CHAPTER 1

Digital communications overview

1.1 Electronic communications

History, present requirements and future demands

Communication can be defined as the imparting or exchange of information [Hanks]. Telecommunication, which is more narrowly the topic of this book, refers to communication over a distance greater than would normally be possible without artificial aids. In the present day such aids are invariably electrical, electronic or optical and communication takes place by passing signals over wires, through optical fibres or by wireless transmission through space using electromagnetic waves.

Modern living demands that we have access to a reliable, economical and efficient means of communication. We use communication systems, particularly the public switched telephone network (PSTN), and its extension into cellular systems to contact people all around the world. Telephony is an example of point-to-point communication and normally involves a two-way flow of information. Another type of communication, which (traditionally) involves only one-way information flow, is broadcast radio and television. In these systems information is transmitted from one location but is received at many locations using many independent receivers. This is an example of point-to-multipoint communication.

Communication systems are now very widely applied. Navigation systems, for example, pass signals between a transmitter and a receiver in order to determine the location of a vehicle, or to guide and control its movement. Signalling systems for tracked vehicles, such as trains, are also simple communication systems.

All early forms of communication system (e.g. smoke signals, semaphore, etc.) used digital traffic. The earliest form of electronic communications, telegraphy, was developed in the 1830s, Table 1.1. It was also digital in that the signals, transmitted over wires,

Table 1.1 *Important events in the history of electronic communications.*

Year	*Event*	*Originator*	*Information*
1837	Line telegraphy perfected	Morse	Digital
1875	Telephone invented	Bell	Analogue
1887	Wireless telegraphy	Marconi	Digital
1897	Automatic exchange step by step switch	Strowger	
1905	Wireless telephony demonstrated	Fessenden	Analogue
1907	First regular radio broadcasts	USA	Analogue
1918	Superheterodyne radio receiver invented	Armstrong	Analogue
1928	All electronic television demonstrated	Farnsworth	Analogue
1928	Telegraphy signal transmission theory	Nyquist	Digital
1928	Information transmission	Hartley	Digital
1931	Teletype		Digital
1933	FM demonstrated	Armstrong	Analogue
1937	PCM proposed	Reeves	Digital
1939	Voice coder	Dudley	Analogue
1939	Commercial TV broadcasting	BBC	Analogue
1940	Spread spectrum proposed		Digital
1943	Matched filtering proposed	North	Digital
1945	Geostationary satellite proposed	Clarke	
1946	ARQ systems developed	Duuren	Digital
1948	Mathematical theory of communications	Shannon	
1955	Terrestrial microwave relay	RCA	Analogue
1960	First laser demonstrated	Maiman	
1962	Satellite communications implemented	TELSTAR 1	Analogue
1963	Geostationary satellite communications	SYNCOM II	Analogue
1966	Optical fibres proposed	Kao & Hockman	
1966	Packet switching		Digital
1970	Medium scale data networks	ARPA/TYMNET	Digital
1970	LANs, WANs and MANs		Digital
1971	The term ISDN coined	CCITT	Digital
1974	Internet concept	Cerf & Kahn	Digital
1978	Cellular FDMA radio		Analogue
1978	Navstar GPS launched	Global	Digital
1980	OSI 7 layer reference model adopted	ISO	Digital
1981	HDTV demonstrated	NHK, Japan	Digital
1985	ISDN basic rate access in UK	BT	Digital
1986	SONET/SDH introduced	USA	Digital
1991	GSM TDMA cellular system	Europe	Digital
1991	MPEG video standards	International	Digital
1992	ETSI formed	Europe	
1993	PCN concept launched	Worldwide	Digital
1994	IS-95 CDMA specification	Qualcom	Digital
1995	ADSL transmission	International	Digital
1998	Wideband 3G CDMA	ITU Standards	Digital
2000	IMT 2000/UMTS	International	Digital
2002	Smartphone (PDA)	Blackberry, Canada	Digital
2004	WiMAX	ITU Standard	Digital

were restricted to four types: dots and dashes, representing the Morse coded letters of the alphabet, letter spaces and word spaces. In the 1870s Alexander Graham Bell made analogue communications possible by inventing acoustic transducers to convert speech directly into (analogue) electrical signals.

This led quickly to the development of conventional telephony. Radio communications started around the turn of the century when Marconi patented the first wireless telegraphy system. This was quickly followed by the first demonstration of wireless (or radio) telephony and in 1918 Armstrong invented the superheterodyne radio receiver, which is still an important component of much modern-day radio receiving equipment. In the 1930s Reeves proposed pulse code modulation (PCM) which laid the foundation for nearly all present-day digital communications systems.

Table 1.1 shows some of the principal events in the development of electronic communications over the last century and a half. The Second World War saw rapid, forced, developments in nearly all areas of engineering and technology. Electronics and communications benefited greatly and the new, but associated, discipline of radar became properly established.

In 1945 Arthur C. Clarke wrote his famous article proposing geostationary satellite communications and 1963 saw the launch of the first successful satellite of this type. In 1966 optical fibre communication was proposed by Kao and Hockman and, around the same time, public telegraph and telephone (PTT) operators introduced digital carrier systems.

The first, general purpose, large scale data networks (ARPANET and TYMNET) were developed around 1970, provoking serious commercial interest in packet switching (as an alternative to circuit switching).

The 1970s saw significant improvements in the performance of, and large increases in the volume of traffic carried by, telecommunications systems of all types. Optical fibre losses were dramatically reduced and the capacity of satellites dramatically increased. In the 1980s first analogue, and then digital, cellular radio became an important part of the PSTN. Micro-cellular and personal communications using both terrestrial and satellite based radio technology are now being developed. Wideband personal communications systems providing voice, data and video services have now become possible. Video delivery requires a broadband rather than a narrow (speech) bandwidth connection, Table 1.2.

Increasing demand for traditional services (principally analogue voice communications) has been an important factor in the development of telecommunications technologies. Such developments, combined with more general advances in electronics and computing, have made possible the provision of entirely new (mainly digitally based) communications services. This in turn has stimulated demand still further. Figure 1.1 shows the past and

Table 1.2 *Comparison of nominal bandwidths for several information signals.*

Information signal	*Bandwidth*
Speech telephony	4 kHz
High quality sound broadcast	15 kHz
TV broadcast (video)	6 MHz

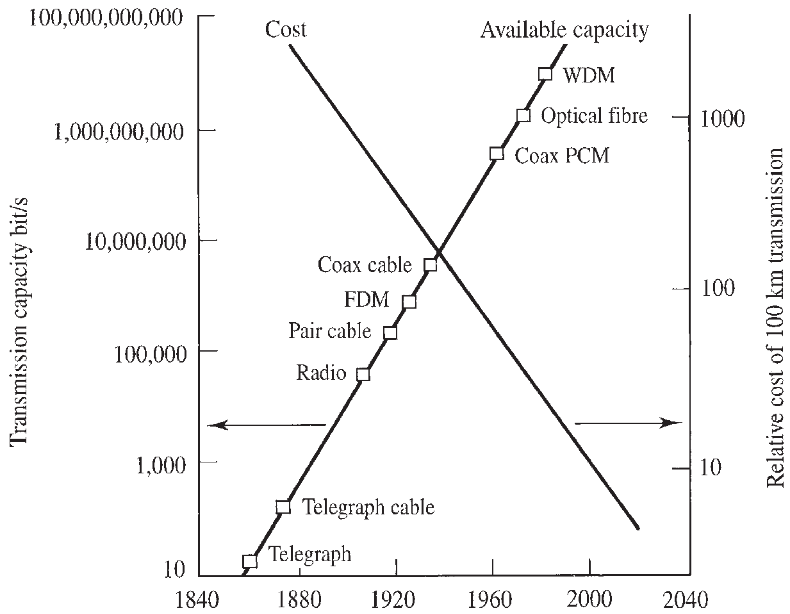

Figure 1.1 *Past and predicted growth of telecommunications traffic (source: Technical demographics, 1995, reproduced with permission of the IEE).*

predicted future growth of telecommunications traffic and Figure 1.2 shows the proliferation of services which have been, or are likely to be, offered over the same period.

In telecommunications there are various standards bodies which ensure interoperability of equipment. The International Telecommunication Union (ITU) is an important international communications standards body which only has the power to make recommendations for specifications. Within the ITU are the PTTs (post, telephone and telegraph organisations) from individual nations, e.g. British Telecom and Deutsche Bundespost. In Europe there was, until recently, the Confederation of European PTTs (CEPT), responsible for overseeing the actual implementation of technical standards. CEPT has now been replaced with the European Telecommunications Standards Institute (ETSI) [WWW, Temple].

The 1990s saw tremendous advances in new digital transmission techniques. These include digital subscriber line (DSL) technology, which increases the maximum possible data rate over low bandwidth copper cables, MPEG standards for efficient video compression, and time division multiple access (TDMA) and code division multiple access (CDMA) mobile cellular communication systems. With the recent launch of third generation mobile cellular systems supporting both speech and data transmission these exciting advances are set to continue into the near future.

1.2 Sources and sinks of information

Sources of information can be either natural or human-made. An example of the former might be the air temperature at a given location. An example of the latter might be a set of company accounts. (A third example, speech, falls, in some sense, into both categories.) Digital communications systems represent information, irrespective of its type or origin, by a discrete set of allowed symbols. It is this alphabet of symbols and the device or mechanism which selects them for transmission that is usually regarded here as the information source.

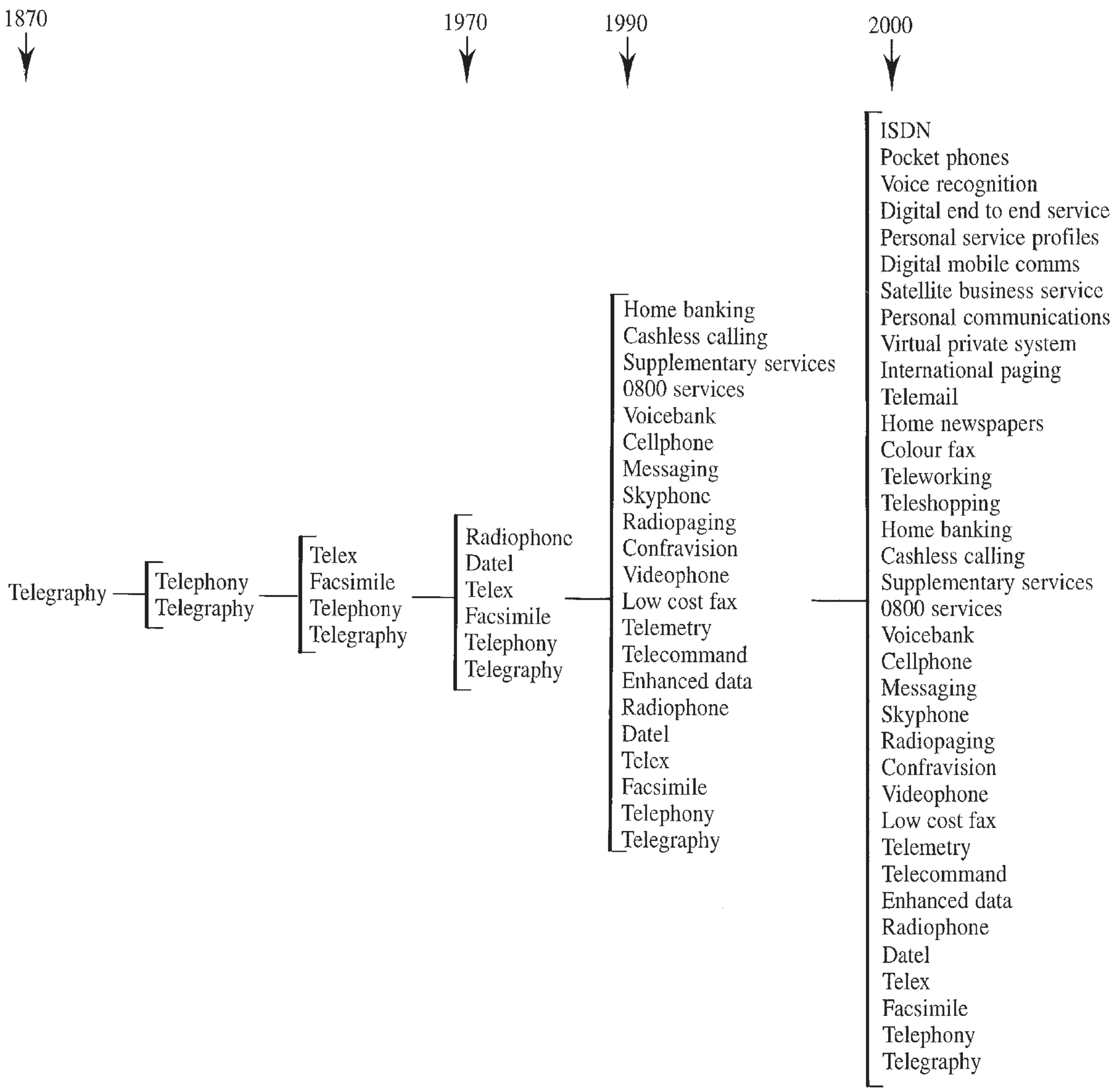

Figure 1.2 *Service proliferation in telecommunications (source: Earnshaw, 1991, reproduced with permission of Peter Peregrinus).*

The amount of information conveyed by each symbol, as it is selected and transmitted, is closely related to its selection probability. Symbols likely to be selected more often convey less information than those which are less likely to be selected. Information content (measured in bits) is thus related to symbol rarity.

Sinks of information are, ultimately, people, although various types of information storage and display devices (computer disks, magnetic tapes, loudspeakers, VDUs, etc.) are usually involved as a penultimate destination.

Transmitters are the devices that impress source information onto an electrical wave (or carrier) appropriate to a particular transmission medium (e.g. optical fibre, cable, free space). Receivers are the devices which extract information from such carriers. They often also reproduce this information in the same form as it was originally generated (e.g. as speech).

1.3 Digital communications equipment

An important objective in the design of a communication system is often to minimise equipment cost, complexity and power consumption whilst also minimising the bandwidth occupied by the signal and/or transmission time. (Bandwidth is a measure of how rapidly the information bearing part of a signal can change and is therefore an important parameter for communication system design. Table 1.2 compares the nominal bandwidth of three common types of information signal.) Efficient use of bandwidth and transmission time ensures that as many subscribers as possible can be accommodated within the constraints of these limited, and therefore valuable, resources.

The component parts of a hypothetical digital communications transceiver (transmitter/receiver) are shown in Figure 1.3. Much of the rest of this book is concerned with the operating principles, performance and limitations of a communication system formed by a transmitter/receiver pair linked by a communications channel. Here, however, we give a qualitative overview of such a system, incorporating a brief account of what each block in Figure 1.3 does and why it might be required. (The transceiver in this figure has been chosen to include all the elements commonly encountered in digital communications systems. Not all transceivers will employ all of these elements of course.)

1.3.1 CODECs

At its simplest a transceiver CODEC (coder/decoder) consists of an analogue to digital converter (ADC) in the transmitter, which converts a continuous analogue signal into a sequence of codewords represented by binary voltage pulses, and a digital to analogue converter (DAC) in the receiver, which converts these voltage pulses back into a continuous analogue signal.

The ADC consists of a sampling circuit, a quantiser and a pulse code modulator (Figure 1.3). The sampling circuit provides discrete voltage samples taken, at regular intervals of time, from the analogue signal. The quantiser approximates these voltages by the nearest level from an allowed set of voltage levels. (It is the quantisation process which converts

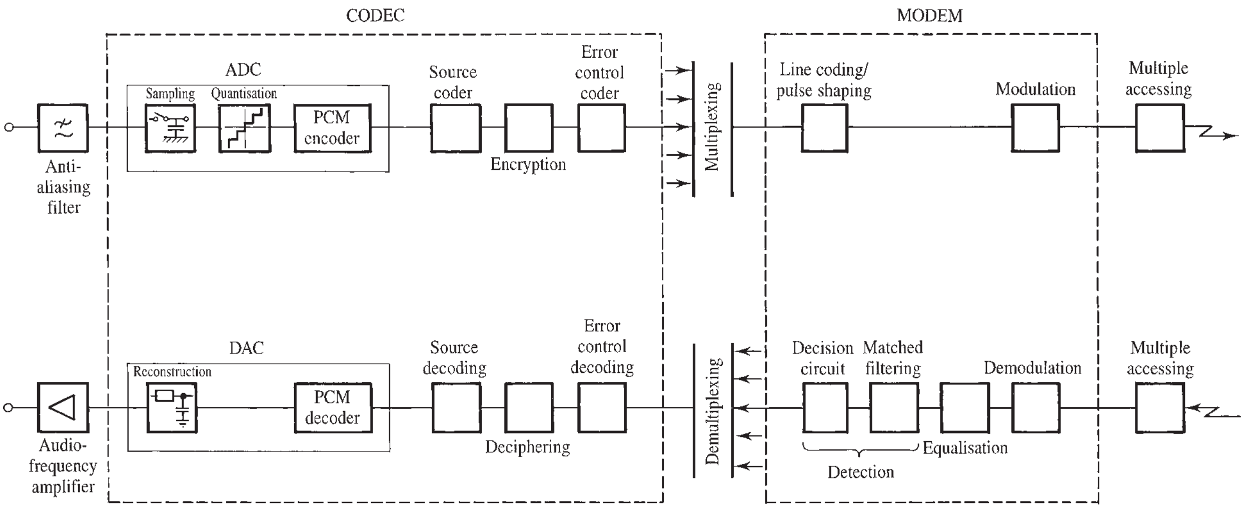

Figure 1.3 *Hypothetical digital communications transceiver.*

the analogue signal to a digital one.) The PCM encoder converts each quantised level to a binary codeword, digital ones and zeros each being represented by one of two voltages. An anti-aliasing filter is sometimes included prior to sampling in order to reduce distortion that can occur as a result of the sampling process.

In the receiver's DAC received binary voltage pulses are converted to quantised voltage levels by a PCM decoder which is then smoothed by a low pass filter to reconstruct (at least a good approximation to) the original analogue signal.

Digitisation of analogue signals usually increases the signal's transmission bandwidth but it permits reception at a lower signal-to-noise ratio than would otherwise be the case. This is an example of how one resource (bandwidth) can be traded off against another resource (transmitter power).

CODECs make widespread use of sophisticated digital signal processing techniques to encode efficiently the signal prior to transmission and also to decode the received signals when they are corrupted by noise, distortion and interference. This increases transceiver complexity, but allows higher fidelity, repeatable, almost error-free transmission to be achieved.

1.3.2 Source, security and error control coding

In addition to PCM encoding and decoding a CODEC may have up to three additional functions. Firstly (in the transmitter), it may reduce the number of binary digits (called bits, or sometimes binits) required to convey a given message. This is source coding and can be thought of as effectively removing redundant (i.e. unrequired or surplus) digits. Secondly, it may encrypt the source coded digits using a cipher for security. This can yield both privacy (which assures the sender that only those entitled to the information being transmitted can receive it) and authentication (which assures the receiver that the sender is who they claim to be). Finally, the CODEC may add extra digits to the (possibly source coded and/or encrypted) PCM signal, which can be used at the receiver to detect, and possibly correct, errors made during symbol detection. This is error control coding and has the effect of incorporating binary digits at the transmitter which, from an information point of view, are redundant.

In some ways error control coding, which adds redundancy to the bit stream, is the opposite of source coding, which removes redundancy. Both processes may be employed in the same system, however, since the type of redundancy which occurs naturally in the information being transmitted is not necessarily the type best suited to detecting and correcting errors at the receiver.

The source, security and error control decoding operations in the receiver, Figure 1.3, are the inverse of those in the transmitter.

1.3.3 Multiplexers

In digital communications, multiplexing, to accommodate several simultaneous transmissions, usually means, more specifically, time division multiplexing (TDM). Time division multiplexers interleave either PCM codewords, or individual PCM binary digits, to allow more than one information link to share the same physical transmission medium. This can be cable, optical fibre or a radio frequency channel. If communication is to occur in real time this implies that the bit rate of the multiplexed signal is at least N times that of each of the N tributary PCM signals, and this in turn implies an increased bandwidth requirement. The requirement for an increase in bandwidth comes from the fact that the transmitted signal now comprises shorter duration pulses, which have a wider spectral response.

Demultiplexers split the received composite bit stream back into its component PCM signals.

1.3.4 MODEMs

MODEMs (modulators/demodulators) condition binary pulse streams so that the information they contain can be transmitted over a given physical medium, at a given rate, with an acceptable degree of distortion, in a specified or allocated frequency band. The modulator in the transmitter may change the voltage levels representing individual, or groups of, binary digits. Typically, the modulator also shapes, or otherwise filters, the resulting pulses to restrict their bandwidth, and shifts the entire transmission to a convenient allowed frequency band. The input to a modulator is thus a baseband digital signal whilst the output is often a bandpass waveform.

The demodulator in a receiver reconverts the received waveform into a baseband signal. Equalisation corrects (as far as possible) signal distortion that may have occurred during transmission. Detection converts the demodulated baseband signal into a binary symbol stream. The matched filter, shown as one component of the detector in Figure 1.3, represents one type of signal processing that can be employed, prior to the final digital decision process, in order to improve error performance.

1.3.5 Multiple accessing

Multiple accessing refers to those techniques, and/or rules, which allow more than one transceiver pair to share a common transmission medium (e.g. one optical fibre, one satellite transponder or one piece of coaxial cable). Several different types of multiple accessing are currently in use, each type having its own advantages and disadvantages. The multiple accessing problem is essentially one of efficient and (in some sense) equitable sharing of the limited resource represented by the transmission medium.

1.4 Radio receivers

Many radio receivers (both digital and analogue) incorporate superheterodyning as part of their demodulation process. In these receivers (Figure 1.4) the incoming radio frequency (RF) signal, with carrier frequency f_{RF}, is mixed (i.e. multiplied) with the signal from a local oscillator (LO) of frequency f_{LO}. The sum $(f_{RF} + f_{LO})$ and difference $(f_{RF} - f_{LO})$ frequency products which appear at the mixer output are then filtered to select only the latter, which is called the intermediate frequency or IF. The LO frequency is, therefore, always altered or tuned to ensure that the receiver operates with a fixed value of IF (i.e. $f_{RF} - f_{LO}$) irrespective of which RF channel is being received. This allows a considerable effort to be invested in the design of the receiver beyond this point, consisting typically of high gain (fixed frequency) IF amplifiers and high selectivity filters followed by an appropriate IF signal demodulator and/or detector.

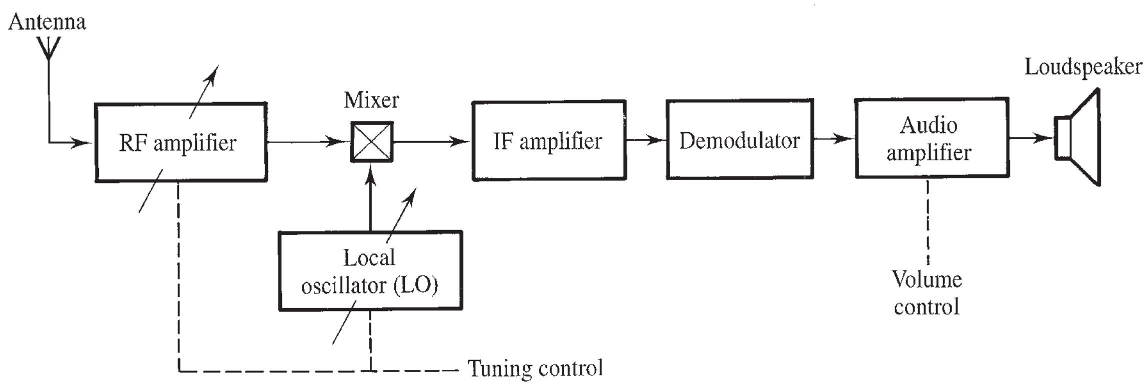

Figure 1.4 *Superheterodyne receiver.*

The superheterodyne receiver can be made more sophisticated by using double frequency conversion in which there are two mixing stages. This enables higher gain and greater selectivity to be achieved in order to increase rejection of unwanted interfering signals.

The principal problem with the superheterodyne design is that the receiver is equally sensitive to RF bands centred on $f_{LO} + f_{IF}$ (which is the wanted band) and $f_{LO} - f_{IF}$ (which is an unwanted band). The unwanted 'image' band of frequencies, separated from the wanted RF band by twice the IF, represents a potentially serious source of RF interference and additional noise. A tunable image rejection filter (needing only modest selectivity) can be placed before the mixer in the RF amplifier of Figure 1.4 to attenuate or remove this unwanted band of frequencies.

1.5 Signal transmission

The communications path from transmitter to receiver may use lines or free space. Examples of the former are wire pairs, coaxial cables and optical fibres. The most important use of the latter is radio, although in some situations infrared and optical free space links are also possible (e.g. remote controls for TV, video and hi-fi equipment and also some security systems). Whatever the transmission medium, it is at this point that much of the attenuation, distortion, interference and noise is encountered.

Attenuation can be compensated for by introducing amplifiers or signal repeaters at intermediate points along the multiple hop link, Figure 1.5. Distortion may be compensated by equalisers, and interference and noise can be minimised by using appropriate predetection signal processing (e.g. matched filters).

The nature and severity of transmission medium effects is one of the major influences on the design of transmitters, receivers and repeaters.

1.5.1 Line transmission

The essential advantages of line transmission are:

1. Path loss is usually modest.
2. Signal energy is essentially confined and interference between different systems is seldom severe and often negligible.

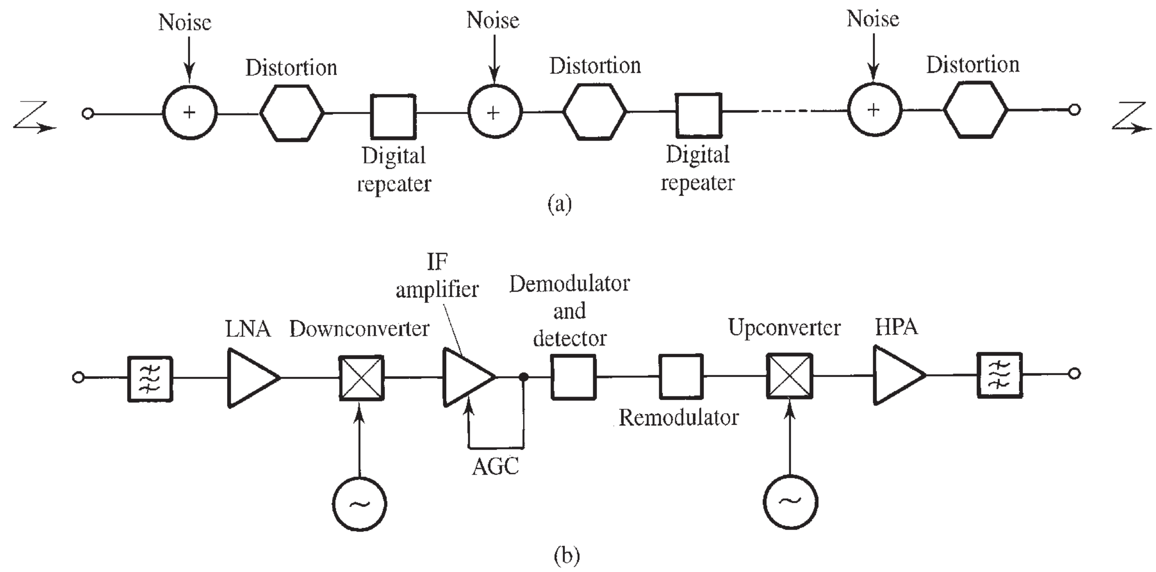

Figure 1.5 *(a) Digital communications (multi-hop) channel; (b) digital repeater (as typically used in terrestrial microwave relay applications).*

3. Path characteristics (e.g. attenuation and distortion) are usually stable and relatively easy to compensate for.
4. Capacity is unlimited in that bandwidth can always be reused by laying another line.

The disadvantages of line transmission are:

1. Laying cables in the ground or constructing overhead lines is generally expensive.
2. Extensive wayleaves and planning permission may be needed for underground cables and overhead wires.
3. Broadcasting requires a physical connection to a complex network for each subscriber.
4. Mobile communications services cannot be provided.
5. Networks cannot easily be added to, subtracted from, or otherwise reconfigured.

The degree to which a signal is attenuated by a transmission line depends on the material from which the line is made, its physical construction and the signal's frequency. Figures 1.6(a) to (e) show some typical attenuation/frequency characteristics for the most common types of line. Open wire has particularly low loss but it is expensive to maintain and susceptible to interference. Loaded cable, Figure 1.6(c) and Table 1.3, is only effective for speech bandwidth signals. Twisted pairs, as used underground, have higher installation costs but lower maintenance costs. (Low loss circular waveguides can also be used as a transmission medium, but advances in optical fibre technology have, at least for the present, made this technology essentially redundant.) Optical fibre cables have an enormous information carrying capacity with typical bandwidth–distance products of 0.5 GHz km.

Table 1.3 summarises the nominal frequency range of selected types of line, their typical attenuations and transmission delays, and typical repeater spacings. The useful bandwidths of the lines, which determine the maximum information transmission rate they can carry, are often, but not always, determined by their attenuation characteristics. Twisted wire pairs, for example, are normally limited to (line coded PCM) data rates of 2 Mbit/s.

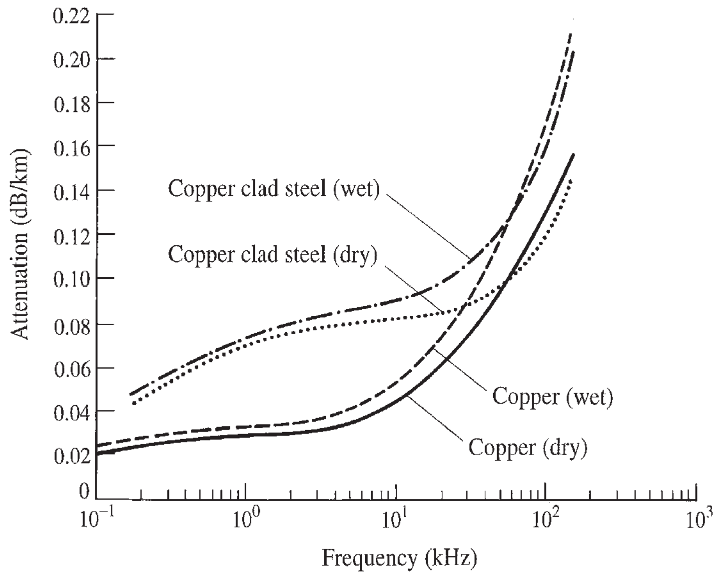

Figure 1.6(a) *Typical attenuation/frequency characteristics for aerial open wire pair lines.*

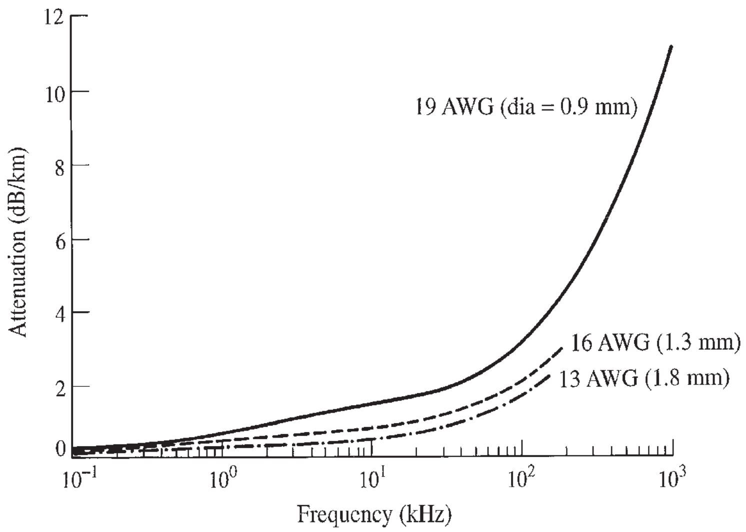

Figure 1.6(b) *Typical characteristics for twisted pair cable transmission lines.*

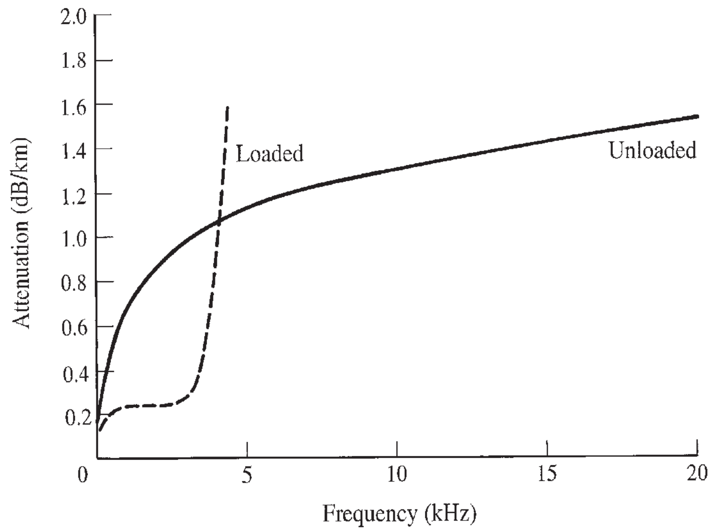

Figure 1.6(c) *Comparison between inductively loaded and unloaded twisted wire pairs.*

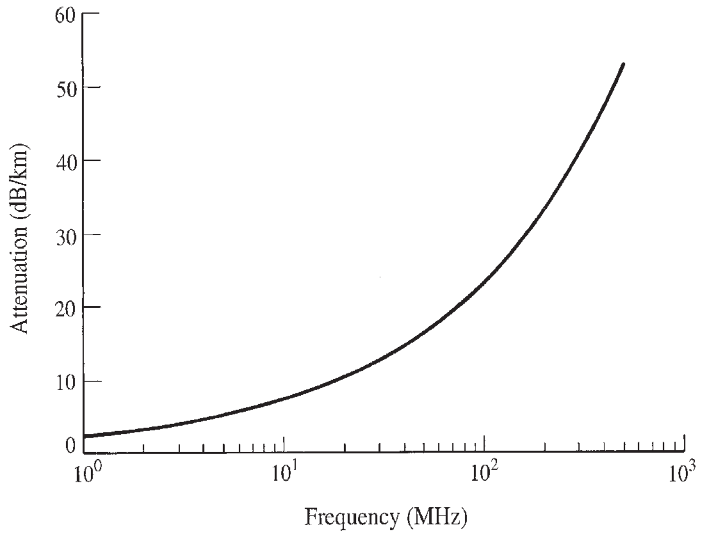

Figure 1.6(d) *Typical attenuation/frequency characteristic for coaxial cable.*

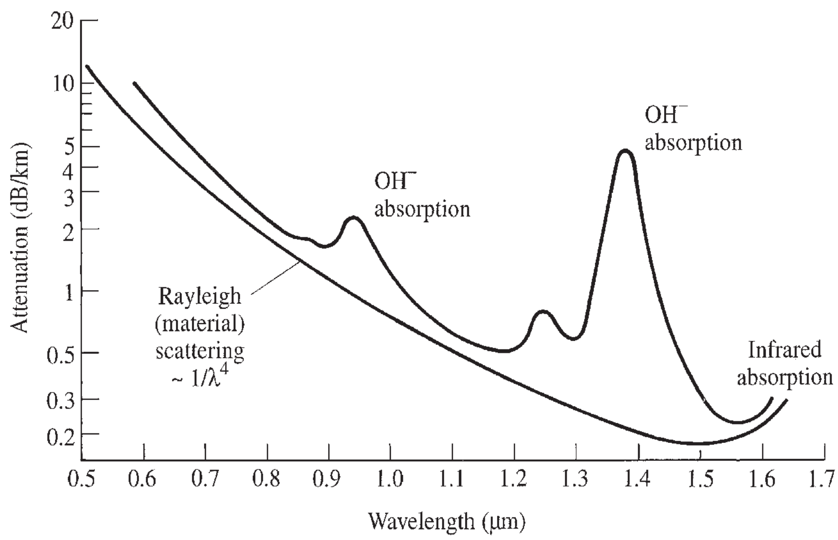

Figure 1.6(e) *Typical attenuation/wavelength characteristics for optical fibres (source: Young, 1994).*

Table 1.3 *Nominal properties of selected transmission lines.*

	Frequency range	*Typical attenuation*	*Typical delay*	*Repeater spacing*
Open wire (overhead line)	0–160 kHz	0.03 dB/km @ 1 kHz	3.5 μs/km	40 km
Twisted pairs (multi-pair cables)	0–1 MHz	0.7 dB/km @ 1 kHz	5 μs/km	2 km
Twisted pairs (with L loading)	0–3.5 kHz	0.2 dB/km @ 1 kHz	50 μs/km	2 km (L spacing)
Coaxial cables	0–500 MHz	7 dB/km @ 10 MHz	4 μs/km	1–9 km
Optical fibres	$\lambda = 1610$–810 nm	0.2 to 0.5 dB/km	5 μs/km	100s km

Coaxial cables, Figure 1.6(d), routinely carry 140 or 155 Mbit/s PCM signals but can handle symbol rates several times greater. Optical fibres have very large bandwidth potential, but may be limited to a fraction of this by factors such as the spectral characteristics of optical sources and dispersion effects. Nevertheless, optical fibre PCM bit rates of hundreds of Gbit/s are possible.

1.5.2 Radio transmission

The advantages of radio transmission are:

1. It is relatively cheap and quick to implement.
2. Wayleaves and planning permission are often only needed for the erection of towers to support repeaters and terminal stations.
3. It has an inherent broadcast potential.
4. It has an inherent mobile communications potential.
5. Communications networks can be quickly reconfigured and extra terminals or nodes easily introduced or removed.

The principal disadvantages of radio are:

1. Path loss is generally large due to the tendency of the transmitted signal energy to spread out, most of this energy effectively missing the receive antenna.
2. The spreading of signal energy makes interference between different systems a potentially serious problem.
3. Capacity in a given locality is limited since bandwidth cannot be reused easily.
4. Path characteristics (i.e. attenuation and distortion) tend to vary with time, often in an unpredictable way, making equalisation more difficult and limiting reliability and availability.
5. The time varying nature of the channel can result in anomalous propagation of signals to locations well outside their normal range. This may cause unexpected interference between widely spaced systems.
6. Points 2 and 5 mean that frequency coordination is generally required when planning radio systems. Such coordination is difficult to achieve comprehensively and is expensive.

The appropriate radio propagation model for a communication system, the dominant fading and noise processes, and typical system range, all depend on frequency. Table 1.4 shows the electromagnetic spectrum used for radio transmissions and summarises these models and processes. At the lowest frequencies propagation is best modelled by oscillating electromagnetic modes which exist in the cavity between the concentric conducting spheres formed by the earth and its ionosphere. From a few kilohertz up to a few hundred kilohertz, vertically polarised radio energy will propagate (by diffraction) around the curved surface of the earth for thousands of kilometres. This is called surface wave propagation and is the mechanism by which long wave radio broadcasts are received.

At slightly higher frequencies in the medium frequency (MF) band some radio energy propagates as a surface wave and some is reflected from the conducting ionosphere as a sky wave. The relative path lengths and phasing of these two signals may result in destructive

Table 1.4 *Frequency bands commonly used for radio communication.*

Band	*Frequency*	*Wavelength*	*Propagation mechanism*	*Fading process*	*Noise process*	*Range*	*Applications*
ELF	30–300 Hz	10^4–10^3 km	Waveguide modes	Diurnal variations due to D-layer	Human-made and atmospherics (lightning discharges)	Worldwide	Submarine
VF	300–3000 Hz	1000–100 km					
VLF	3–30 kHz	100–10 km	Surface waves	None			Standards/navigation
LF	30–300 kHz	10–1 km				1000s km	Maritime mobile, LW b'cast
MF	300–3000 kHz	1000–100 m	Sky waves	Surface/sky wave intf.		100s km	MW broadcast
HF	3–30 MHz	100–10 m		Complex ionospherics		4000 km/hop	Amateur
VHF	30–300 MHz	10–1 m	Line of sight	None	Galactic (synchrotron radiation)	Line of sight	FM broadcast
UHF	300–3000 MHz	100–10 cm		Ray bending and multipath	Cosmic background		TV broadcast, mobile, LOS
SHF	3–30 GHz	10–1 cm		Rain attenuation	Thermal noise from ground & atmosphere		Microwave LOS, satellite
EHF	30–300 GHz	10–1 mm				Short	

interference causing fading of the received signal, which will vary in severity as the relative strengths and phases of the sky wave and surface wave change. The exact condition of the ionosphere may be critical in this respect, making the quality of signal reception vary, for example, with the time of day or night.

In the high frequency (HF) band the sky wave is usually dominant and ranges of thousands of kilometres are possible, sometimes involving multiple reflections between the ionosphere and ground. At very high frequency (VHF) and above, signals propagate essentially along line-of-sight (LOS) paths although reflection, refraction and, at the lower frequencies, diffraction can play an important role in the overall characteristics of the channel. At ultra high frequency (UHF), currently used for both TV transmissions and cellular radio communications, multipath (i.e. multiple path) propagation caused by reflections from, and diffraction around, buildings and other obstacles in urban areas is the principal cause of signal fading. In the super high frequency (SHF) band (usually called the microwave or centimetric wave band) applications tend to be point-to-point (or fixed-point) communications and the first-order outdoor fading problem is often due to rain induced attenuation. These frequencies are also used for indoor radio local area networks (LANs). Extra high frequency (EHF) and higher frequencies are not yet widely used for communication systems, partly due to the significant gaseous background attenuation and large fades that occur in rain. However, millimetre wave wideband links are under consideration. As the electromagnetic spectrum becomes more congested, however, and as the demand for communications becomes yet greater (in terms of both traffic volume and service sophistication), the use of these higher frequency bands will almost certainly become both necessary and economic.

1.6 Switching and networks

Many modern communication systems are concerned exclusively with data traffic. One example is the Internet, over which users can transmit e-mail messages or browse distant information sources and transfer large data, video, film and audio files. The data networks themselves, and the configuration of computer terminals on a user site, can be organised in many different ways using ring, star or bus connections. In order to ensure interoperability, standards have developed for these topologies and also for the signalling and switching protocols that control the assembly and routing of traffic.

The seven-layer ISO model is used throughout data communications networks as the standard hierarchical structure for organising data traffic. The data itself is usually sent as fixed length packets with associated overhead bits, which provide addresses, timing or ordering information and assist in error detection. The physical data interfaces follow evolved standards, e.g. X.25, IEEE 802, which develop progressively to higher data rates as the new high speed (wideband optical) transmission systems are introduced.

With packet data traffic there are inevitable delays while the packets are queued for access to the transmission system. These queues are not serious problems in simple mail networks but, if attempting to transmit speech or video traffic in real time, queue delays and lost packets due to queue overflow in finite length buffers can seriously degrade the operation of the communications link.

1.7 Advantages of digital communications

Digital communications systems usually represent an increase in complexity over the equivalent analogue systems. We therefore list here some of the reasons why digital communications have become the preferred option for most new systems and, in many instances, have replaced existing analogue systems.

1. Increased demand for data transmission.
2. Increased scale of integration, sophistication and reliability of digital electronics for signal processing, combined with decreased cost.
3. Facility to source code for data compression.
4. Possibility of channel coding (line, and error control, coding) to minimise the effects of noise and interference.
5. Ease with which bandwidth, power and time can be traded off in order to optimise the use of these limited resources.
6. Standardisation of signals, irrespective of their type, origin or the services they support, leading to an integrated services digital network (ISDN).

The increase in demand for broadband data connections is the primary driving force behind the growth in telecommunications. The traffic in the backbone network, expressed as equivalent voice circuits, is shown in Figure 1.7. This figure not merely reflects the explosive growth in mobile communications for the final customer connections but shows world capacity for transmission.

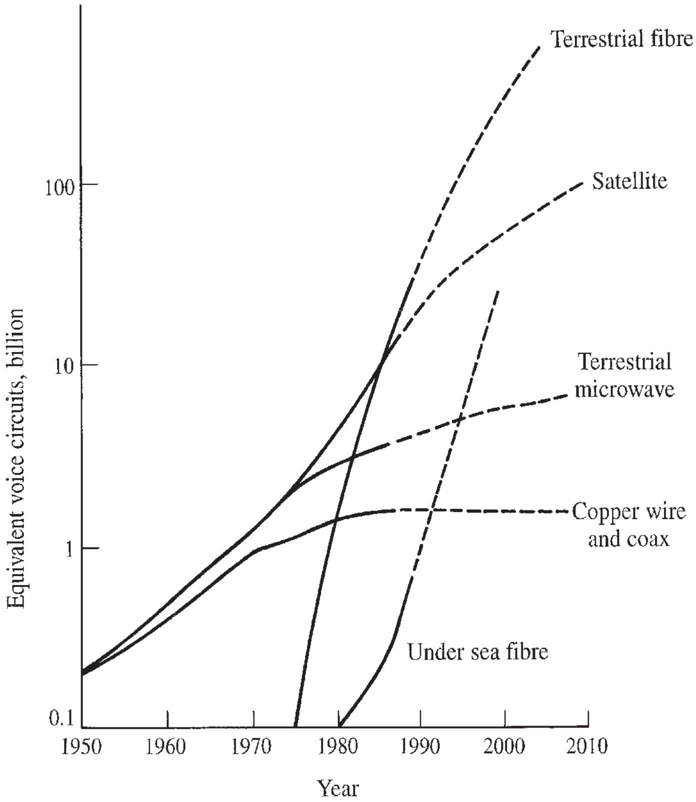

Figure 1.7 *Growth in world transmission capacity (source: Cochrane, 1990, reproduced with permission of British Telecommunications plc.).*

1.8 Summary

The history of electronic communications over the last century and a half has demonstrated an essentially exponential growth in traffic and a continuously increasing demand for greater access to evermore sophisticated services. At present, this trend shows no sign of changing.

Most modern telecommunications systems are digital and use some form of PCM irrespective of the origin of the information they convey. PCM signals are often coded to improve system performance and/or provide security. Many PCM signals can be combined as a single (time division) multiplex to allow their simultaneous transmission over a single physical medium. Line coding and/or modulation can then be used to match the characteristics of the resulting multiplex to the transmission line or radio channel being used. Multiple accessing techniques allow many transceiver pairs to share a given transmission resource (e.g. cable, fibre, satellite transponder). Switching allows telecommunications networks to be designed which, at reasonable cost, can emulate a fully interconnected set of transceivers.

It is the purpose of this book to describe the operating principles and performance of modern digital communications systems. The description is presented at a systems, rather than a circuit, level and, in view of this, Part One of the book (Chapters 2 through 4) reviews some pertinent mathematical models and properties of signals, noise and systems. Part Two (Chapters 5 through 13) describes the analogue to digital conversion process, coding and modulation techniques used to ensure adequate performance of a wide range of digital communications systems (Chapters 5 through 11); Chapter 12 is concerned with physical aspects of noise and the prediction of carrier-to-noise ratio (CNR) at the end of a single or multi-hop transmission link; Chapter 13 discusses the computer simulation of communications systems. Part Three (Chapters 14 through 16) discusses modern digital telephony, terrestrial and satellite microwave systems, mobile cellular radio and video coding systems. Part Four (Chapters 17 through 21) describes switching and telecommunications networks including topologies, protocols, queueing theory and packet data transmission. It also includes a discussion of switched networks, wide area networks (WANs) and the public switched telephone network (PSTN) realised with the early plesiochronous digital heirarchy (PDH) and the subsequent synchronous digital hierarchy (SDH), which accommodates both telephony and data traffic. Finally, broadcast networks and LANs are included.