UNIT - I
BASICS OF SWITCHING SYSTEM

LESSON 1:
INTRODUCTION TO TELEPHONE COMMUNICATION

Objective

The objective of the courses is to provide the graduate engineers with modern evaluation and implementation procedures in the area of telecommunication services and networks. The students, upon completion of the course will have acquired the ability to model and design telecommunication/data networks using up-to-date techniques. Various telecommunication and data networking concepts will be introduced, but the focus will be on the standards and practices of data communications, as well as tools for performance evaluation. Students will be equipped with important knowledge and training in the evaluation and implementation of telecommunication services and networks.

Introduction

In 1876, an inventor named Alexander Graham Bell was awarded a patent for one of the most significant devices in our lives- the telephone set. Mr. Bell spent many years trying to develop a method of communication with his wife. You see, Mrs. Bell was deaf. Alexander was looking for a way to convert sound into some other form of communication so that his wife could understand him. While she was in a hospital for deaf in Boston, Massachusetts, he was busy at work trying to solve his basic problem, of communication.

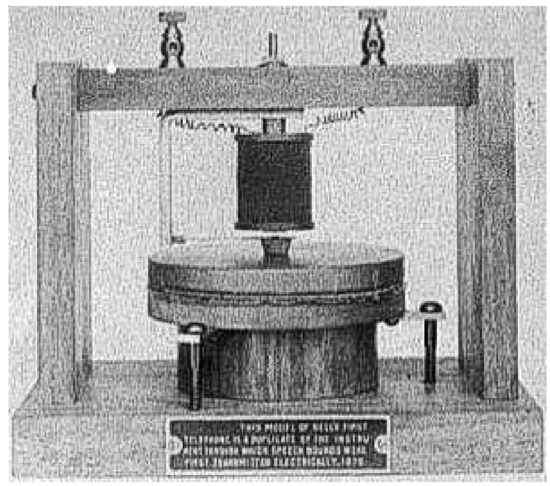
Having some experience with the working of the telegraphy, by which coded messages could be sent across a cable, Bell decided to mimic this means of communication. Using the basic principle that communication could be converted from sound into electricity, he would be able to speak into communication device that, in turn, would convert the sound waves into electric energy. Literally, what Bell wanted to achieve was the transmission of the voice over the telegraph, or by today's standard voice over the data network. This electrical energy could then be used to produce a coded message similar to a telegraph message. Many frustrations were experienced by Bell and his assistant Dr. Watson.

Then one day, while working in a lab by himself (Watson had been there, but left for moment), Bell spilled some acid on his worktable. This acid acted as a catalyst to produce a battery effect. Without realizing what occurred at that time, Bell called out for Watson. His call of " Watson, come here, I need you!" activated the experimental device they had set up for the communicator. Hearing the call for help, Watson ran to the aid of his partner.

The two researchers discovered that if a battery is applied across the electrical circuit (the wires) while the users speaks, the sound wave produced by the human voice could be carried across this same pair of wires to a receiver set up to accept this electrical current and convert the electricity back to sound. Hence, on that fateful day, the birth of a new industry occurred. The telephone was invented.

Model of Alexander Graham Bell's Telephone

This model of Bell's first telephone (right) is a duplicate of the instrument through which speech sounds were first transmitted electrically (1875).



Let us start with basics of telephone communication; I think you know the basics of communication. Most human activities depend on using information. This comes in a variety of forms including human speech, written & printed documents and computer data. The information can be stored & transported & technologies have been developed to perform all these functions, one of the most important means of transporting information is by converting it into electrical signals & transmitting these over a distance i.e. telecommunication. Electrical communication began with the invention of the telegraph, it consist mainly of separate point-to point sending information in one direction at a time. It is conceivable that cables of telephone wires could be laid underground or suspended overhead, communicating by branch wires with private dwelling, houses, etc, uniting them through the main cable with a central office where the wires could be connected as desired establishing direct communication between any two places in the city. Telecommunication network have grown up in all countries of the world have been joined up by an international network which links more than 800 million telephones in over 200 countries. These networks now provide many different services, including telegraphy, telephony, data communications & television transmission.

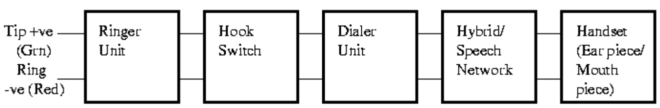
Consequently, practical use of Bell's invention on a large scale or even on a moderate scale demanded not only the telephone sets & the pairs of wires, but also the switching system. Switching system is also called the switching network or the exchange. With the introduction of switching systems the subscribers are not connected directly to one another.

The telephone network consists of your phone at home that is connected (by the Local Loop) to the Central Office. The Central Office is in turn connected to a Hierarchical Phone Network. Worldwide, there are over 300 million (300,000,000) telephones - 98% of them interconnected.

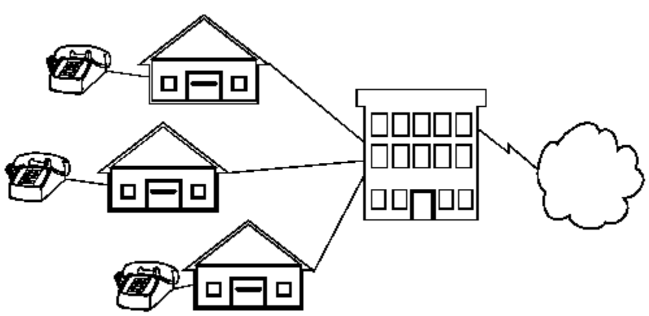
POTS - Plain Old Telephone Set

The POTS, or Plain Old Telephone Set, consists of these 5 sections:

i. Ringer Unit
ii. Hook Switch
iii. Dialer Unit
iv. Hybrid/Speech Network
v. Hand Set



The connection to the CO (Central Office) comprises only 2 wires: Tip and Ring. This connection is called the "Local Loop."



The Tip is positive and colored green. The Ring is negative and colored Red. If you look at a phone jack in your house, you will see that it is wired for 4 wires: Red, Green, Black and Yellow. However, black and yellow are not normally used.

The black and yellow wires can be used for a second telephone line or they can be used for running a Network Physical layer protocol called Phonenet (by Farralon). Phonenet uses the black and yellow for Network communications. It is for use with Appletalk, and is a replacement for Localtalk. It runs at the Localtalk speed of 230 Kbps, reasonable for small networks.

i. Ringer Unit

The ringer is a device that alerts you to an incoming call: it interprets the ringing voltage from the Central Office. Originally, the ringer was a electromagnetic bell. Today, though, most ringers are electronic devices.

The Central Office sends the following:

- a 90 to 120 VAC ringing voltage
- Frequency of 20 Hz
- Cadence for North America is 2 sec On/ 4 sec Off

ii. Hook Switch

The hook switch is activated by lifting the handset off of the cradle. The position of the hook switch determines whether the telephone is waiting for a call, or is actively using the line. The off-hook position informs the network of a request for use. The on-hook position releases the use of the network.

iii. Dialer Unit

There are two types of Dialer Units: Rotary and Touch Tone. Rotary is the old "put your finger in the hole and spin" type. The rotary dial operates by toggling the Hook Switch on and off.

High Group Frequencies (Hertz)

Low Group Frequencies (Hertz)	1209	1336	1477
697	1	ABC 2	DEF 3
770	GHI 4	JKL 5	MNO 6
852	PRS 7	TUV 8	WXY 9
941	*	OPER 0	#

Touch Tone is the modern method where 2 frequencies per push button are sent. Touch Tone is a trade name; the correct name is DTMF (Dual Tone Multi Frequency).

iv. Hybrid/Speech Network

The Hybrid/Speech Network performs these functions:

- It converts the Tx/Rx 4 wires from the Handset to the 2 wires for the Local Loop.
- It interfaces the signals from the Dialer Unit to the telephone line.
- It provides auto line compensation for line length to keep the volume constant.

v. Handset

The Handset contains transducers that convert mechanical energy into electrical energy. The microphone converts speech into electrical energy while the diaphragm (or speaker) converts electrical signals into audible signals.

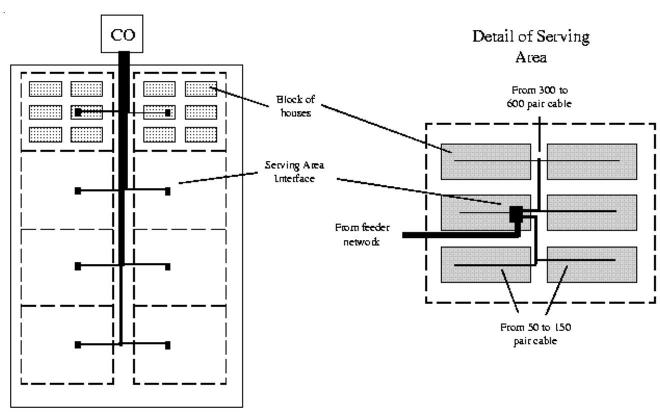
Functions of a Telephone Set are shown below.

i. Request use of network from the CO (Central Office).
ii. Inform you of the network status: Dial-tone, Ringing, Busy, Fast Busy (Talk Mail)
iii. Informs CO of desired number.
iv. Informs you when a call is incoming (phone rings).
v. Releases use of network when call is complete (hang-up)
vi. Transmit speech on network & receives speech from distant caller.
vii. Adjust power levels and compensates for line length.

Local Loops

Year 1870 AD	--→	--→	Year 1970 AD --→	Year 1990 AD --→	Year 2000 AD --→
• Telegraphy	• Telephony • Telegraphy	• Telex • Fascimile • Telephony • Telegraphy	• Radiophone • Datel • Telex • Fascimile • Telephony • Telegraphy	• Home banking • Cashless calling • Supplementary services • 0800 services • Voice Bank • Cellphone • Messaging • Skyphone • Radiopaging • Confravision • Videophone • Low cost fax • Telemetry • Telecommand • Enhanced data • Radiophone • Datel • Telex • Fascimile • Telephony • Telegraphy	• Packet phone • Voice recognition • Digital End-to-End services • Personal services profiles • Digital mobile comms. • Satellite business service • Personal communications • Virtual private systems • International paging • Sky phone • Teleworking • Home banking • Cashless calling • Supplementary services • 0800 services • Voice Bank • Cell phone • Messaging • Tele mail • Home Newspapers • Colour fax • Radiopaging • Confravision • Video phone • Low cost fax • Telemetry • Tele command • Enhanced data • Radio phone • Datel • Telex • Fascimile • Telephony • Telegraphy

The Local Loop is the connection between the Central Office and the home or business. Two wires (1 pair) are run into every home. The pair does not go directly to the Central Office. Instead, it goes to those big green boxes-that you see on the street corners-called "Serving Area Interfaces" (SIA). Large multi-conductor bundles of wires then go from there to the Central Office.



Central Office

The Central Office provides the following functions:

i. It supplies the battery voltage for the telephone system. The On-hook voltage is 48 V dc +/- 2V. Off-hook voltage is - 6.5 Vdc.

ii. It supplies the Ringing Generator - 90 to 120 VAC, 20 Hz, 2 sec on/ 4 sec off

iii. It supplies the Busy signal (480 + 620 Hz, 0.5 sec On/ 0.5 sec Off), Dial Tone (350 + 440 Hz) and Fast Busy (480 + 620 Hz, 0.2 sec On/ 0.3 sec Off).

iv. It has the digital switching gear that determines if the number is an Interoffice call (local) or an Intraoffice call (Toll - long distance).

These are the basics of telephone communication, next we star with network structure i.e. how can we connect all these systems together.

Growth Of Telecommunication Services

Telecommunications networks have grown up in all the countries of the world. These networks have been joined up by an international network. This international network links more than 800 million telephones in over 200 countries. These networks now provide many different services, including telegraphy, telephony, data communications and television transmission. The amount of traffic carried and variety of services provided have grown steadily and may be expected to grow further in the future. These services are illustrated in Fig. 1.1

Fig. 1.1 Illustration of Growth of Telecommunication Services

The business of telecommunications involves many partici-pants. These are: the user, the public telecommunication operators (PTO) providers of services that involve telecommu-nications, manufacturers of equipments and components (both hardware and software), financial investors and governments.

Since the users must pay charges to cover the cost of providing the network users are usually called subscriber or customers.

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 the year 1837 (AD) in Great Britain and in the year 1845 (AD) in France. Telephony was introduced by Alexander Graham Bell in the year 1876 (AD).

Graham Bell demonstrated a point-to-point telephone connection. A network using point-to-point connections is shown in Fig. 1.2.

In such a network, a calling subscriber chooses the appropriate link to establish connection with the called subscriber. We need some form of signalling with each link before information exchange between calling subscriber and called subscriber. The signalling is initiated from the calling subscriber. If the called subscriber is engaged, a suitable indication should be given to the calling subscriber by means of signalling.

There are five entities (subscribers or points) and ten point-to-point links in the network shown in Fig.1.2. In general case, if there is N entities in a network then there will be (N / 2)* (N-1) links.

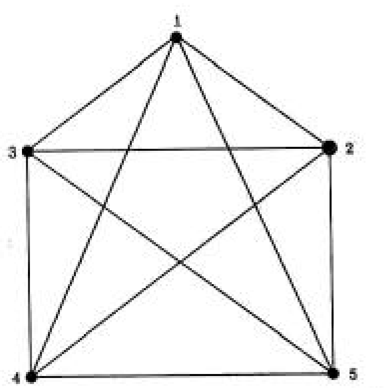


Fig. 1.2 A networks with point-to-point links.

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.

Subscribers allover the world cannot be connected to a single switching system unless we have a gigantic switching system in the sky and every subscriber have a direct access to the same. Although entire globe is covered by a communication satellite system and low cost roof top antenna present such a scenario. The capacity of such a system is limited at present. The major part of the telecommunication networks is still ground based. At ground-based telecommunication networks, 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 subscriber must be located within a few kilometers from the switching system. Communication capability can be established among the subscribers in the same locality by introducing a number of stand-alone switching systems in the appropriate geographical locations. However, for subscribers in different localities to communicate, it is necessary that the switching systems are interconnected in the form of network. A telecommunication network is shown in Fig. 1.3.

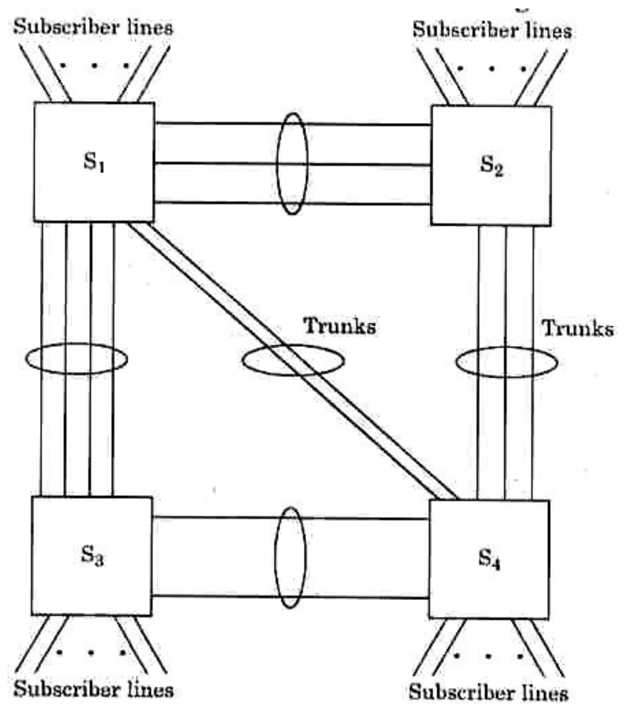
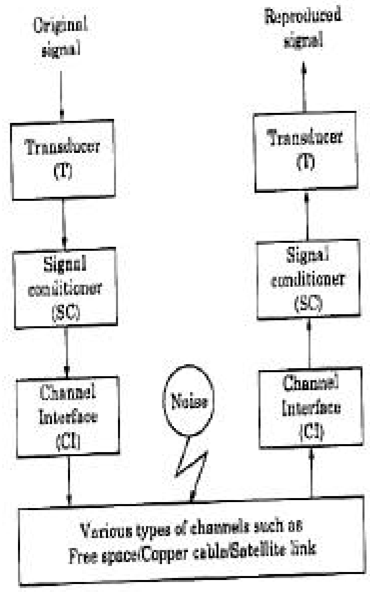


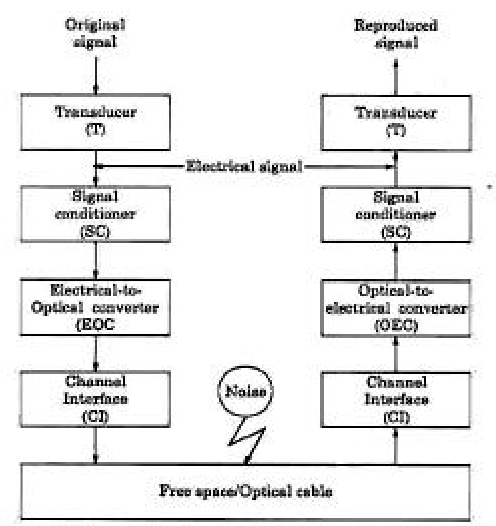
Fig. 1.3 A telecommunication network (Here S_1, S_2, S_3, and S_4 are the switching systems).

The links that run between the switching systems are called trunks. The links that run to the subscriber premises are known as subscriber lines. The number of trunks may vary between pairs of switching systems. The number of trunks can be determined on the basis of traffic between them. As the number of switching systems increases, interconnection between 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.

A modern telecommunication network may be viewed as an aggregate of a large, number of point-to-point electrical or optical communication systems. Elements of modern telecommunication system are shown in Fig. 1.4. An electrical communication system is shown in Fig. 1.4(a).



An optical communication system is shown in Fig. 1.4 (b).



(b) An optical communication system.

Fig. 1.4 Elements of a communication system.

These electrical or optical communication systems are capable of carrying electrical or optical signals. But the information to be conveyed in not always in the electrical or optical form. For example, human speech signals need to be converted to electrical or optical signals before they can be carried by a communication system. Transducers are used for 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. At the receiving and optical signals are converted to electrical signals before the original signal is reproduced. A medium is required to carry the signals. This medium is known as channel. The channel may be the free space, a copper cable or the free space in conjunction with a satellite in the case of electrical, communication system.

An optical communication system may use the line-of-sight (LOS) fire space or fiber optic cables as the channel. Channels, in general, are lousy and prone to external noise that corrupts the information-carrying signal. Different channels exhibit different loss characteristics and are affected to different degrees by noise. 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 links. Therefore, the signals reach the destination with acceptable level of intelligibility and fidelity. Signal conditioning may include amplification, filtering, band limiting multiplexing and demultiplexing. Fiber-optic communication systems are emerging as major transmission systems for telecommunica-tions.

The channel and the signal characteristics of individual commu-nication systems in a telecommunication network may change widely. For example, the communication system between the subscriber and the switching system uses most often a pair of copper wires at the channel. But the communication system between the switching systems may use a coaxial cable or the free space (microwave) as the channel. In similar fashion, the type of end equipment used at the subscriber premises would decide at the electrical characteristics of the 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 can lead to the development of different service specific telecommunication networks that operate independently. These telecommunication services are:

1. Telegraph networks.
2. Telex networks.
3. Telephone networks.
4. Data networks.

Management and maintenance of multiple networks are expensive. Now one question arises in our mind that: Is it possible to design a single network that can carryall the services mentioned above? The key to the solution of this question lies in the digitalization of services. If all the service specific signals can be connected to a common digital domain then we can obtain a network which is capable of transporting digital signals which can carry a multitude of services. This approach leads to the evolution of the Integrated Services Digital Network (ISDN).

Network Structures

If communications is required between N users station, it could be provided by a network consisting of a line from each station to every other. It is shown in Fig. 1.5 (a). This network is called a Mesh Network. Each station needs lines to N -1 others. Thus, if the line from user A to user B can also convey calls from B to A, the total number of lines required is,

$$N_t = \frac{N}{2}(N-1)$$

If N >> 1, then N_t is approximately proportional to N^2. This arrangement is impracticable if N is small and the lines are short. For example, a small system serves a number of telephones in the same office. However, as N increases and the lines become longer, the arrangement becomes much too expensive. For example, a system serving 10,000 users stations would need nearly 50 million lines.

Instead of each station being connected to every other, they can all be connected to a single line. This forms a bus or a ring. The bus and the ring network configurations are shown in Fig. 1.5 (b) and (c), respectively. These networks are useless for normal telephony since only one conversation at a time can take place. However, bus and ring networks can be used for data communication by transmitting data over the common circuit at a much higher rate than it is generated by the individual terminals. When the common circuit is already in use, a terminal that needs to send a message stores it until the circuit becomes free. These configurations are used for local area networks (LAN) for data transmission over short distances.

For telephony, two-way communication is required, on demand, between any pair of stations. It is also possible in telephony, that many conversations can take place at the same time. These requirements can be met by providing a line from each user's station to a telephone exchange (e.g. a central switching centre), which connects the lines together as required. This network configuration is called a star network. It is shown in Fig. 1.5 (d). The number of lines is reduced from

$$N_t = \frac{N}{2}(N-1) \quad \text{to only } N_t = N.$$

If N_t is large, the cost of providing the switching centre is far out weighted by the saving in line costs.

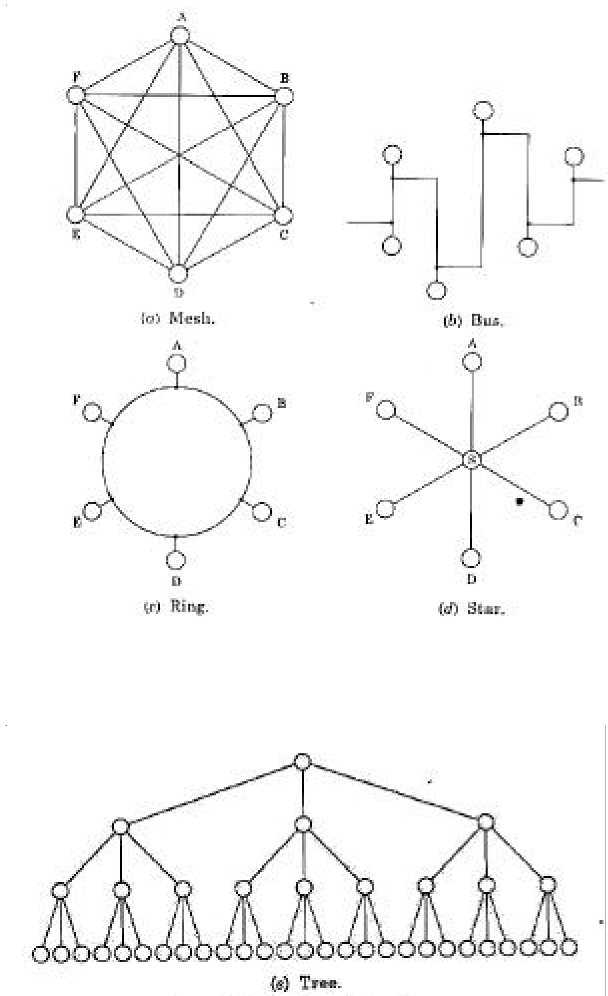
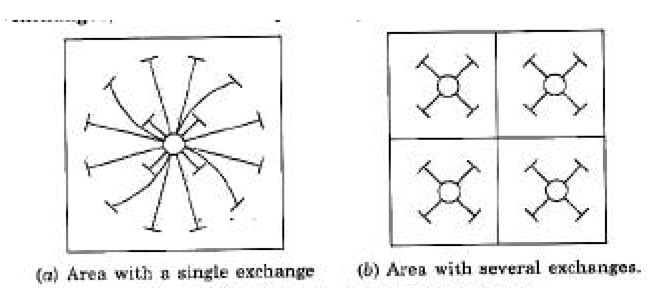


Fig. 1.5 Network configurations.

As the area covered by a star network and the number of stations served by it grow, line costs increase. It then becomes economic to divide the network into several smaller networks, each served by its own exchange. It is shown in Fig. 1.6. The average length of customer's line and thus the total line cost, decreases with the number of exchanges, but the cost of providing the exchanges increases.



(a) Area with a single exchange (b) Area with several exchanges.

Fig. 1.6 Subdivision of an exchange area

Thus, there are an optimum number of exchanges for which the total cost is a minimum. It is shown in Fig. 1.7. If an area is served by several exchanges, customers on each exchange will wish to converse with customers on the other exchanges.

It is therefore necessary to provide circuits between the exchanges. These are called Junction circuits. These Junction circuits form a Junction network. If Junctions are provided between all exchanges, the junction network has mesh configuration. However, if the cost of the junction circuits is high, it will be uneconomic to connect all the exchanges directly and cheaper to make connections between the customer's local exchanges via a central switching centre called a tandem exchange. The junction network then has a star configuration.

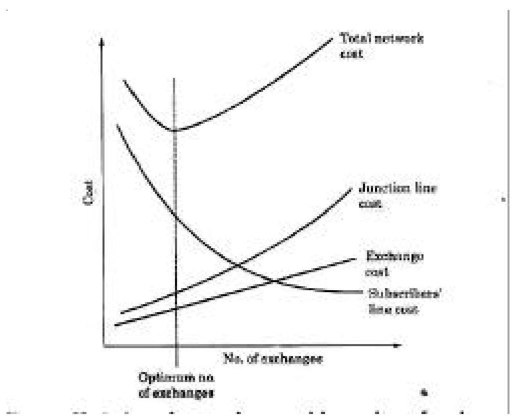


Fig. 1.7 Variation of network cost with number of exchanges

In practice, direct junctions between two local exchanges provide economy when there is a high community of interest between their customers (resulting in low transmission costs).

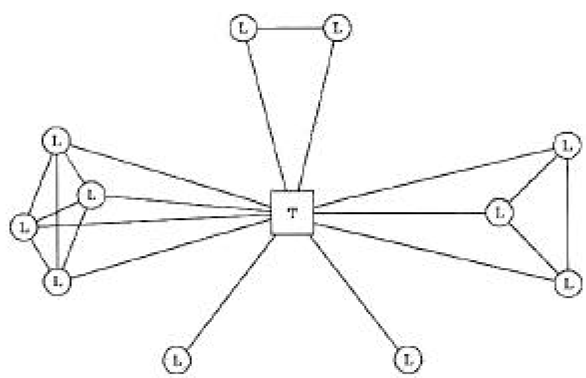


Fig.1.8 Multi-exchange area, L = Local exchange, T = tandem exchange

Conversely, indirect routing via a tandem exchange is cheaper when the traffic is small or the distance large. Consequently, a multi-exchange usually has direct junctions between some exchanges, but traffic between the others is routed via the tandem exchange. The network of the area is there a mixture of a star network joining all local exchanges to the tandem exchange, and mesh networks connecting some of the local exchanges together. It is shown in Fig. 1.8.

Customers wish to communicate with people in other parts of the country in addition to those in their own area. The different areas of the country are interconnected by long distance circuits. The interconnections of long-distance circuits form a trunk network or a toll network. Since all local exchanges in an area have junctions to the tandem exchange, this provides convenient access to the trunk network. However, in large cities, the long distance traffic is sufficient for the local tandem switching and the trunk switching functions to be performed by separate exchange.

It is usually uneconomic for all local exchanges in an area to be fully interconnected. It is often uneconomic for all the trunk exchanges of a country to be fully interconnected. Consequently, routing between different areas is provided by tandem connections via trunk transit exchanges. In a large national network, even these may not be fully interconnected and one or more higher levels of switching centre are introduced. This produces concatenation of star networks, resulting in a tree configuration. It is shown in Fig. 1.5(e). However, direct routes are provided where the traffic is high and transmission costs are low. Thus the "lack-bone" tree is complemented by lateral routes between some exchanges at the same level. It is shown in Fig. 1.9.

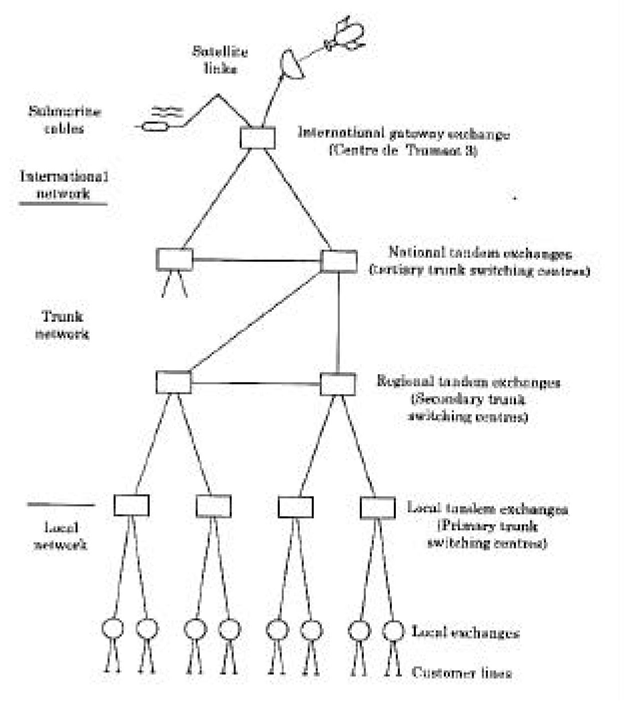


Fig. .1.9 National telecommunications network.

In a network of the kind shown in Fig. 1.9, when there is a direct route between two exchanges at the same level, there is also a possible alternative route between them *via* an exchange at the next higher level.

Thus, if the direct circuit is not available (e.g. because of a cable break-down), it is possible to divert traffic to the indirect route. In older switching systems, such changes must be made by manual rearrangement. However, modern switching systems provide automatic alternative routing (AAR).

With automatic alternative routing (AAR), if an originating exchange is unable to find a free circuit on the direct route to a destination exchange, it automatically routes the call through the higher-level exchange. This takes place not only when there are no direct circuits available because of a breakdown but also when they are all busy. Thus, tandem connections augment the number of circuits available to carry peak traffic and fewer circuits are needed on the direct route. In a modern network, use of AAR improves the resilience of the network to withstand both breakdowns and traffic overloads.

A national public switched telecommunications network (PSTN) is shown in Fig. 1.9. It consists of the following hierarchy:

1. **Local networks:** These connect customer's stations to their local exchanges. Local networks are also called subscribers distribution network, customer access networks or the customer loop.
2. **Junction Networks:** These interconnect a group of local exchanges serving an area and a tandem or trunk exchange.
3. **The trunk network or toll network:** These networks provide long distance circuits between local areas throughout the country.

The totality of (2) and (3) is sometimes called the Core Network, the inner core consisting of the trunk network and enter one consisting of the junction networks.

Above this hierarchy, there is the international network, which provides circuits linking the national networks of different countries. The national network is connected to the international network by one or more international gateway exchanges.

Below the hierarchy of the national public network, some customers have internal lines serving extension telephones. These are connected to one another and to lines from the public exchange by a private branch exchange (PBX).

For data communications, they may have a local area network (LAN), which is also connected to a public data network. Large companies also have private networks (usually employing circuits leased from the public telecommunications operator), which link their PBXs in the different parts of the country, or even across several countries.

A telecommunications network contains a large number of transmission links joining different locations, which are known as the nodes of the network. Thus, each customer's terminal is a node. Switching centres form other nodes. At some nodes, certain circuits are not switched but their transmission paths are joined semi-permanently. Customers require connection to nodes where there are telephone operators to assist them in making calls and to public emerging services such as police, fire and ambulance.

They also wish to obtain connections to commercial providers of 'value-added' network services (VANS) such as voice mailboxes, stock-market prices and sports results. Consequently, a telecommunications network may be considered to be the totality of the transmission links and the nodes.

The nodes may be of the following types:

i. Customer Nodes

ii. Switching Nodes

iii. Transmission Nodes

iv. Service Nodes.

In order to set up a connection to the required destination, and clear it down when no longer required, the customer must send information to the exchange. For a connection that passes through several exchanges, such information must be sent between all exchanges on the route. This interchange of information is called signalling.

A telecommunications network may therefore be considered as a system consisting of the following interconnecting subsystems:

i. Transmission Systems

ii. Switching Systems

iii. Signalling Systems.

Simple Telephone Communication

In the simplest form of a telephone circuit, there is a one-way communication involving two entities. These entities are receiving & transmitting. It is also known as simplex communication, shown in Fig.1.10.

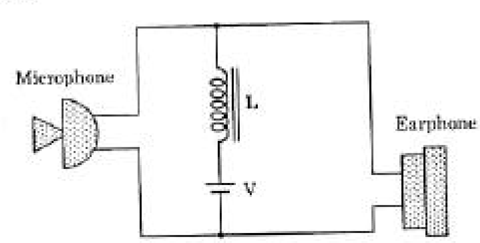


Fig. 1.10 A simplex telephone circuit.

The microphone and the earphone are the transducer elements of the telephone communication system. The microphone converts speech signals (acoustic waves) into electrical signals. The earphone converts electrical signals into audio signals.

Most commonly used microphone is a carbon microphone. Carbon microphones do not produce high fidelity (quality of reproduction) 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. The resistance offered by carbon granules 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 (acoustic) waves impinge on the diaphragm, it vibrates, causing the carbon granules to compress or expand, thus resistivity offered by the carbon granules changes. If a voltage is applied to the microphone, the current in the circuit varies according to the vibrations of the diaphragm. We know from the theory of carbon microphone that microphone functions like an amplitude modulator.

When the sound waves impinge on the diaphragm, the instantaneous resistance of carbon microphone is given by

$R_i = R_0 - R \sin wt$ ……....Eq.1

Where,

R_0 = Quiescent resistance of the microphone where there is no speech signal.

R = Maximum variation in resistance offered by the carbon granules, $R < R_0$

R_i = Instantaneous resistance

We know from Eqn. 1 that when the carbon granules are compressed the resistance decreases and vice-versa.

Instantaneous current in the microphone (when ignoring impedances external to the microphone) in the circuit of Fig. 1.10 is given by

$$I_i = V / R_i$$

Substituting Eqn. 1 in Eqn. 2 We get

$$I_i = \frac{V}{R_0 - R\sin\omega t} = \frac{\left(\frac{V}{R_0}\right)}{\left(\frac{R_0}{R_0}\right) - \left(\frac{R}{R_0}\right)\sin\omega t}$$

$$= \frac{\left(\frac{V}{R_0}\right)}{1 - \left(\frac{R}{R_0}\right)\sin\omega t} = \frac{I_0}{1 - m\sin\omega t}$$

or $I_i = I_0\,(1 - m\sin\omega t)^{-1}$ Eq.3

where,

$I_O = V / R_O$ = Quiescent current in the microphone

$m = R / R_O$, $m < 1$ By using binomial theorem, Eqn.3 can be expanded as $I_i = I_O (1 - m \sin wt)^{-1}$

$= I_O (1 + m \sin wt + m^2 \sin^2 wt + m^3 \sin^3 wt + ...)$ ……..Eq.4

If the value of m is sufficiently small (which is usually the case in practice) higher order terms can be ignored in Eqn.4, we get

$I_i = I_O (1 + m \sin wt)$ ……….Eq.5

Eq.5 resembles the Amplitude Modulation (AM) Equation. Thus, carbon granule microphone acts as a modulator of direct current I_O 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 Eqn.4 represent higher-order harmonic distortions. Hence it is essential that the value of m be kept sufficiently low. If the quiescent current I_O is zero in Eq.5 then instantaneous current, i.e., the alternating current output I_i is zero. Hence, the flow of this steady current through the microphone is essential and the current itself is known as Energizing Current. The inductor (L) shown in Fig. 1.10 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. The magnetic diaphragm 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 variations in the force exerted by the electromagnet. Therefore, it helps in vibrating the diaphragms and produces sound waves. It is required for the faithful reproduction of the signals by the receiver that the magnetic diaphragm be displaced in one direction from its unstressed position. The quiescent current I_O provides this bias. In some circuits, a permanent magnet is used to provide the necessary displacement instead of the quiescent current. The instantaneous magnetic flux linking the poles of the electromagnet and the diaphragm is given by

$\varnothing_i = \varnothing_O + \varnothing \sin \omega t$ ………..Eq.6

where, $\varnothing_0$ = constant magnetic flux due to the quiescent current or the permanent magnet

$\varnothing$ = maximum amplitude of flux variation

$\varnothing < \varnothing_O$

$\varnothing_1$ = Instantaneous magnetic flux.

Eq.6 assumes that the vibrations of the diaphragm are too small to affect the length of the air gap and that the reductance of the magnetic path is constant. The instantaneous force exerted on the diaphragm is directly proportional to the square of the instantaneous flux linking the path. It is expressed as

$F = K [\varnothing_O + \varnothing \sin wt]^2$ ………..Eq.7

where K is the constant of proportionality.

On expanding RHS of Eqn.7, we get

$F = K [\varnothing_O^2 + \varnothing^2 \sin^2 wt + 2\varnothing_O\varnothing \sin wt]$. ………Eq.8

We can ignore term $\varnothing^2 \sin^2 wt$ from Eq.8 when we have assumed that,

$\varnothing / \varnothing_O \leq 1.$

$$F = K [\varnothing_O^2 + 2\varnothing_O\varnothing \sin wt]$$

$$= K \varnothing_O^2 [1 + (2\varnothing / \varnothing_O) \sin wt]$$

$$= K \varnothing_O^2 [1 + K_1 I_O \sin wt] \quad \text{………………..Eq.9}$$

where $I_O \sin wt$ is the current flowing through the coil. From above discussion we 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 in 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.

A form of communication where the information transfer takes place both ways but not simultaneously is called half duplex communication.

If the information transfer takes place in both directions simultaneously, then it is called full-duplex communication.

There is a need to modify Fig. 1.10 to achieve half-duplex communication by the introduction of a transmitter and receiver at both ends of the circuit. It is shown in Fig. 1.11. In this circuit, the speech of A is heard by B as well as in A's own earphone.

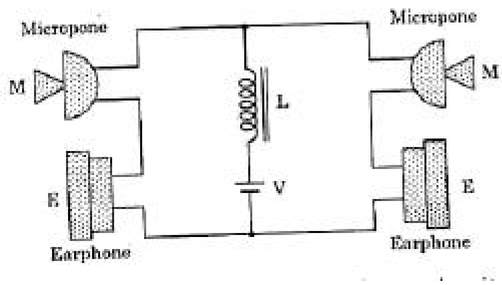


Fig. 1.11 A half-duplex telephone circuit

Here E = Earphone and M = Microphone

The 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. If too much of sidetone is present, there is a tendency to reduce the speech to a very low level. In Fig. 1.11, the entire speech intensity is heard as a sidetone, which is not desirable.

A circuit where a small level of sidetone and the full speech signal from the other party are coupled to the receiver is shown in Fig. 1.12. 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'. Consequently, with proper side tone coupling the speech signal from the microphone divides more or less equally in the two windings W_1 and W_2. Since the signals in these two windings are in the opposite direction. Therefore, only a small-induced voltage appears in the receiver circuit providing the side tone when a signal is received from the other entity, it travels in the same direction in both windings W_1 and W_2 inducing a large signal in the receiver circuit.

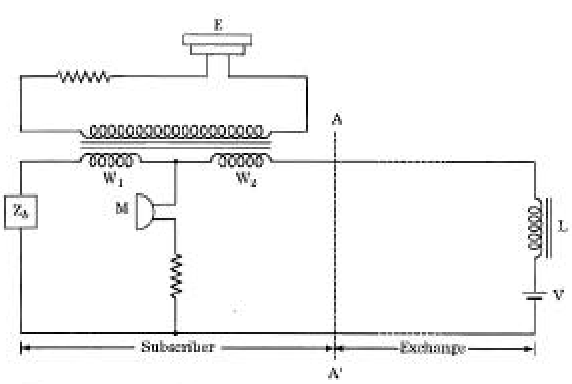


Fig. 1.12 A telephone circuit with sidetone coupling.

Notes