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Introduction to Switching Systems

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1.1. INTRODUCTION

Telecommunication networks carry information signals among entities, which are geographically far apart. An entity may be a computer or human being, a facsimile machine, a teleprinter, a data terminal and so on. The entities are involved in the process of information transfer which may be in the form of a telephone conversation (telephony) or a file transfer between two computers or message transfer between two terminals etc. Today it is almost truism to state that telecommunication systems are the symbol of our information age.

With the rapidly growing traffic and untargeted growth of cyberspace, telecommunication becomes a fabric of our life. The future challenges are enormous as we anticipate rapid growth items of new services and number of users. What comes with the challenge is a genuine need for more advanced methodology supporting analysis and design of telecommunication architectures. Telecommunication has evaluated and growth at an explosive rate in recent years and will undoubtedly continue to do so.

The communication switching system enables the universal connectivity. The universal connectivity is realized when any entity in one part of the world can communicate with any other entity in another part of the world. In many ways telecommunication will acts as a substitute for the increasingly expensive physical transportation.

The telecommunication links and switching were mainly designed for voice communication. With the appropriate attachments/equipments, they can be used to transmit data. A modern society, therefore needs new facilities including very high bandwidth switched data networks, and large communication satellites with small, cheap earth antennas.

1.2. HISTORICAL DEVELOPMENT

By the early 1800's scientists had developed ways to generate and transmit electricity. In 1819, oersted discovered the relation between magnetism and electricity. Ampere, Faraday and others continued this work in 1820. In 1834, Gauss and Weber wired over the roofs of Gottingen to make a telegraph system.

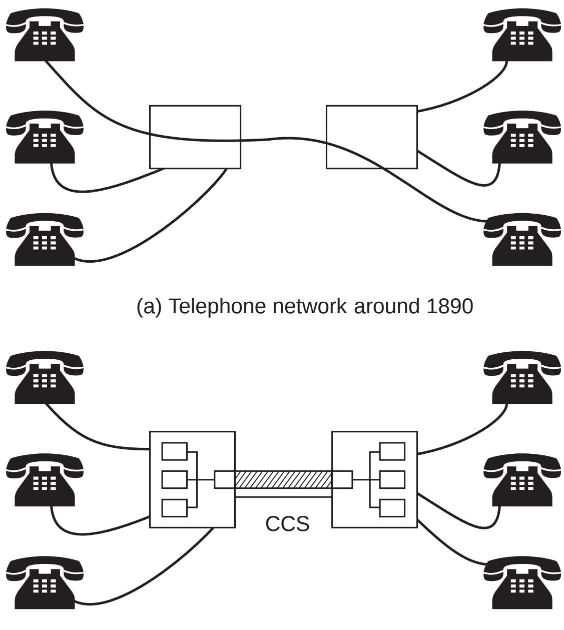
Samuel F.B. Morse's developed the first significant work in telecommunication. F.B. Morse developed code telegraphy in 1837. In 1844, a 40 mile telegraph line was setup between Baltimore and Washington by F.B. Morse. In 1845, Morse formed a telegraph company based on his technology. In 1849, the first slow telegraph printer link was setup. In 1874, Ban dot invented a "Multiplexes" system which enables up to six signal from telegraph machines to be transmitted together over the same line.

Elisha Gray and Alexander Graham Bell contributed significant works and filed paper related to telephony. The early stages of the development of telecommunication were due to A.G. Bell, G. Marconi and C.E. Shannon. In 1876, Bell invented a telephone system. In 1897 Marconi patented a wireless telephone system. Teletypewriter service was initiated in 1931.

In early days, a very simple exchanges whose control is provided by a human operator and the elements of the switch assemblies are plugs and sacks.With increase in demand of service, human operator exchange was replaced by the invention of range of electromechanical switching devices. Of all the electromechanical switching devices that become available over the years, the step-by-step switching system invented by Almon B. Strowger in 1892 is still quite popular. The next automatic electromechanical switching system was crossber switching. First patent for crossbar device was granted in 1915 to J.N. Reynolds of wester Electric, USA. In 1919, two Swedish Engineers, Betulander and Palmgren got patent for crossbar switch. In 1938, AT & T laboratories in US introduced crossbar-switching system in the field.

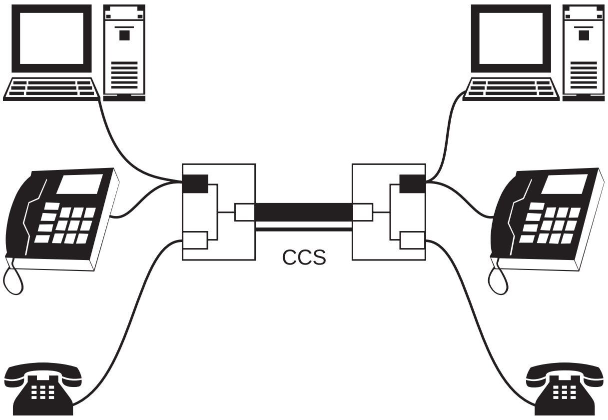
The electromechanical switching systems have been replaced by computer controlled switching systems referred to as stored program control (SPC). In SPC, switching is controlled by software program. The first computer controlled switch was introduced in 1960. Till 1965, computer controlled switching was used transistors and printed circuit technology. Since 1965 switching are based on microprocessors.

The use of computers to control the switching led to the designation "electronic" switching system (ESS) or Electronic automatic exchange (EAX). In 1970, first electronic switching system No. 1 ESS or No. 1 EAX was introduced. Digital electronic switching matrices were first introduced into the U.S. Public network in 1976 with AT & T's No. 4 ESS digital toll switch. By the mid 1980's the interoffice transmission environment has changed to almost exclusively digital. Fig. 1.1 shows the various telephone networks.



(a) Telephone network around 1890

(b) Telephone network around 1988



(c) Telephone network after 1990 with ISDN

Fig. 1.1. Various telephone networks.

1.3. SIGNAL CHARACTERISTICS

Telecommunication is mainly concerned with the transmission of messages between two distant points. The signal that contains the messages is usually converted into electrical waves before transmission. Our voice is an analog signal which has amplitude and frequency characteristic.

Voice frequencies. The range of frequencies used by a communication device determines the communication channel, communicating devices, bandwidth or information carrying capacity. The most commonly used parameter that characterizes an electrical signal is its bandwidth of analog signal or bit rate if it is a digital signal. In telephone system, the frequencies it passes are restricted to between 300 to 3400 Hz. Thus the network bandwidth is 3100 Hz. The bandwidth and bit rate for various types of system are shown in Table 1.1.

Table 1.1. Bandwidth requirements of various applications

Type	*Bandwidth*	*Bit Rate*
Telephone (speech)	300—3400 Hz	—
Music	50 Hz—16 kHz	—
Facsimile	40 kHz	—
Broadcast televison	0—55 MHz	—
Personal communication	—	300 to 9600 bits/sec
E—Mail transmission	—	2400 to 9600 bits/sec
Digitized voice phone call	—	6400 bits/sec
Digital audio	—	1 to 2 M bits/sec
Compressed video	—	2 to 10 M bits/sec
Document imaging	—	10 to 100 M bits/sec
Full motion video	—	1 to 2 G bits/sec

Speech spectrum. The telephone channel over which we wish to send data are designed to transmit electrical oscillations (microphone converts sound into equivalent number of electrical oscillation) of voice. Fig. 1.2 is described as a speech spectrum diagram. It illustrates human speech strength variations at various frequencies. Most of the energy is concentrated between 300 Hz to 3400 Hz.

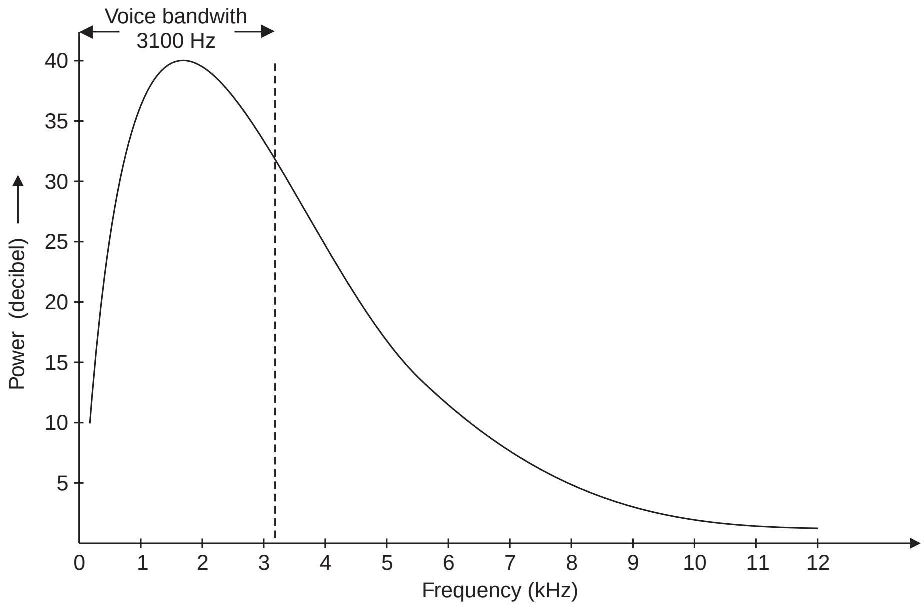


Fig. 1.2. Speed spectrum.

Decibels. The decibel is a valuable unit for telecommunication because losses or gains in signal strength may be added or subtracted if they are referred to in decibels. The signal strength at various frequencies is expressed by the unit of decibel (dB) in telecommunication. The decibel is a unit of power ratio. The power ratio is expressed as

$$G = 10 \log_{10} \frac{P_2}{P_1} \qquad ...(1.1)$$

Where P_1 is input power (Normally) and P_2 is output power.

The decibel is also used to be defined as the unit of attenuation. One decibel attenuation means that a signal has dropped to 0.794 of its original power. One decibel gain means that a signal has increased to 1.259 of its original power. The decibel concept is further discussed in later chapter.

Voltage and current level can be quoted in decibel as follows

$$G = 10 \log_{10} \frac{P_2}{P_1} = \frac{V_2 I_2}{V_1 I_1} = \frac{{I_2}^2 R}{{I_1}^2 R} \qquad ...(1.2)$$

$$G = 10 \log_{10} (I_2/I_1)^2 \qquad ....(1.3)$$

$$G = 20 \log (I_2/I_1) \qquad ...(1.4)$$

Similarly in voltage ratio,

$$G = 20 \log_{10} V_2/V_1 \qquad ...(1.5)$$

$$\text{Gain in nepers} = \log_e \frac{I_2}{I_1} = \log_e \frac{V_2}{V_1} \qquad ...(1.6)$$

$$\text{Relation : } \quad 1\text{ N} = 8.69\text{ dB} \qquad ...(1.7)$$

Example 1.1. If input power is 16 μW and output power is 30 mW, find the power ratio and express it in decibel and nepers.

$$\text{Power} = \frac{P_2}{P_1} = \frac{30 \times 10^{-3}}{16 \times 10^{-6}} = 1875 = 1.875 \times 10^3$$

Power in decibel, $G = 10 \log_{10} 1.875 \times 10^3 = 32.73$ dB

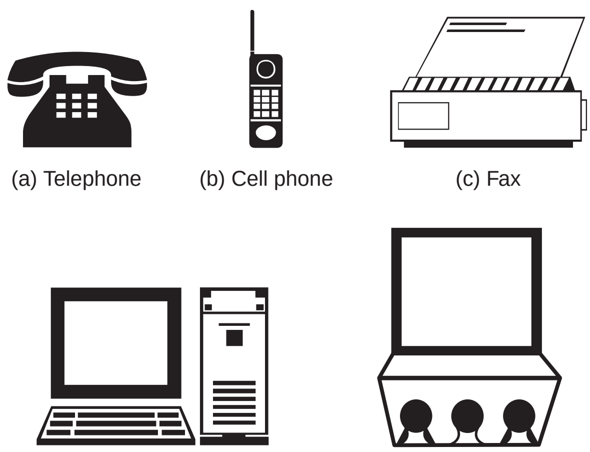
Power in nepers, $G = 3.76$ N.

1.4. ELEMENTS OF COMMUNICATION SWITCHING SYSTEM

The purpose of a telecommunication switching system is to provide the means to pass information from any terminal device to any other terminal device selected by the originator. Telecommunication system can be divided into four main parts. They are

1. End system or Instruments
2. Transmission system
3. Switching system
4. Signaling.

End Systems or Instruments. The end system or instruments are a transmitter or receiver that are responsible for sending information or decoding or inverting received information or message into an intelligible message. End systems in the telelphone network have evolved from analog telephones to digital handsets and cellular phones. However, endless arrays of other devices are being attached to telephone lines, including computer terminals used for data transmission. Fig. 1.3 shows some of the end instruments.



(a) Telephone (b) Cell phone (c) Fax

(d) Computer (e) Video conference

Fig. 1.3. Some of the end instruments.

Transmission System. Signals generated by the end system or the instruments should be transported to the destination by some means. The transmission on links conveys the information and control signals between the terminals and switching centers. A transmission link can be characterized by its bandwidth, link attenuation and the propagation delay. To maintain signal quality, the signal must be regenerated after a certain distance.

In general a communication path between two distinct points can be setup be connecting a number of transmission lines in tandem. The transmission links include two-wire lines, co-axial cables microwave radio, optical fibers and satellites. Functionally, the communication channels between switching system are referred to as trunks. Fig. 1.4 shows the various possible transmission media.

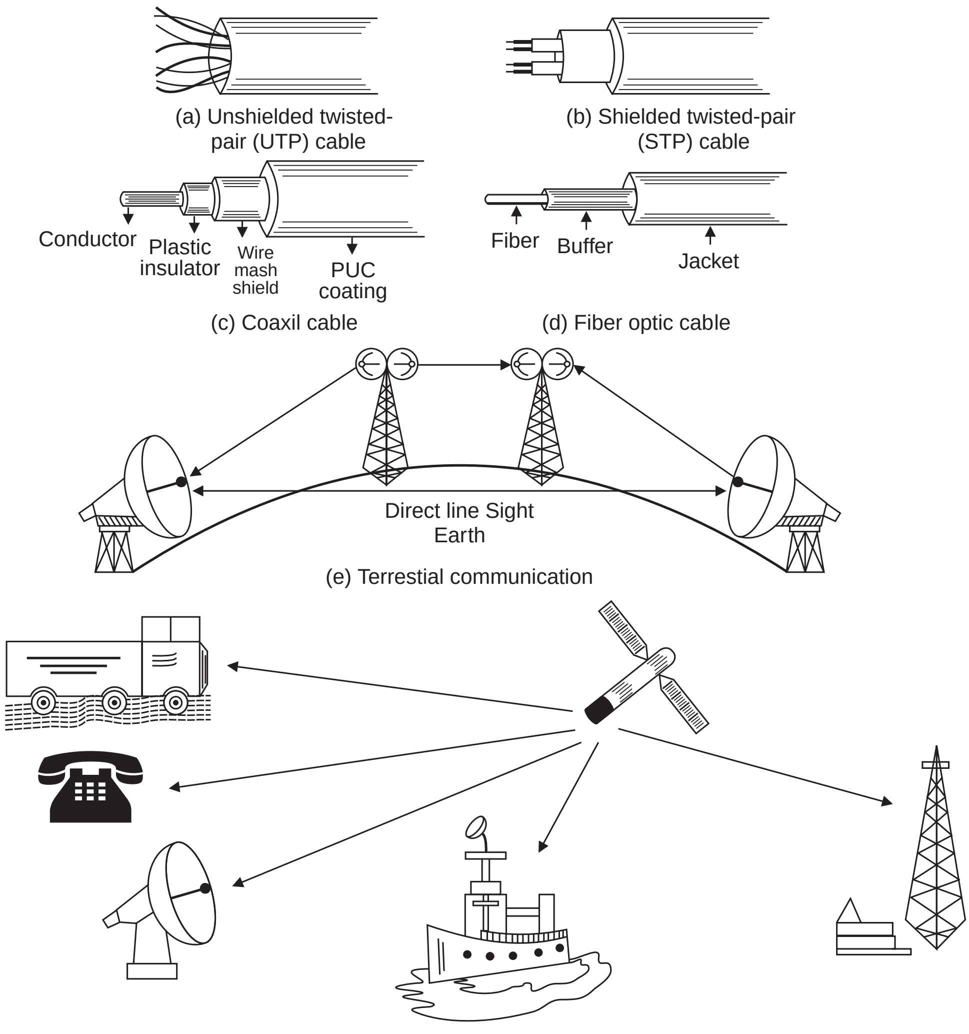


Fig. 1.4. Various transmission media.

Switching System. The switching centers receives the control signals, messages or conversations and forwards to the required destination, after necessary modification (link amplifications) if necessary. A switching system is a collection of switching elements arranged and controlled in such a way as to setup a communication path between any two distant points. A switching center of a telephone network comprising a switching network and its control and support equipment is called a central office.

In computer communication, the switching technique used is known as packet switching or message switch (store and forward switching). In telephone network the switching method used is called circuit switching. Some practical switching system are step-by-step, cross barred relay system, digital swtiching systems, electronic switching system etc.

Signalling Systems. A signalling system in a data communication networks exchanges signalling information effectively between subscribers. The signalling systems are essential building blocks in providing the ultimate objective of a worldwide automatic telephone services standardized. Signalling provides the interface between different national systems. The introduction of signalling system was the big step in improving the PSTN.

The consultative committe on international telegraphy and telephony (CCITT) based in Geneva, recommended seven formats related to signalling. The first five formats related to In-band signalling and the last two in the category of common channel signalling. In In-band signalling, voice information and signalling information travel on common paths, where as in common channel signalling, they travel on separate paths. Further classification and detained study are carried out in later chapter.

1.5. CRITERIA FOR THE DESIGN OF TELECOMMUNICATION SYSTEM

Traditionally, the design for telephone switching center or equipment requirement in a telecommunication system are determined on the basis of the traffic intensity of the busy hour. The traffic intersity is defined as the product of the calling rate and the average holding time. The busy hour is defined as that continuous sixty-minute period during which the traffic intersity is highest.

The calling rate is the average number of request for connection that are made per unit time. If the instant in time that a call request arises is a random variable, the calling rate may be stated as the probability that a call request will occur in a certain short interval of time. The holding time is the mean time that calls last. Otherwise the average holding time is the average duration of occupancy of traffic path by a call.

Grade of Service. In telephone field, the so called busy hour traffic are used for planning purposes. Once the statistical properties of the traffic are known, the objective for the performance of a switching system should be stated. This is done by specifying a grade of service (GOS). GOS is a measure of congestion expressed as the probability that a call will be blocked or delayed. Thus when dealing with GOS in traffic engineering, the clear understanding of blocking criteria, delay criteria and congestion are essential.

Blocking criteria. If the design of a system is based on the fraction of calls blocked (the blocking probaility), then the system is said to be engineered on a blocking basis or call loss basis. Blocking can occur if all devices are occupied when a demand of service is initiated.

Blocking criteria are often used for the dimensioning of switching networks and interoffice trunk groups. For a system designed on a loss basis, a suitable GOS is the percentage of calls which are lost because no equipment is available at the instant of call request.

Delay criteria. If the design of a system is based on the fraction of calls delayed longer than a specified length of time (the delay probability), the system is said to be a waiting system or engineered on a delay basis. Delay criteria are used in telephone systems for the dimensioning of registers. In waiting system, a GOS objective could be either the percentage of calls which are delayed or the percentage which are delayed more than a certain length of time.

Congestion. It is the condition in a switching center when a subscriber can not obtain a connection to the wanted subscriber immediately. In a circuit switching system, there will be a period of congestion during which no new calls can be accepted. There are two ways of specifying congestion.

1. **Time congestion.** It is the probability that all servers are busy. It is also called the probability of blocking.

2. **Call congestion.** It is the proportion of calls arising that do not find a free server. Call congestion is a loss system and also known as the probability of loss while in a delay system it is referred to as the probability of waiting.

If the number of sources is equal to the number of servers, the time congestion is finite, but the call congestion is zero. When the number of sources is large in comparison with servers, the probability of a new call arising is independent of the number already in progress and therefore the call congestion is equal to the time congestion. In general, time and call congestions are different but in most practial cases, the discrepancies are small.

Measure of GOS. GOS is expressed as a probability. The GOS of 2% (0.02) mean that 98% of the calls will reach a called instrument if it is free. Generally, GOS is quoted as P.02 or simply P02 to represent a network busy probability of 0.02. GOS is applied to a terminal-to-terminal connection. For the system connection many switching centers, the system is generally broken into following components.

(*i*) an internal call (calling subscriber to switching office)

(*ii*) an outgoing call to the trunk network (switching office to trunk)

(*iii*) The trunk network (trunk to trunk)

(*iv*) A terminating call (switching office to called subscriber)

The GOS of each component is called component GOS.

The GOS for internal calls is 3 to 5%, for trunk calls 1-3%, for outgoing calls 2% and for terminating calls 2%. The overall GOS of a system is approximately the sum of the component grade of service. In practice, in order to ensure that the GOS does not deteriorate disastrously if the actual busy hour traffic exceeds the mean, GOS are specified 10% or 20% more of the mean.

1.6. FUNDAMENTALS FOR THE DESIGN OF TELECOMMUNICATION NETWORK

A telephone network is composed of a variety of all processing equipments, interstate switching links and inters office trunks. Because of the random nature of the call request, the design of equipments switching links and trunks are quite difficult. Thus, the traffic analysis is the fundamental request for the design of cost effective, efficient and effective configuration of networks. The effectiveness of a network can be evaluated intermes of how much traffic it carries under normal or average loads and how often the traffic volume exceeds the capacity of the network.

Fundamental problem in the design of telecommunication networks concerns the dimensioning of a route. To dimension the route, volume of traffic required grade of service and capacity (in bits per sec) must be known.

Traffic. In telecommunication system, traffic is defined as the occupancy of the server in the network. There are two types of traffic viz. voice traffic and data traffic. For voice traffic, the calling rate is defined as the number of calls per traffic path during the busy hour. In a day, the 60 minutes interval in which the traffic is highest is called busy hour (BH).

Average occupancy. If the average number of calls to and from a terminal during a period T second is '*n*' and the average holding time is '*h*' seconds, the average occupancy of the terminal is given by

$$A = \frac{nh}{T} \qquad ...(1.8)$$

The average occupancy is also referred as traffic flow of traffic intensity. The international unit of telephone traffic is the Erlang.

1.7. CENTRALIZED SWITCHING SYSTEM

Distributed Method

A simplest way of structuring the telecommunication switching is the terminal-to-terminal connection. This kind of switching is called distributed switching and applied only to small telephone system. Some examples of distributed switching are shown here. Fig. 1.5 shows the full interconnection of five terminals.

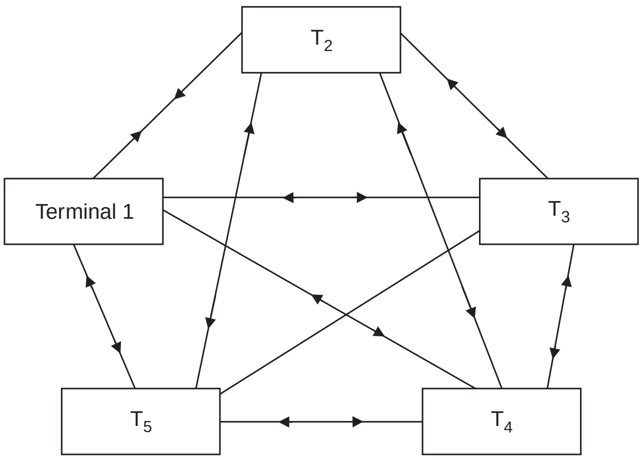


Fig. 1.5. Distributed model.

Each terminal have two kind of switches, one to make required link and other to connect a link to receive a call. By this method, for N terminals, the numbers of links required are $\frac{1}{2}$ N (N – 1) Fig. 1.6 shows the interconnection of four terminals but only with 4(N) links. Here each terminal is connected permanently to one channel and all other terminals may be accessed by operating a switch. Also it removes the need to connect a terminal to a link for an incoming call.

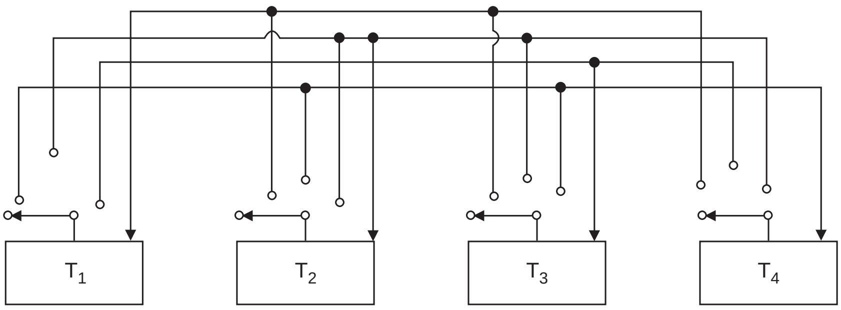


Fig. 1.6. Type of centralised model.

The circuit in Fig. 1.7 is similar arrangement of the figure, but with fever than N links.

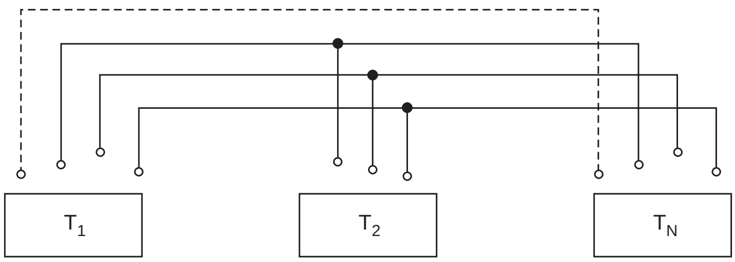


Fig. 1.7. Centralised model with (N – 1) links.

In this arrangement, a calling terminal sends a calling signal to indicate the called terminal to which the terminal should be switched in order to receive the call. The recognition of an incoming call and switching operation may be performed automatically in system using coded signals.

Centralised Model. The distributed system cannot be extended to large terminal cases and the increased geographical separation of terminals. A simple centralized system, which reduces the average length of transmission link, and hence the transmission cost is shown in Fig. 1.8. But this system increases the total switching costs.

Introducing more local centers instead of one national center switching machine can further reduce the transmission cost. Two local centers are connected by links called trunk. A trunk in telephone system is a communication path that contains shared circuits that are used to interconnect central offices. Fig. 1.9 shows the telecommunication system for short distances, with two exchanges (switching offices).

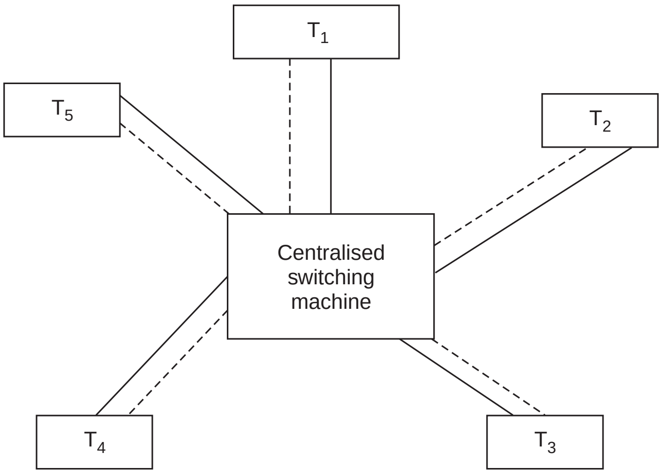


Fig. 1.8. Type of centralised model.

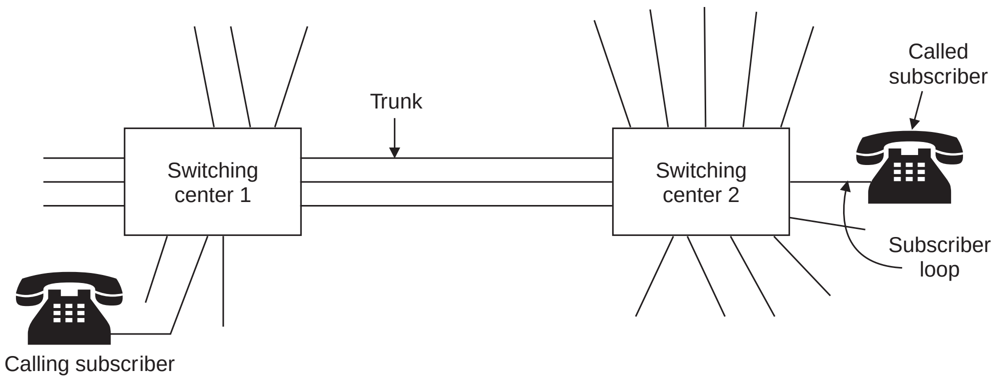


Fig. 1.9. Short distance centralised system.

Even though the increase in the number of switching centers lower the total transmission costs, the total switching cost tend to increase for two reasons.

1. The local centers become more complex because they must be able to decide on a suitable routing to another center.

2. Economy of scale is lost with an increased number of local centers because of additional numbers.

Hierarchical system. Central offices may be interconnected by direct trunk groups or by intermediate office known as a tandem, toll or gateway office. The process of centralizing switching centers can occur at several levels leading to the hierarchical network. Typical interconnection of central office is shown in Fig. 1.10.

Star connection may be used where traffic intensity is less. Mesh connection are used when there are relatively high traffic levels between offices such as in metropolitan network.

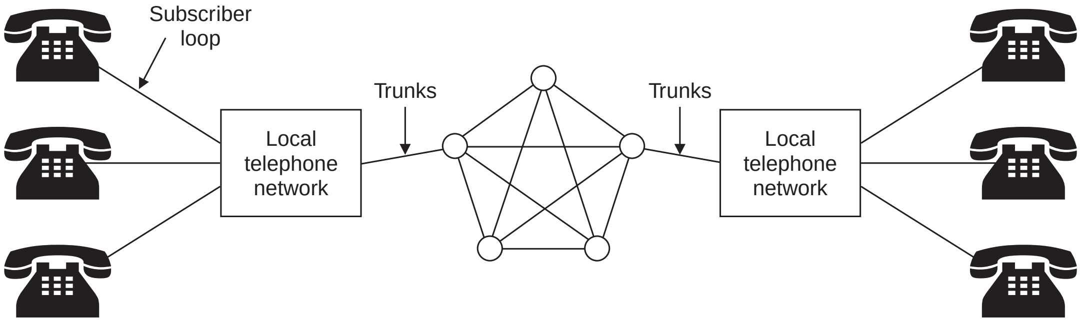


Fig. 1.10. Hierarchical network long level network (Star Connection).

1.8. AT & T AND ITU—(OR CCITT) HIERARCHICAL NETWORKS

The telephone network has developed dramatically in recent years so that it is now possible to make calls automatically between subscribes separated by thousands of miles. Long distance calls pass through several stages of switching and several possible transmission links before reaching their destination. In selecting the structure and layout, we must consider the trades-off between the cost of the network and the grade of service.

A popular concept in networking is to provide alternate routing when some parts of the network are congested. Also, the network must be adaptable to various traffic patterns, such as festival traffic, summer vacation traffic, weekend traffic etc. Alternative routing introduces switching complication. When alternate routing are sought, a call might be routed on many transmission links or routed in complex path. Thus the quality of the call may be affected severely.

In order to avoid unnecessary complications, to route traffic effectively and economically, AT & T and ITU-T developed two types of hierarchical networks. Each types serving about 50% of the wireless telephones. The hierarchical structures of the AT & T and the CCITT networks are shown in Fig. 1.11 on next page.

The AT & T (American Telephone and Telegraph in the united states) network is generally used in North America and ITU-T (international Telecommunication union—Telecommunication sector) network is used in rest of the countries.

1.9. TELECOMMUNICATION NETWORKS

Telecommunication netwoks have been evolving in the last 160 years and would continue to evolve to provide wider services. Telecommunication networks may be categorized according to networks emerged as a result of computer and communication technologies. The networks based on geographical area are characterized by the area (town, city or village), subscriber densities, traffic pattern, distance between the local exchanges and the subscribers character (residential are or business area or Govt. offices location)

Urban or metropolitan area networks (MAN). Metropolitan area networks, in general connect business to business and business to WAN and internet. The telephone companies have provided MAN services in the form of SONET rings for years. MAN cover aproximately 100 miles, connection multiple networks, which are located in different locations of a city or town.

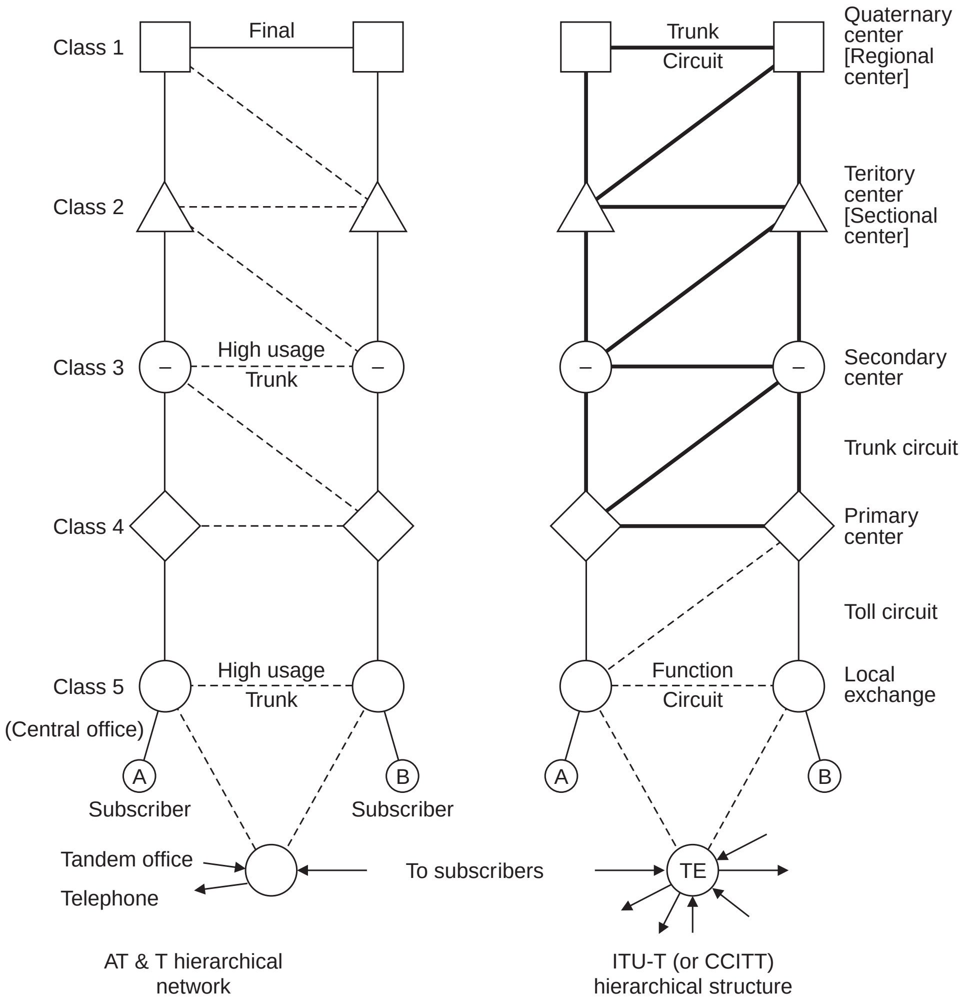


Fig. 1.11. Hierarchical structures of AT & T and ITU-T.

Rural networks, long distance or toll or wide area networks (WAN). WAN is used for long distance transmission of information. WANs cover a large geographical area such as an entire country or continent. WANs may use lines leased from telephone companies or public switched data networks (PSDN) or satellite for communication links. Rural areas are characterized by light traffic per subscriber, widely dispersed subscribers, local exchanges usually separated apart etc., these areas are served by rural networks or WAN.

The most common telecommunication network is Public Switched Telephone Network (PSTN) or sometimes known as plain old telephone system (POTS). The second major class of telecommunication is the data netwoks.

ARPNANET. In 1968, the United States Department of Defence (DOD) created the Defence Advanced Research Project Agency (DARPA) for research on packet switching networks. In 1969, DARPA created the Advanced Research Project Agency (ARPA). ARPA built an experimental network (ARPANET). It is highly useful in interconnecting heterogeneous systems.

TYMNET. It is an another large scale, general purpose data network introduced in 1970, interconnecting geographically distributed computer systems, users and peripherals.

ISDN. Integrated Services Digital Network is now emerging as an major telecommunication network. It is capable of carrying multimedia services like voice, data, video and facsimile.

Intelligent Network. It is the public telephone network that contains the logic for routing calls, establishing connections and providing advanced features such as unique customer services and customer programming of the network. This consists of a signalling path that is separate from the central logic call circuit. Call setup information in handled by SS7 (signalling system 7), and the information transferred via packets across an overlay packet switching network.

New Public Network (NPN). It is the convergence of PSTN and the Internet. It allows Internet phone users to connect with PSTN telephone users and vice versa. If provides the reliability and 99.999% of availability of the PSTN. Internet engineers have developed their own set of protocols that provide telephony services over the Internet and interconnection with the PSTN.

ACRONYMS

ARPA	—	Advanced Research Project Agency
AT & T	—	American Telephone and Telegraph
CCITT	—	Consultative Committee on International Telegraphy and Telephony
DARPA	—	Defense Advanced Research Project Agency
DOD	—	Department of Defense
EAX	—	Electronic Automatic Exchange
ESS	—	Electronic Switching System
GOS	—	Grade of Service
IN	—	Intelligent Network
ISDN	—	Integrated Services Digital Network
ITU-T	—	International Telecommunication Union-Telecommunication sector
MAN	—	Metropolitan Area Network
NPN	—	New Public Network
POTS	—	Plain Old Telephone systems
PSTN	—	Public Switched Telephone Network
SPC	—	Stored Program Control
WAN	—	Wide Area Network

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REVIEW QUESTIONS

1. What is meant by telecommunication network ?
2. What is the range of voice frequencies ?
3. Define bandwidth.
4. Tabulate bandwidth and bit-rate of various applications.
5. Plot the speech spectrum.
6. Define decibel.
7. What are the elements of telecommunication systems ?
8. List the end systems of instruments of telecommunication systems.
9. List the various methods of transmission systems.
10. What are the various switching techniques in computer communication ?
11. What is meant by GOS ?
12. What is known as blocking criteria ?
13. What is meant by delay criteria ?
14. Define congestion.
15. Explain briefly the two types of congestion.
16. How the GOS can be expressed ?
17. What is meant by component GOS ?
18. Define traffic.
19. Define average occupancy.
20. Explain briefly with neat diagrams, the centralized switching and distributed switching.
21. Draw the typical hierarchical network structure and explain.
22. Compare with neat sketch, the AT and T and CCITT hierarchical structure and explain.
23. Define MAN and WAN.
24. Write short notes on (*a*) ISDN (*b*) IN and (*c*) NPN.