国外电子与通信教材系列

英文版

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Telecommunication Switching Systems and Networks

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内容简介

本书全面介绍了电信交换与网络的基本内容。全书分为13章，内容涉及基础知识、史特鲁乔式交换系统、纵横制交换、电子空分交换、语音数码化和传输、时分交换、光纤系统、流量管理、电话网络、数据网络、集成服务与数字网络（ISDN）、异步传输模式（ATM）、软交换以及下一代网络等，是一本关于电信交换技术与网络的全景式总结。

全书语言简洁，图形及示例清楚，可作为高校电信交换与网络课程的双语教材，也可作为相关人员的参考用书。

Telecommunication Switching Systems and Networks
By Thiagarajan Viswanathan

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Contents

Chapter 1

Introduction

The field of telecommunications has evolved from a stage when signs, drum beats and semaphores were used for long distance communication to a stage when electrical, radio and electro-optical signals are being used. Optical signals produced by laser sources and carried by ultra-pure glass fibres are recent additions to the field. Telecommunication networks carry information signals among entities which are geographically far apart. An entity may be a computer, a human being, a facsimile machine, a teleprinter, a data terminal, and so on. Billions of such entities the world-over are involved in the process of information transfer which may be in the form of a telephone conversation or a file transfer between two computers or a message transfer between two terminals, etc. In telephone conversation, the one who initiates the call is referred to as the **calling subscriber** and the one for whom the call is destined is the called **subscriber**. In other cases of information transfer, the communicating entities are known as **source** and **destination**, respectively.

The full potential of telecommunications is realised only when any entity in one part of the world can communicate with any other entity in another part of the world. Modern telecommunication networks attempt to make this idea of 'universal connectivity' a reality. Connectivity in telecommunication networks is achieved by the use of switching systems. This text deals with the telecommunication switching systems and the networks that use them to provide worldwide connectivity.

1.1 Evolution of Telecommunications

Historically, transmission of telegraphic signals over wires was the first technological development in the field of modern telecommunications. Telegraphy was introduced in 1837 in Great Britain and in 1845 in France. In March 1876, Alexander Graham Bell demonstrated his telephone set and the possibility of telephony, i.e. long-distance voice transmission. Graham Bell's invention was one of those rare inventions which was put to practical use almost immediately. His demonstrations laid the foundation for telephony.

Graham Bell demonstrated a point-to-point telephone connection. A network using point-to-point connections is shown in Fig. 1.1. In such a network, a calling subscriber chooses the appropriate link to establish connection with the called subscriber. In order to draw the attention of the called subscriber before information exchange can begin, some form of **signalling** is required with each link. If the called subscriber is engaged, a suitable indication should be given to the calling subscriber by means of signalling.

In Fig. 1.1, there are five entities and 10 point-to-point links. In a general case with n entities, there are $n(n-1)/2$ links. Let us consider the n entities in some order. In order to connect the first entity to all other entities, we require $(n-1)$ links. With this, the second entity is already connected to the first. We now need $(n-2)$ links to connect the second entity to the others. For the third entity, we need $(n-3)$ links, for the fourth $(n-4)$ links, and so on. The total number of links, L, works out as follows:

$$L = (n-1) + (n-2) + \cdots + 1 + 0 = n(n-1)/2 \tag{1.1}$$

Networks with point-to-point links among all the entities are known as **fully connected networks**. The number of links required in a fully connected network becomes very large even with moderate values of n. For example, we require 1225 links for fully interconnecting 50 subscribers. Consequently, practical use of Bell's invention on a large scale or even on a moderate scale demanded not only the telephone sets and the pairs of wires, but also the socalled **switching system** or the **switching office** or the **exchange**. With the introduction of the switching systems, the subscribers are not connected directly to one another; instead, they are connected to the switching system as shown in Fig. 1.2. When a subscriber wants to communicate with another, a connection is established between the two at the switching system. Figure 1.2 shows a connection between subscriber S_2 and S_{n-1}. In this configuration, only one link per subscriber is required between the subscriber and the switching system, and the total number of such links is equal to the number of subscribers connected to the system. Signalling is now required to draw the attention of the switching system to establish or release a connection. It should also enable the switching system to detect whether a called subscriber is busy and, if so, indicate the same to the calling subscriber. The functions performed by a switching system in establishing and releasing connections are known as **control functions**.

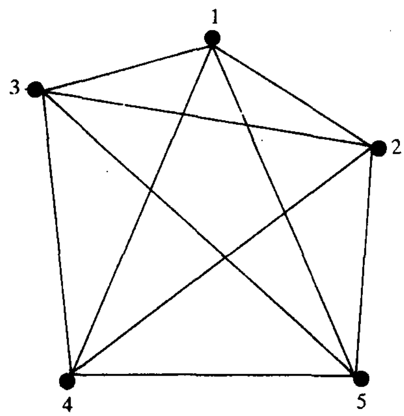


Fig. 1.1 A network with point-to-point links.

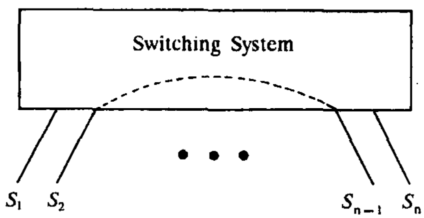


Fig. 1.2 Subscriber interconnection using a switching system.

Early switching systems were manual and operator oriented. Limitations of operator manned switching systems were quickly recognized and automatic exchanges came into existence. Automatic switching systems can be classified as **electromechanical** and **electronic**. Electromechanical switching systems include **step-by-step** and **crossbar systems**. The step-by-step system is better known as Strowger switching system after its inventor A. B. Strowger. The control functions in a Strowger system are performed by circuits associated with the switching elements in the system. Crossbar systems have hard-wired control subsystems which use relays and latches. These subsystems have limited capability and it is virtually impossible to modify them to provide additional functionalities. In electronic switching systems, the control functions are performed by a computer or a processor. Hence, these systems are called **stored program control (SPC)** systems. New facilities can be added to a SPC system by changing the control program. The switching scheme used by electronic switching systems may be either **space division switching** or **time division switching**. In space division switching, a dedicated path is established between the calling and the called subscribers for the entire duration of the call. Space division switching is also the technique used in Strowger and crossbar systems. An electronic exchange may use a crossbar switching matrix for space division switching. In other words, a crossbar switching system with SPC qualifies as an electronic exchange.

In time division switching, sampled values of speech signals are transferred at fixed intervals. Time division switching may be analog or digital. In analog switching, the sampled voltage levels are transmitted as they are, whereas in digital switching, they are binary coded and transmitted. If the coded values are transferred during the same time interval from input to output, the technique is called **space switching**. If the values are stored and transferred to the output at a later time interval, the technique is called **time switching**. A time division digital switch may also be designed by using a combination of space and time switching techniques. Figure 1.3 summarises the classification of switching systems. In Chapters 2 and 3, we deal with electromechanical switching systems. Electronic space division networks are discussed in Chapter 4. Digitisation of speech, which is a fundamental requirement for electronic time division switching networks, is discussed in Chapter 5, and the time division switching techniques in Chapter 6.

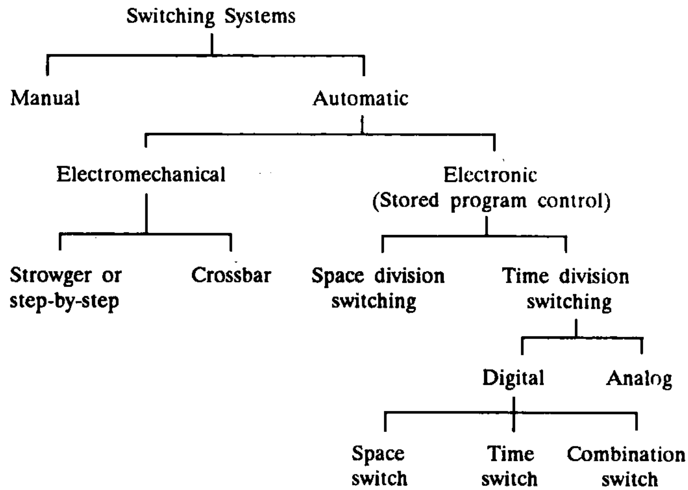


Fig. 1.3 Classification of switching systems.

Subscribers all over the world cannot be connected to a single switching system unless we have a gigantic switching system in the sky and every subscriber has a direct access to the same. Although communication satellite systems covering the entire globe and low cost roof-top antenna present such a scenario, the capacity of such systems is limited at present. The major part of the telecommunication networks is still ground based, where subscribers are connected to the switching system via copper wires. Technological and engineering constraints of signal transfer on a pair of wires necessitate that the subscribers be located within a few kilometres from the switching system. By introducing a number of stand-alone switching systems in appropriate geographical locations, communication capability can be established among the subscribers in the same locality. However, for subscribers in different localities to communicate, it is necessary that the switching systems are interconnected in the form of a network. Figure 1.4 shows a telecommunication network. The links that run between the switching systems are called **trunks**, and those that run to the subscriber premises are known as **subscriber lines**. The number of trunks may vary between pairs of switching systems and is determined on the basis of traffic between them. As the number of switching systems increases, interconnecting them becomes complex. The problem is tackled by introducing a hierarchical structure among the switching systems and using a number of them in series to establish connection between subscribers. The design and analysis of switching systems and telecommunication networks are based on the traffic engineering concepts; these are covered in Chapter 8.

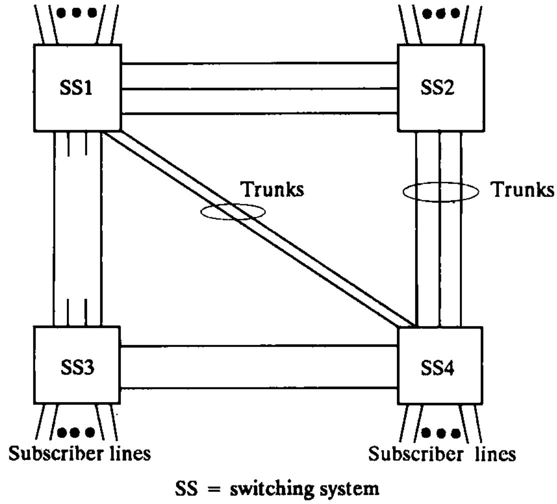


Fig. 1.4 A telecommunication network.

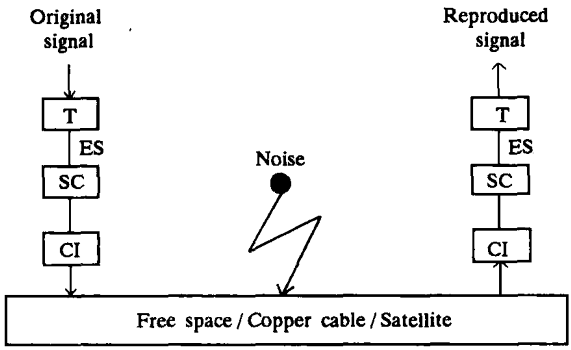
A modern telecommunication network may be viewed as an aggregate of a large number of point-to-point electrical or optical communication systems shown in Fig. 1.5. While these systems are capable of carrying electrical or optical signals, as the case may be, the information to be conveyed is not always in the form of these signals. For example, human speech signals need to be converted to electrical or optical signals before they can be carried by a communication system. Transducers perform this energy conversion. Present day optical sources require electrical signals as input, and the optical detectors produce electrical signals as output. Hence, the original signals are first converted to electrical signals and then to optical signals at the transmitting end of an optical communication system and at the receiving end optical signals are converted to electrical signals before the original signal is reproduced. A medium is required to carry the signals. This medium, called the channel, may be the free space, a copper cable, or the free space in conjunction with a satellite in the case of an electrical communication system. An optical communication system may use the line-of-sight free space or fibre optic cables as the channel. Channels, in general, are lossy and prone to external noise that corrupts the information carrying signals. Different channels exhibit different loss characteristics and are affected to different degrees by noise. Accordingly, the chosen channel demands that the information signals be properly conditioned before they are transmitted, so that the effect of the lossy nature of the channel and the noise is kept within limits and the signals reach the destination with acceptable level of intelligibility and fidelity. Signal conditioning may include amplification, filtering, bandlimiting, multiplexing and demultiplexing. Fibre optic communication systems are emerging as major transmission systems for telecommunications. Chapter 7 deals with this newly emerging communication system.

The channel and the signal characteristics of individual communication systems in a telecommunication network may vary widely. For example, the communication system between the subscriber and the switching system uses most often a pair of copper wires as the channel, whereas the communication system between the switching systems may use a coaxial cable or the free space (microwave) as the channel. Similarly, the type of end equipment used at the subscriber premises would decide the electrical characteristics of signals carried between the subscriber end and the switching system. For example, electrical characteristics of teleprinter signals are completely different from those of telephone signals. In fact, such wide variations in signal characteristics have led to the development of different service specific telecommunication networks that operate independently. Examples are:

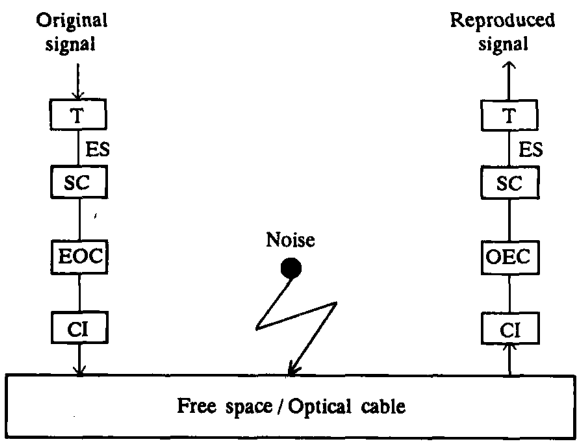
1. Telegraph networks
2. Telex networks

3. Telephone networks
4. Data networks

We discuss the telephone networks in Chapter 9 and the data networks in Chapter 10. Management and maintenance of multiple networks are expensive. The question then arises: Is it possible to design a single network that can carry all the services? The key to the solution of this problem lies in the digitalisation of services. If all the service specific signals can be converted to a common digital domain, a network capable of transporting digital signals can carry the multitude of services. This approach is leading to the evolution of the integrated services digital network (ISDN) which is discussed in Chapter 11.



(a) An electrical communication system



(b) An optical communication system

CI = channel interface EOC = electrical to optical converter
ES = electrical signal OEC = optical to electrical converter
SC = signal conditioner T = transducer

Fig. 1.5 Elements of a communication system.

1.2 Simple Telephone Communication

In the simplest form of a telephone circuit, there is a one way communication involving two entities, one receiving (listening) and the other transmitting (talking). This form of one way communication shown in Fig. 1.6 is known as **simplex communication**. The microphone and the earphone are the transducer elements of the telephone communication system. Microphone converts speech signals into electrical signals and the earphone converts electrical signals into audio signals. Most commonly used microphone is a carbon microphone.

Carbon microphones do not produce high fidelity signals, but give out strong electrical signals at acceptable quality levels for telephone conversation. In carbon microphones, a certain quantity of small carbon granules is placed in a box. Carbon granules conduct electricity and the resistance offered by them is dependent upon the density with which they are packed. One side of the box cover is flexible and is mechanically attached to a diaphragm. When sound waves impinge on the diaphragm, it vibrates, causing the carbon granules to compress or expand, thus changing the resistivity offered by the granules. If a voltage is applied to the microphone, the current in the circuit varies according to the vibrations of the diaphragm. The theory of the carbon microphone indicates that the microphone functions like an amplitude modulator. When the sound waves impinge on the diaphragm, the instantaneous resistance of the microphone is given by

$$r_i = r_0 - r \sin \omega t \tag{1.2}$$

where

r_0 = quiescent resistance of the microphone when there is no speech signal
r = maximum variation in resistance offered by the carbon granules, $r < r_0$
r_i = instantaneous resistance

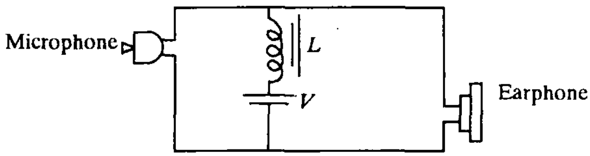


Fig. 1.6 A simplex telephone circuit.

The negative sign in Eq. (1.2) indicates that when the carbon granules are compressed the resistance decreases and vice versa. Ignoring impedances external to the microphone in the circuit given in Fig. 1.6, without loss of generality, the instantaneous current in the microphone is given by

$$i = V/(r_0 - r \sin \omega t) = I_0(1 - m \sin \omega t)^{-1} \tag{1.3}$$

where

$I_0 = V/r_0$ = quiescent current in the microphone
$m = r/r_0, \quad m < 1$

By binomial theorem, Eq. (1.3) may be expanded as

$$i = I_0(1 + m \sin \omega t + m^2 \sin^2 \omega t + \cdots) \tag{1.4}$$

If the value of m is sufficiently small, which is usually the case in practice, higher-order terms can be ignored in Eq. (1.4), giving thereby

$$i = I_0(1 + m \sin \omega t) \tag{1.5}$$

which resembles the amplitude modulation (AM) equation. Thus, the carbon granule microphone acts as a modulator of the direct current I_0 which is analogous to the carrier wave in AM systems. The quantity m is equivalent to the modulation index in AM. The higher-order terms in Eq. (1.4) represent higher-order harmonic distortions, and hence it is essential that the value of m be kept sufficiently low. In Eq. (1.5), the alternating current output i is zero if the quiescent current I_0 is zero. Hence, the flow of this steady current through the microphone is essential, and the current itself is known as energising current. In Fig.1.6, the inductor acts as a high impedance element for voice frequency signals but permits the d.c. from the battery to flow to the microphone and the receiver. The voice frequency signals generated by the microphone reach the earphone without being shunted by the battery arm and are converted to audio signals there.

The earphone is usually an electromagnet with a magnetic diaphragm which is positioned such that there is an air gap between it and the poles of the electromagnet. When the electromagnet is energised by passing a current, a force is exerted on the diaphragm. The voice frequency current from the microphone causes variation in the force exerted by the electromagnet, thus vibrating the diaphragm and producing sound waves. Faithful reproduction of the signals by the receiver requires that the magnetic diaphragm be displaced in one direction from its unstressed position. The quiescent current provides this bias. In some circuits, a permanent magnet is used to provide the necessary displacement instead of the quiescent current. The instantaneous flux linking the poles of the electromagnet and the diaphragm is given by

$$\phi_i = \phi_0 + \phi \sin \omega t \tag{1.6}$$

where

ϕ_0 = constant flux due to the quiescent current or the permanent magnet
ϕ = maximum amplitude of flux variation, $\phi < \phi_0$
ϕ_i = instantaneous flux

Equation (1.6) assumes that the vibrations of the diaphragm are too small to affect the length of the air gap and that the reluctance of the magnetic path is constant. The instantaneous force exerted on the diaphragm is proportional to the square of the instantaneous flux linking the path. Therefore,

$$F = K(\phi_0 + \phi \sin \omega t)^2 \tag{1.7}$$

where K is the constant of proportionality. Expanding the right-hand side of Eq. (1.7), we have

$$F = K(\phi_0^2 + \phi^2 \sin^2 \omega t + 2\phi_0\phi \sin \omega t) \tag{1.8}$$

When $(\phi/\phi_0) << 1$, we can ignore the second-order term in Eq.(1.8). We then have

$$F = K\phi_0^2(1 + K_1 I_0 \sin \omega t) \tag{1.9}$$

where $I_0 \sin \omega t$ is the current flowing through the coil. We thus see that the force experienced by the diaphragm is in accordance with the signals produced by the microphone.

In a normal telephone communication system, information is transferred both ways. An entity is capable of both receiving and sending although these do not take place simultaneously. An entity is either receiving or sending at any instant of time. When one entity is transmitting, the other is receiving and vice versa. Such a form of communication where the information transfer takes place both ways but not simultaneously is known as **half-duplex communication**. If the information transfer takes place in both directions simultaneously, then it is called **full-duplex communication**.

Figure 1.6 may be modified to achieve half-duplex communication by the introduction of a transmitter and receiver at both ends of the circuit as shown in Fig. 1.7. In this circuit, the speech of *A* is heard by *B* as well as in *A*'s own earphone. This audio signal, heard at the generating end, is called **sidetone**. A certain amount of sidetone is useful, or even essential. Human speech and hearing system is a feedback system in which the volume of speech is automatically adjusted, based on the sidetone heard by the ear. If no sidetone is present, a person tends to shout, and if too much of sidetone is present, there is a tendency to reduce the speech to a very low level. In the circuit of Fig. 1.7, the entire speech intensity is heard as sidetone, which is not desirable. Figure 1.8 gives a circuit where a small level of sidetone and the full speech signal from the other party are coupled to the receiver. The impedance Z_b, is chosen to be more or less equal to the impedance seen by the circuit to the right of section *AA'*. As a consequence, with proper sidetone coupling the speech signal from the microphone M divides more or less equally in the two windings *P* and *Q*. Since the signals in these two windings are in the opposite direction, only a small induced voltage appears in the receiver circuit providing the sidetone. When a signal is received from the other entity, it travels in the same direction in both windings P and Q, inducing a large signal in the receiver circuit.

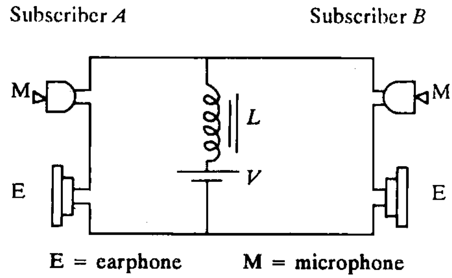


Fig. 1.7 A half-duplex telephone circuit.

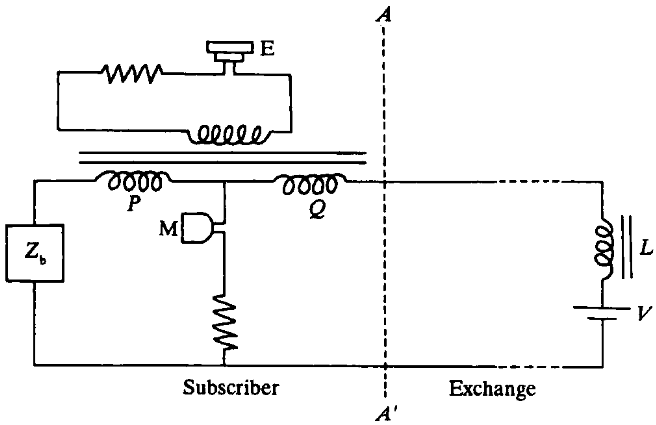


Fig. 1.8 A telephone circuit with sidetone coupling.

1.3 Basics of a Switching System

A major component of a switching system or an exchange is the set of input and output circuits called **inlets** and **outlets**, respectively. The primary function of a switching system is to establish an electrical path between a given inlet-outlet pair. The hardware used for establishing such a connection is called the **switching matrix** or the **switching network**. It is important to note that the switching network is a component of the switching system and should not be confused with telecommunication network. Figure 1.9(a) shows a model of a switching network with N inlets and M outlets. When $N = M$, the switching network is called a **symmetric network**. The inlets/ outlets may be connected to local subscriber lines or to trunks from/to other exchanges as shown in Fig. 1.9(b). When all the inlets/outlets are connected to the subscriber lines, the logical connection appears as shown in Fig. 1.9(c). In this case, the output lines are folded back to the input and hence the network is called a **folded network**. In Fig. 1.9(b), four types of connections may be established:

1. Local call connection between two subscribers in the system
2. Outgoing call connection between a subscriber and an outgoing trunk
3. Incoming call connection between an incoming trunk and a local subscriber
4. Transit call connection between an incoming trunk and an outgoing trunk