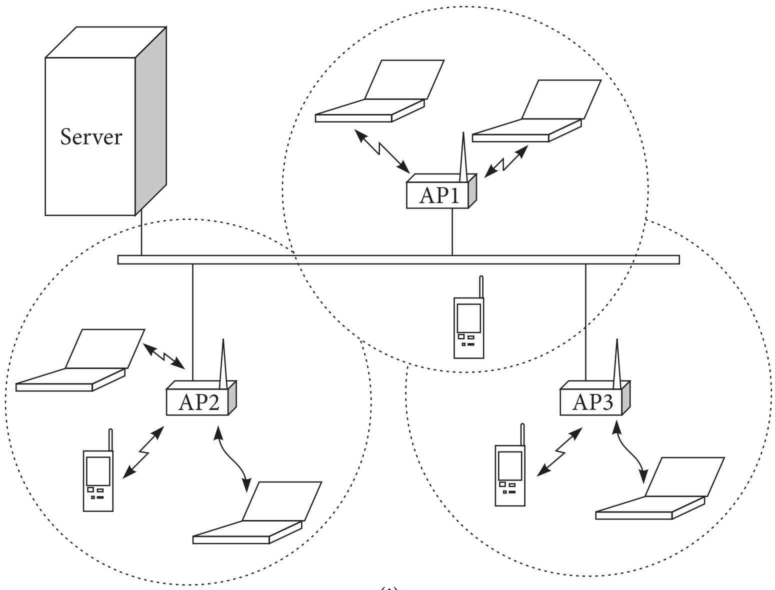
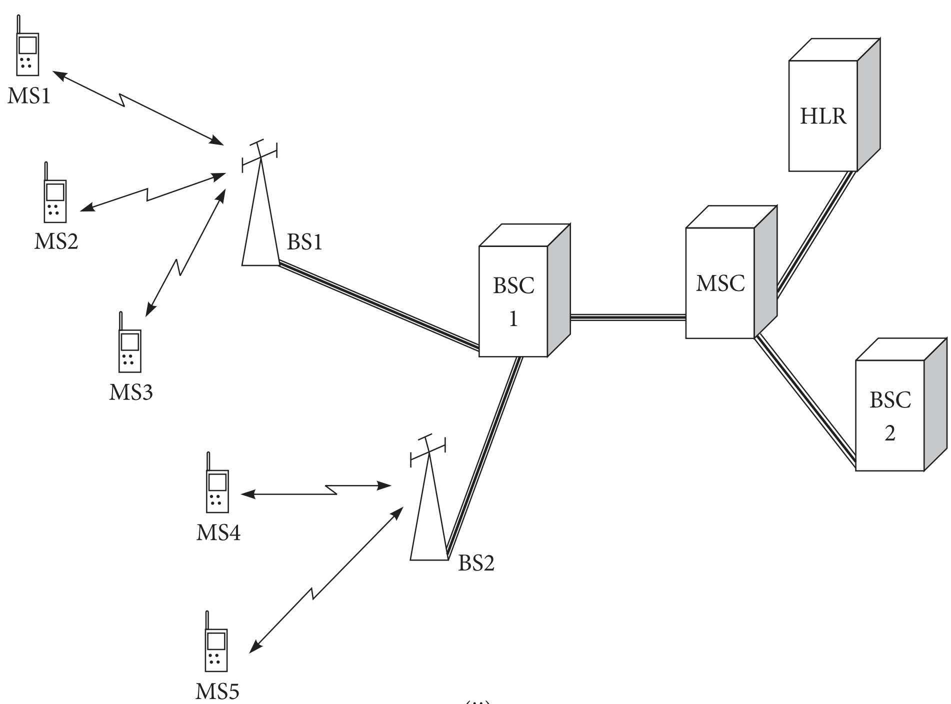


(i)



(ii)

Fig. 1.1 Examples of wireless infrastructure based network: (i) WLAN (ii) Cellular telephone network

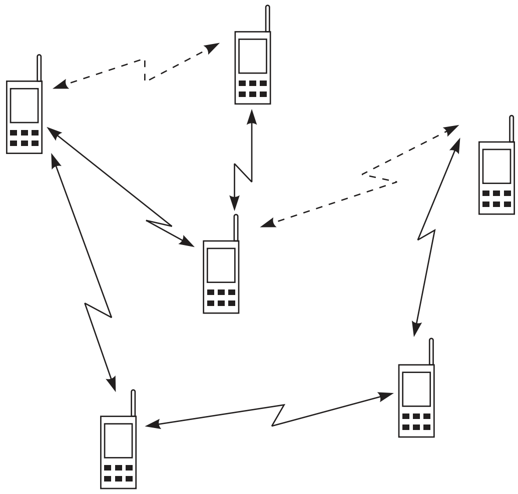


Fig. 1.2 Adhoc network

1.4 Functional Blocks

The earlier generations of wireless system standards used analog communication techniques. With increased system and customer requirements, the communication technique soon shifted from analog to digital. Some of the striking advantages offered by the latter are listed as follows:

- Apart from voice service supported by analog communication systems, digital communication systems can support data, voice and video service. For example, in the case of mobile communications, the first generation standards like AMPS/TACS using analog communication techniques allowed customers to avail voice services. The higher generation beginning from the second generation replaced analog with digital communication techniques and new services like Short Messaging Service (SMS), internet browsing, email service, video calling and the likewere provided to customers under different generation standards.
- The components of digital systems have less power requirement, higher capacity, faster processing speed and smaller dimensions than their analog counterparts
- Digital systems can secure information transmitted over attack-prone air interface by using encryption and authentication techniques
- Error detection, error correction, signal compression and combining techniques can be used in digital systems to remove the degradation caused during signal propagation

Figure 1.3 illustrates the block diagram of a wireless communication system. The transmitter section typically consists of a source encoder, channel encoder, modulator, spread spectrum modulator, power amplifier and transmit antenna system. The receiver consists of blocks which complement the blocks in the transmitter, namely receiver antenna system, receiver front end, spread spectrum demodulator, channel decoder and

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source decoder. The functioning of each block in brief is given here. For a detailed explanation, refer to the chapters included under Part I: Fundamentals of Wireless Communication, of this book.

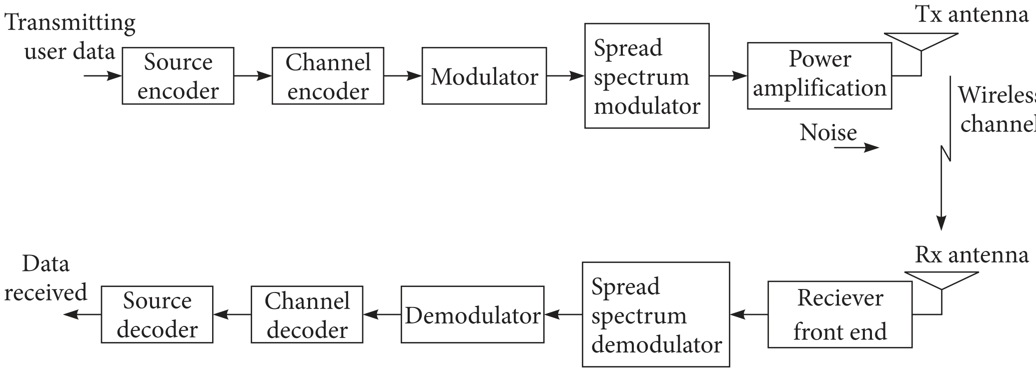

Fig. 1.3 Block diagram of a wireless digital communication system

- ***Source encoder/decoder***: The user generates information that needs to be forwarded to the destination over the air interface. The generated user message contains several redundancies. The primary function of the source encoder is to convert the user message to a format that will reduce the bandwidth requirement yet allow proper reconstruction of the original message at the receiver end using the source decoder. In Chapter 2 on modulation and coding, source coding techniques will be discussed in detail.
- ***Channel encoder/decoder***: The user message in wireless communication travels through the air interface which is highly prone to noise and error introduction. The channel encoder adds systematic redundancy in order to protect the user message from error. The reverse process is done by the decoder at the receiver end. There are two variants of channel codes – error detection code and error correction code. The former code can be used to detect error introduced in the user message while the latter has the capability to correct the error as well. In Chapter 2 on modulation and coding, channel coding techniques will be discussed in detail.
- ***Modulator/demodulator***: The user baseband signals are practically unsuitable for transmission over air. The objective of the modulation process is to convert the baseband signal into a suitable form before transmission. The reverse process is accomplished at the receiver end by the demodulator. In Chapter 2 on modulation and coding, modulation techniques will be discussed in detail.
- ***Spread spectrum modulator/demodulator***: A second line modulation is often performed in wireless communication in order to secure user data – this is done by providing resistance against multi-path effects and jamming. In this method, a wideband signal is used to modulate the user message signal. Demodulating is only possible by the intended receiver which is aware of the modulating signal

pattern. Chapter 4 on spread spectrum technology will discuss the techniques in detail.

- ***Power amplifier/receiver front end***: After processing of the user message is complete, before transmission, a power amplifier is used to amplify the signal strength. For example, consider the case of satellite communication where the propagation distance is very large. If the transmitted signal power is not sufficiently large, due to, atmospheric losses, the signal reaching the satellite may get damaged beyond repair. Hence, the power amplifier serves as an important system component. The receiver front end comprises of entities like the Low Noise Amplifier which amplifies and strengthens the input signal. Although, these amplifiers amplify the noise portion as well, the strength of desired signal is made much higher and hence, is easily detectable.
- ***Transmit and receive antenna***: Antenna are responsible for transmitting and receiving radio frequency signals over the air interface. Chapter 5 will explain the basics of the antenna and will highlight the antenna families used in wireless communication systems.

1.5 Spectrum Allocation Methods

The end users of wireless communication systems including mobile communication, satellite communication, radio broadcasting, television broadcasting and so on, exchange information over the air interface. A portion of the available spectrum resource is allocated to every user during the information exchange process. Efficient working of each wireless communication system is naturally dependent on the available spectrum.

Spectrum is a limited resource whose proper planning and allocation is highly essential to reduce the adverse effects arising from interference and congestion. The International Telecommunication Union (ITU), a specialized agency of the United Nations, is responsible for providing the global regulatory framework. In European countries, the Electronic Communications Committee (ECC) plays a similar role to ITU in providing a regulatory framework. The global regulatory framework is developed with the objective of allocating different frequency range for different services in order to prevent harmful interference.

The spectrum allocation task is achieved in two major steps. They are as given here:

Step I The first step involves allocation of blocks of spectrum through an international agreement for varied services.

Step II The second step involves assignment of licence for use of specific frequencies from the allocated spectrum for specific services by the spectrum regulatory bodies of each nation. Table 1.1 lists the regulatory bodies in different countries.

Licence can be allotted to different companies in each country for different services by following one of the four possible licence allocation methods.

Table 1.1 National regulatory authorities in different countries

Continent	Country	Regulatory authorities
Australia	Australia	ACMA – Australian Communications Authority
Asia	India	TRAI – Telecom Regulatory Authority of India
	Japan	Ministry of Public Management, Home Affairs, Post and Telecommunications
	Sri Lanka	TRCSL – Telecommunications Regulatory Commission of Sri Lanka
	Pakistan	Pakistan Telecommunication Authority
	Iran	CRA – Communications Regulatory Authority of Iran
	Malaysia	MCMC-Malaysian Communications and Multimedia Commission
	Nepal	Nepal Telecommunications Authority
	Bahrain	Telecommunications Regulatory Authority
	Singapore	IDA – Infocomm Development Authority of Singapore
	Taiwan	The Directorate General of Telecommunications
	Jordon	Telecommunications Regulatory Commissions
	Lebanon	Ministry of Telecommunications
	Philippines	National Telecommunications Commission
	Saudi Arabia	Communications and Information Technology Commissions
	Turkey	Telekomunikasyon Kurumu
	United Arab Emirates	Telecommunications Regulatory Authority UAE
Europe	Austria	Telekom Control
	Belarus	Ministry of Post and Telecommunications
	Italy	Italian Communications Authority
	United Kingdom	UK Office of Communication
	Romania	National Regulatory Authority of Communications
	Belgium	Belgian Institute of Postal Service and Telecommunications
	Luxembourg	Institute Luxembourgeois de Regulation
	Bosnia and Herzegovina	The Communication Regulatory Agency
	Greece	National Telecommunications and Post Commission
	Bulgaria	Communication Regulation Commission
	Germany	The Federal Network Agency

Contd...

Continent	Country	Regulatory Authorities
Europe	Czech Republic	Czech Telecommunications Office
	Denmark	National IT and Telecom Agency
	Estonia	Ministry of Transport and Communication
	Liechtenstein	Amt fur Kommunikation
	Georgia	Georgian National Communications Commission
	Iceland	Ministry of Communications
	Switzerland	Federal Office for Communications
	Finland	Ministry of Transport and Communication
	France	Autorite de Regulation des Communications Electronigues et des Postes
	Hungary	Ministry of Transport, Communication and Water Management
	Ireland	Office of the Director of Telecommunications Regulation
	Latvia	Latvia Telecommunication State Inspection
	Portugal	Autoridade Nacional de Comunicacoes
	Sweden	The National Post and Telecom Agency
	Malta	Malta Communications Authority
	Netherlands	OPTA – Onafhankelijke Post en Telecommunicatie Autoriteit
	Spain	Comision del Mercado de las Telecomunicaciones
	Norway	Norwegian Post and Telecommunications Authority
	Poland	Office of Telecommunications and Post Regulation
	Slovakia	Telecommunications Office of the Slovak Republic
America	Canada	Canadian Radio Television and Telecommunications Commission
	Mexico	Comision Federal de Telecomunicaciones
	USA	FCC – Federal Communications Commission
	Dominica	Eastern Caribbean Telecommunications Authority
	El Salvador	Superintendencia General de Electricidad y Telecommunicaciones
	Grenada	Eastern Caribbean Telecommunications Authority
	Brazil	ANATEL – Agência Nacional de Telecomunicações
	Argentina	Secretaria de Comunicaciones
	Chile	Subsecretaria de Telecommunicaciones
Africa	Botswana	Botswana Telecommunications Authority
	Egypt	Telecommunications Regulatory Authority
	South Africa	The Independent Communications Authority of South Africa
	Zambia	The Communications Authority

- ***Administrative method*** : This is the oldest practiced technique for spectrum allocation in which the government is solely responsible for determining the criteria for licence allocation. After finalization of the criteria, an in-house expert committee is formed whose responsibility is to study the proposals submitted by different firms. Finally, licence is allotted to the firm whose proposal is in accordance to the laid criteria. Although, this method gives the government complete power, it is highly time consuming and gives ample scope for favouritism.
- ***First come first served method*** : As the name implies, in this method, licence is allocated to the firm which first arrives with a proposal. This method proves to be less time consuming however, at the same time, it is inefficient as it allows less competent firms to win licence over technologically stronger competitors.
- ***Lottery method*** : This is another time-efficient process employed for spectrum allocation. Different firms participate and on the basis of lottery, a firm is chosen. This method also suffers from a similar drawback like the first come first serve method.
- ***Auction method*** : In this method, the firm with the highest bid price is allocated the licence. It proves to be highly beneficial for earning revenue for the government. This method is popularly employed in most countries for allocating mobile communication spectrum licence.

Apart from licensed spectrum allocation, a portion of the available spectrum is kept aside as an unlicensed band. This portion of the spectrum is used for low-cost implementation and research works. Some popular systems which have been developed to work in unlicensed bands are Bluetooth, Wireless Local Area Network and ZigBee. One of the biggest limitations faced by systems working on these bands is interference. That is, if too many devices using the unlicensed band co-exist, they cause excessive interference and make the band unusable.

For efficient spectrum utilization, another solution is to use underlay systems. Underlay systems are developed such that their end users work as secondary users while the end user of the overlay system works as primary users. If primary users are active, then the secondary user should limit the transmitter power in order to minimize the effect of interference. Ultra-Wide Band systems work on this principle and have been explained later in this chapter.

Although all the methods explained here are still in use, owing to the fast paced advancement in wireless systems, the user base and spectrum requirement for new services is ever growing. The problem of efficient spectrum utilization has been taken up by many researchers. One competing solution is the use of Cognitive Radio. It can be simply understood as an intelligent wireless communication system which can sense and adapt to the changing RF environment. A detailed discussion on Cognitive Radio has been included in Appendix C of this book.