architecture for level 1 control, Software architecture for level 2 control, Software architecture for level 3 control, Digital switching system software classification, Call models, Connect sequence, Software linkages during call, Call features, Feature flow diagram, Feature interaction.

6 Hours

UNIT – 7 MAINTENANCE OF DIGITAL SWITCHING SYSTEM: Introduction, Scope, Software maintenance, Interface of a typical digital switching system central office, System outage and its impact on digital switching system reliability, Impact of software patches on digital switching system maintainability, Embedded patcher concept, Growth of digital switching system central office, Generic program upgrade, A methodology for proper maintenance of digital switching system, Effect of firmware deployment on digital switching system, Firmware-software coupling, Switching system maintainability metrics, Upgrade process success rate, Number of patches applied per year, Diagnostic resolution rate, Reported critical and major faults corrected, A strategy improving software quality, Program for software process improvement, Software processes improvement, Software processes, Metrics, Defect analysis, Defect analysis.

8 Hours


6 Hours

TEXT BOOKS:


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UNIT 1: DEVELOPMENT OF TELECOMMUNICATION SYSTEMS

Network structure, Network services, terminology, Regulation, Standards. Introduction to telecommunications transmission, Power levels, Four wire circuits, Digital transmission, FDM, TDM, PDH and SDH, Transmission performance.

8 hours

TEXT BOOKS:


NETWORK STRUCTURE

Transmission of telegraphic signals over wires was the first technological development in the field of modern telecommunications.

Telegraphy was introduced in 1837 by Wheatstone and Morse in Great Britain and in 1845 in France. In March 1876, Alexander Graham Bell invented the telephone and the first telephone exchange at New Haven and he demonstrated a point to point telephone connection.

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 can begin, some form of signaling is required with each link. If the called subscriber is engaged, a suitable indication should be given to the calling subscriber by means of signaling.

A network using point to point connection is shown.

In the figure, there are 5 entities and 10 point to point links. In general case with n entities, there are n(n-1)/2 links.

e.g., n=5 then 5(5-1)/2 = 10 links

Total number of links \( L = \frac{n(n-1)}{2} \)

In order to connect the first entity to all other entities, we require (n-1) links. With this 2nd entity is already connected to the 1st, we now need (n-2) links to connect the 2nd entity to the others. For the 3rd entity we need (n-3) links and so on...

Therefore total number of links

\[
L = (n-1) + (n-2) + (n-3) + \ldots + 1 + 0 = n(n-1)/2
\]
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. Due to this problem, practical use of Bell’s invention on a large scale even on a moderate scale demanded not only the telephone sets and the pairs of wires but also the so-called switching system or the switching office or the exchange.

With the introduction of switching systems, the subscribers are not connected directly to one another; instead, they are connected to the switching system as shown in the figure.

![Switching System Diagram](image)

When subscribers want to communicate with one another, a connection is established between them at the switching system. The figure above 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.

Signaling 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 the 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**.

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 electro mechanical and electronic as shown.

Classification of switching systems

Electro mechanical switching systems include Step by step and Crossbar systems. Step by step system is 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 sub-systems which are relays and latches. These sub-systems have limited capabilities 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 an SPC system by changing the control program. Electronic switching systems maybe either space division switching or time division switching.

In space division, a dedicated path is established between the calling and the called subscribers for the entire duration of the call. Space division switching technique is also used in Stroger and Crossbar systems.
An electronic exchange may use a Crossbar switching matrix. For space division switching, a Crossbar switching system with SPC acts as an electronic exchange.

In time division switching, sampled values of speech signals are transferred at fixed intervals. Time division switching maybe 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 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.

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 antennae present such a scenario, the capacity of such systems is limited. At present, the major part of the telecommunication network is still ground based, where subscribers are connected to the switching system via copper wires. Technological and engineering constraints of signal transfer on pair of wires necessitate that the subscribers be located within a few kilometers from the switching system.

By introducing a number of standalone 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 inter-connected in the form of a network. Figure 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.

Here SS1, SS2, SS3, and SS4 are switching systems. The number of trunks may vary between pairs of switching systems and is determined on the basis of traffic between them.
Direct links (junctions) between two local exchanges prove economical when there is high community of interest between their customers resulting in a high traffic load or when the distance between them is short resulting in low transmission costs.

Indirect routing via a tandem exchange (central switching centre) is cheaper when the traffic is small or the distance is large.

Hence a multi-exchange area usually has direct junctions (trunks or links) between some exchanges but traffic between the others is routed via the tandem exchange. The network of the area as shown below is then a mixture of a star network, joining all local exchanges to the tandem exchange and mesh networks connecting some of the local exchanges together. As the number of switching systems increases interconnecting them becomes complex.

Multi exchange area

The problem is solved by introducing a hierarchical structure among the switching systems and using a number of them in series to establish connection between subscribers as shown in the figure below.
In a large national network, all the exchanges may not be fully interconnected and one or more higher levels of switching centre are introduced. This produces a concatenation of star networks resulting in a tree configuration as shown.

However direct routes are provided when the traffic is high and transmission costs are low. Thus the backbone tree is complemented by lateral routes between some exchanges at the same level as shown.

In the network shown in the figure, where there is a direct link 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 (like because of cable breakdown) it is possible to divert traffic to the indirect route. Modern switching systems provide automatic alternative routing.

A national public switched telecommunications network (PSTN) as shown in the figure consists of the following hierarchy.

a. Local networks which connect customers stations to their local exchanges (these are also called subscribers distribution networks, customer access networks or the customer loops)

b. Junction networks which interconnect a group of local exchanges serving an area and a tandem or trunk exchange.

c. Trunk or toll network which provides long distance circuits between local areas throughout the country.

The totality of b. and c. is sometimes called the core network; the inner core consisting of the trunk network and the outer network consisting of the junction networks.

Above in 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.

A telecommunication network consists of a large number of transmission links, joining different locations, which are known as the nodes of the network. Thus each customer terminal is a node. Switching centers 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 emergency services. Customers may also wish to obtain connections to commercial providers of value added network services (VANS) such as voice mailboxes, stock market prices and sports results.

Hence a telecommunication network may be considered to be the totality of transmission links and the nodes which are of the following types:

- Customer nodes
- Switching nodes
- Transmission nodes
- Service nodes

In order to setup 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 signaling.

A telecommunication network may therefore be considered as a system consisting of the following three interacting sub-systems:

- Transmission systems
• Switching systems
• Signaling systems

A modern telecommunication network may be viewed as an aggregate of a larger number of point to point electrical or optical communication systems as shown in the following figures.

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. E.g. 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.

Optical sources require electrical signals as input and optical detectors produces 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 is called the channel, which may be free space, copper cables or the free space in conjunction with 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.

Elements of a communication system

Original signal

\[ T \]

Reproduced signal

\[ \square \]

Free space/ copper cable/ satellite

Fig. An electrical communication system

Free space/ optical cable

Fig. An optical communication system

Different channels exhibit different loss characteristics and are affected to different degrees by noise. Hence 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, band limiting, filtering, multiplexing and demultiplexing. Fibre optic communication systems are emerging as major transmission systems for telecommunication.

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 co-axial cable or the free space (microwaves) 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 and the switching system. For example electrical characteristics of teleprinter signals are completely different from those of telephone signals. Such wide variations in signal characteristics have led to the development of different service specific telecommunication networks that operate independently such as:

- Telegraph networks
- Telex networks
- Telephone networks
- Data networks

Management and maintenance of multiple networks are expensive. In order to design a single network that can carry all the services, the key solution to this problem lies in the digitalization 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 integrated service digital network (ISDN).

**Four Wire Circuits**

The term four wire implies that there are two wires carrying the signals in one direction and two wires carrying them in opposite direction. In normal telephone service, the local loops are two wire circuits, on which a single telephone call can be transmitted in both directions. If the distance between the subscribers is substantial, the amplifiers (repeaters) are necessary to compensate the attenuation. As the amplifiers are unidirectional, for two-way communication, four-wire transmission is necessary. The switching equipment in the local exchange and the line from subscriber to local office (local loops) are two wire operation. The local exchange will switch the subscriber loop to a toll connecting trunk. This is also a two-wire transmission.

Telephone and Transmission Systems 35 The toll offices are interconnected with inter tool trunks (which connects towns and cities). These trunks are of four-wire transmission. Fig. 3.10 shows the simple arrangement of the two wire and four wire transmission.
A four-wire circuit has amplifiers in its repeaters for each direction of transmission. The four wire circuits may be physical four wire or equivalent four wire. For short distances, actual four wires used for transmission is referred as physical four wire circuits. But for long distance trunks physical four wire is undesirable and usually equivalent four wire transmission is used, needing one pair of wires only. The two directions of transmission use different frequency bands so that they do not interfere with each other. The two directions are separated in frequency rather than space. At the toll office, the two wires are converted into four wire for long transmission. A hybrid coil accomplishes this conversion.

**Echos and Singing**

Echos and singing both occurs as a result of transmitted signals being coupled into a return path and fed back to the respective sources. Coupling will be zero only when perfect impedance matching occurs. Impedance matching between trunks and subscriber loop (two wire to four wire at hybrid) is difficult due to various subscriber loop lengths. A signal reflected to the speaker’s end of the circuit is called **talker echo** and at the listener’s end is called **listeners echo**. The talker echo is more troublesome. When the returning signal is repeatedly coupled back into the forward path to produce oscillations, **singing** occurs. Basically singing results if the loop gain at some frequency is greater than unity. An echo coming 0.5 msec after the speech is not much effect. The echoes with a round trip delay of more than 45 msec cannot be tolerated. Fig. 3.12 explains the path of the echo and the losses and gain of the signals at various parts of the system.
For the round trip delay of above 45 msec (representing approximately 2900 km of wire) attenuators are introduced to limit the loudness of echo to a tolerable level. The attenuation required is related to the time delay. Hence long distance circuits require significant attenuation to minimize echo annoyance. The total attenuation from one two wire circuit to the other ($\alpha_2$) is

$$\alpha_2 = \alpha_{24} + \alpha_{42} - G_4 \ldots (3.1)$$

where $\alpha_{24}$ = attenuation between 2 to 4 wire line
$\alpha_{42}$ = attenuation on between 4 to 2 wire line
$G_4$ = total gain of one side of four wire circuit (in dB)

The $\alpha_{24}$ and $\alpha_{42}$ are normally 3dB. Thus

$$\alpha_2 = 6 - G_4 \ldots (3.2)$$

The transhybrid loss (TL) is the attenuation through the hybrid coil from one side of the four wire circuit to the other and given as

$$TL = 6 + BRL$$

The loss of reflected signal due to the mismatch of the network is given by balancereturn loss (BRL). If impedance of the four wire circuit is $Z_B$ and the impedance of two wire circuit is $Z_2$, the BRL is given as

$$BRL = 20 \log_{10} \left| \frac{Z_B + Z_2}{Z_B - Z_2} \right| \text{dB} \ldots (3.4)$$

If $Z_B$ and $Z_2$ matches $BRL = \infty$. It indicates the attenuation on echo is infinite and no necessity of any attenuators.

The total attenuation on echo is given by net attenuation offered by the four-line circuit minus the gain of the amplifiers. Hence by clockwise movement from talker to talker circuit, $\alpha t = [3 - G_4 + (BRL + 6) - G_4 + 3]$ dB

$$\alpha t = 2\alpha_2 + BRL \ldots (3.5)$$

The echo delayed is $D_t = 2D_4 \ldots (3.6)$
where $D_4$ is the delay of four-wire circuit.
If $P_4$ is incoming power on the 4 wire circuits, $P_2$ power raching the 2 wire circuit and $P_4 - P_2$ is the power reflected onto the return path, the BRL in terms of power is

$$BRL = 10 \log_{10} \frac{P_4}{P_4 - P_2} \text{ dB} \quad \ldots(3.7)$$

BRL in terms of voltage is

$$BRL = 20 \log_{10} \frac{V_4}{V_4 - V_2} \text{ dB} \quad \ldots(3.8)$$

The round trip delay for echo is determined by

$$D_e = \frac{\text{distance in km}}{\text{phase velocity}} \quad \ldots(3.9)$$

Normally, the phase velocity is $3 \times 10^7$ m/sec.

**Cross Talk**

The current from the battery in the subscriber loop (when telephone handset is off hook) is limited to the range of minimum 20 mA to maximum of 60 mA. The current variation depends on the length of the subscriber loop. In long loops the current is less and in short loops the current may exceed 60 mA (an electronic component varistor in telephone set is used to limit the current with in 60 mA). The large current flow causes electromagnetic fields and thus creates signal distortions in adjoining wires. This distortion is called cross talk. Some of the major sources of cross talk are coupling between wire pairs in cable, inadequate filtering or carrier offsets in older frequency division multiplexing (FDM) equipments and the effects of non-linear components on FDM signals.

Cross talk is one of the most disturbing and undesirable imperfections that can occur in a telephone network. In analog system, as the power levels of voice signal considerably varies (40 dB range) the cross talk in this system is difficult to control. In fact cross talk is more noticeable during speech pauses, where the power level of the desired signal is zero. In digital system, by the pulse amplitude modulation, pulse length modulation and pulse position modulation, which are used in TDM system results in attenuation and delay distortion. This causes dispersion of the transmitted pulses. They spread in time and interfere with the pulses of adjacent channels and causes inter channel cross talk. Pulse code modulation is used to overcome the inter channel cross talk problem.

**FDM**

In many communication systems, a single, large frequency band is assigned to the system and is shared among a group of users. Examples of this type of system include:

1. A microwave transmission line connecting two sites over a long distance. Each site has a number of sources generating independent data streams that are transmitted
simultaneously over the microwave link.

2. AM or FM radio broadcast bands, which are divided among many channels or stations. The stations are selected with the radio dial by tuning a variable-frequency filter.

3. A satellite system providing communication between a large number of ground stations that are separated geographically but that need to communicate at the same time. The total bandwidth assigned to the satellite system must be divided among the ground stations.

4. A cellular radio system that operates in full-duplex mode over a given frequency band. The earlier cellular telephone systems, for example AMPS, used analog communication methods. The bandwidth for these systems was divided into a large number of channels. Each pair of channels was assigned to two communicating end-users for full-duplex communications.

*Frequency division multiplexing* (FDM) means that the total bandwidth available to the system is divided into a series of non overlapping frequency sub-bands that are then assigned to each communicating source and user pair. Note that each transmitter modulates its source's information into a signal that lies in a different frequency sub-band (Transmitter 1 generates a signal in the frequency sub-band between 92.0 MHz and 92.2 MHz, Transmitter 2 generates a signal in the sub-band between 92.2 MHz and 92.4 MHz, and Transmitter 3 generates a signal in the sub-band between 92.4 MHz and 92.6 MHz). The signals are then transmitted across a common channel.

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**Figure 1-7a**—A system using frequency division multiplexing.
At the receiving end of the system, bandpass filters are used to pass the desired signal (the signal lying in the appropriate frequency sub-band) to the appropriate user and to block all the unwanted signals. To ensure that the transmitted signals do not stray outside their assigned sub-bands, it is also common to place appropriate passband filters at the output stage of each transmitter. It is also appropriate to design an FDM system so that the bandwidth allocated to each sub-band is slightly larger than the bandwidth needed by each source. This extra bandwidth, called a guardband, allows systems to use less expensive filters (i.e., filters with fewer poles and therefore less steep rolloffs).

FDM has both advantages and disadvantages relative to TDM. The main advantage is that unlike TDM, FDM is not sensitive to propagation delays. Channel equalization techniques needed for FDM systems are therefore not as complex as those for TDM systems. Disadvantages of FDM include the need for bandpass filters, which are relatively expensive and complicated to construct and design (remember that these filters are usually used in the transmitters as well as the receivers). TDM, on the other hand, uses relatively simple and less costly digital logic circuits. Another disadvantage of FDM is that in many practical communication systems, the power amplifier in the transmitter has nonlinear characteristics (linear amplifiers are more complex to build), and nonlinear amplification leads to the creation of out-of-band spectral components that may interfere with other FDM channels. Thus, it is necessary to use more complex linear amplifiers in FDM systems.

Example—FDM for commercial FM radio

The frequency band from 88 MHz to 108 MHz is reserved over the public airwaves for commercial FM broadcasting. The 88–108 MHz frequency band is divided into 200 kHz sub-bands. As we saw in Chapter 6, the 200 kHz bandwidth of each sub-band is sufficient for high-quality FM broadcast of music. The stations are identified by the center frequency within their channel (e.g., 91.5 MHz, 103.7 MHz). This system can provide radio listeners with their choice of up to 100 different radio stations.

TDM OVERVIEW

The TDM interface is similar to the 2-Channel Serial Audio Interface, discussed in Cirrus Applications Note AN282, with the exception that more channels, typically 4, 6 or 8, are transmitted within a sample frame or sample period, as shown in Figure 2. As with the 2-Channel
Serial Audio Interface, the TDM interface is comprised of two control clocks, a frame synchronization pulse (FSYNC) and serial clock (SCLK), and the serial audio data line (SDATA). Figure 2. Generic TDM Interface

1.1 Channel Block
Each channel block is comprised of the audio data word followed by a sufficient number of zero data bits to complete the N-bit channel block. The example shown in Figure 3 shows a 32-bit channel block with 24-bit audio data. Notice that the audio word is typically transmitted with the Most Significant Bit (MSB) first. The industry standard for representing Pulse-Coded-Modulation (PCM) audio data is a 16 to 32 bit word (16- and 24-bit are the most common) coded in a two’s-complement format.

1.2 Frame Synchronization Pulse
The function of the FSYNC pulse is simply to identify the beginning of a frame. The beginning is always indicated by the rising edge of the pulse, as shown in Figure 2. Another notable point is that the frame rate is always at the audio sample rate, such as 44.1 kHz, 48 kHz, etc. The majority of the TDM implementations only use the rising edge of FSYNC and ignore the falling edge. However, device product documentation often implies that the width of the pulse is important. There are two common representations for the required width of the FSYNC pulse. The first is a frame synchronization pulse where the width is equivalent to a channel block. The second is a pulse where the width is equivalent to a single period of the serial clock. Unfortunately, the product documentation rarely supplies a sufficient amount of information to determine if the falling edge is used. The safe approach is to follow the product documentation and assume the falling edge is used or contact the manufacturer for clarification.

1.3 Channel Block Alignment with Frame Sync
There are two common options for the alignment of the first channel block and the rising edge of FSYNC. The first is shown in Figure 2, where the beginning of the channel block aligns with the rising edge of the FSYNC. In the second option, the channel block is delayed one period of the serial clock following the rising edge of the FSYNC.

1.4 Serial Clock
The sole purpose of the serial clock is to shift the audio data into or out of the serial audio ports. The required frequency for the serial clock is directly proportional to the system audio sample rate, the number of channel blocks within a frame and the bit-width of each channel block. As an example, an 8-channel frame with 32-bit channel blocks operating at 48 kHz requires a 12.288 MHz serial clock.

2. The Plesiochronous Digital Hierarchy (PDH)
In a PDH network you have different levels of Multiplexers. Figure 1 shows three levels of multiplexing:

- 2Mbit/s to 8Mbit/s
- 8Mbit/s to 34Mbit/s
- 34Mbit/s to 140Mbit/s
So to carry a 2Mbit/s data stream across the 140Mbit/s trunk requires it to be multiplexed up through the higher order multiplexers into the 140Mbit/s trunk and then to be multiplexed down through the lower order multiplexers. Because Plesiochronous is not quite Synchronous each of the multiplexers need a little bit of overhead on their high speed trunks to cater for the slight differences in data rates of the streams on the low speed ports. Some of the data from low speed ports (that are running too fast) can be carried in the trunk overhead, and this can happen at all multiplexing levels. This is known as Justification or Bit Stuffing.

2.1 PDH Multiplexing Hierarchy

Figure 2 shows that there are two totally different hierarchies, one for the US and Japan and another for the rest of the world. The other thing to notice is that the different multiplexing levels are not multiples of each other. For example CEPT2 supports 120 Calls but it requires more than 4 times the bandwidth of CEPT1 to achieve this. This is because PDH is not exactly synchronous and each multiplexing level requires extra bandwidth to perform Bit Stuffing. So the Plesiochronous Hierarchy requires “Bit Stuffing”, at all levels, to cater for the differences in clocks. This makes it particularly difficult to locate a particular 2Mbit/s stream in the 140Mbit/s trunk unless you fully de-multiplex the 140Mbit/s stream all the way down to 2Mbit/s. **2.2 Drop & Insert a 2Mbit/s stream** To drop & insert a 2Mbit/s stream from a 140Mbit/s trunk you need to break the 140Mbit/s trunk and insert a couple of “34Mbit/s to 140Mbit/s” multiplexers. You can then isolate the appropriate 34Mbit/s stream and multiplex the other 34Mbit/s streams back into the 140Mbit/s trunk. Then you de-multiplex the 34Mbit/s stream, isolate the appropriate 8Mbit/s Stream and multiplex the other 8Mbit/s streams through the higher layer multiplexer, into the 140Mbit/s trunk.
3. The Synchronous Digital Hierarchy (SDH)

SDH, like PDH is based on a hierarchy of continuously repeating, fixed length frames designed to carry isochronous traffic channels. SDH was specifically designed in such a way that it would preserve a smooth interworking with existing PDH networks. The developers of SDH also addressed the weaknesses of PDH. They recognized that it was necessary to adopt not only a Synchronous frame structure but one that also preserves the byte boundaries in the various traffic bit streams. Because SDH is synchronous it allows single stage multiplexing and de-multiplexing. This eliminates hardware complexity. You don’t need multiplexer mountains.

3.1 SDH multiplexing levels

Figure 4 shows the SDH multiplexing levels. The US and Japan use SONET while most of the rest of the world use SDH. Apart from using some different terminology, there is very little difference between SONET and SDH. You can see that the data rates are the same except SDH doesn’t specify a 51 Meg rate. STM-1 forms the basis of the SDH frame structure. For example an STM-4 is a frame consisting of 4 x STM-1s. In Sonet, the STS levels refer to the speed of the bit stream. When these bits are converted to a train of optical pulses in a fibre, they are called an Optical Carrier (OC). You may also see “OC-3c” referred to. This is simply the same bit rate as OC-3, but interpreted as one channel instead of 3 multiplexed OC-1s. The “c” stands for “Concatenated”.

[Diagram of PDH Multiplexing Levels]

[Diagram of The PDH Multiplexing Mountain]
3.4 The SDH Frame

The basis of SDH is the STM-1 Frame as shown in figure 10. The STM-1 frame runs at 155.52Mbit/s, and is 125μS long. This means that you get 8,000 STM-1 frames per second. 8,000 frames a second is a very common rate in telecommunications networks for example G.704 operates at 8,000 frames a second. This means that each Byte in the frame is equal to a 64kbit/s channel. The Frame is made up of a “Section Overhead” field and a “Payload” field. STM-1 Frames are usually represented as 9 Rows by 270 Columns for a total of 2430 Bytes. The bytes are transmitted from Left to Right, Top to Bottom. The first 9 Columns are the section overhead and the other 261 columns are used to carry the payload. The Section Overhead has three parts:-

* Regenerator Section Overhead
* Pointers
* Multiplex Section Overhead

In SDH the actual user data is carried in “Virtual Containers”. The Virtual Containers have a Path Overhead field and they come in a number of different sizes. We will look in detail at Virtual Containers later in the tutorial.

But first we will have a look at the SDH Overhead.
UNIT :2 – EVOLUTION OF SWITCHING SYSTEMS


DIGITAL SWITCHING SYSTEMS: Fundamentals : Purpose of analysis, Basic central office linkages, Outside plant versus inside plant, Switching system hierarchy, Evolution of digital switching systems, Stored program control switching systems, Digital switching system fundamentals, Building blocks of a digital switching system, Basic call processing.

TEXT BOOKS:


INTRODUCTION

switching system associated signaling system are essential to the operation of telecommunication NW. Function performed by switching system or subsystem, in order to provide customer with service are called facilities. This chapter will deal historical approach.

MESSAGE SWITCHING

In the early days of telegraphy a customer might sent a msg from town A to town B although there was no telegraph ckt between A and B. However, if there was a ckt between A and C and between C and B, this achieved by the process known as msg switching. The operator at A send msg to C, this operator recognized the address of msg as being at B & retransmitted the msg over the ckt B. this process as shown in the fig.
Message switching is still used for telegraph traffic & modified form of it, known as packet switching, is used in data communication. Dividing long message into smaller unit, known as pocket. Pocket switch sends each of these as a separate message.

**Circuit switching**

Invention of telephone introduced a new requirement: simultaneous both way communications in real time. Message switching could not meet this requirement because of the delay. It becomes necessary to connect the circuit of a calling telephone to called telephone & to maintain this connection for the duration of the call. This is called circuit switching. In circuit switching, if the required outgoing circuit from a switch is already engaged on another call, the new call offered
to it cannot be connected. The call cannot be stored in message switching. In circuit switching is thus example of lost call system.

**Functions of a switching system:**
The basic functions that all switching systems must perform are as follows,

**Attending:** The system must be continuously monitoring all lines to detect call requests. The calling signal is sometimes known as a ‘seize’ signal because it obtains a resource from the exchange.

**Information receiving:** In addition to receiving calls and clearing signals, the system must receive information from the caller as to the called line (or other service) required. This is called the address signal.

**Information processing:** The system must process the information received in order to determine the actions to be performed and to control these actions. Since both originating and terminating calls are handled differently for different customers, class of service information must be processed in addition to the address information.

**Busy testing:** Having processed the received information to determine the required outgoing circuit, the system must make a busy test to determine whether it is free or already engaged on an other call. If a call is to a customer with a group of lines to PBX( private branch exchanges), or to an outgoing junction route, each line in the group is tested until a free one is found. In an automatic system, busy testing is also required on trunks between switches in the exchange.

**Interconnection:** For a call between two customers, three connections are made in the following sequence;
- A connection to the calling terminal
- A connection to the called terminal
- A connection between the two terminals
In the manual system connections, a and b are made at the two ends of the cord circuit and connection c merely joins them in the cord circuit. Many automatic systems also complete connection c by joining a and b at the transmission bridge. However some modern systems release the initial connections a and b and establish connection c over a separate path through the switching network. This is known as *call-back* or *crank-back*. The calling line is called back and the connection to the called line is cranked back.

**Alerting:** Having made the connection, the system sends a signal to alert the called subscriber. E.g. by sending ringing current to a customers telephone.

**Supervision:** After the called terminal has answered, the system continues to monitor the connection in order to be able to clear it down when the call has ended. When a charge for the call is made by metering, the supervising circuit sends pulses over the private wire to operate a meter in the line circuit of the calling customer. When automatic ticketing is employed, the system must send the number of the caller to the supervisory circuit when the connection is setup. This process is called *calling line identification (CLI)* or *automatic number identification (ANI)*. In SPC system, the data for call charging can be generated by a central processor as it sets up and clears down connections.

**Information sending:** If the called customer’s line is located on another exchange, the additional function of information sending is required. The originating exchange must
signal the required address to the terminating exchange (and possibly to intermediate exchanges if the call is to be routed through them).

**Electronic Switching:**

Electronic techniques prove economic for common controls. In electromechanical exchanges, common controls mainly use switches and relays which are originally designed for use in switching networks. In common controls they are operated much more frequently and wear out earlier. In contrast the life of an electronic device is almost independent of its frequency of operation. This gave an incentive for developing electronic common control and resulted in electronic replacements for registers, markers etc. which have greater reliability than electromechanical devices.

Advances in computer technology led to the development of Stored Program Control (SPC). This enables a digital computer to be used as central control and perform different functions with the same hardware by executing different programs. As a result, SPC exchanges can offer a better range of facilities than other systems. In addition, the facilities provided to an individual customer can be readily altered by changing customers. Class of service data stored in a central electronic memory. Since the processors stored data can be altered electronically, some of these facilities can be controlled by customers.

**Examples include:**

- **Call banning (outgoing or incoming):** The customer can prevent unauthorized calls being made and can prevent incoming calls when wishing to be left in peace.
- **Repeat last call:** If called line is engaged the caller can try again later without having to redial the full number.
- **Reminder calls:** The exchange can be instructed to call customer at a pre-arranged time (wake up call).
- **Call diversion:** Exchange can be instructed to connect calls to a different number when the customer goes away.
- **Three way calls:** The customer can instruct exchange to connect a third party to a call that is already in progress.
- **Charge advice:** As a result of the caller sending the appropriate instructions when starting a call, the exchange calls back at the end of the call to indicate the call duration and the charge.

In order to develop a fully electronic exchange it was necessary to replace electromechanical switches in the speech path, in addition to using common controls. One approach is to replace the relay contacts of the switch in Fig 1 by electronic device multiplied together.

**Consequently switching systems may be classified as:**

**Space Division (SD) systems:** Each connection is made over a different path in space which exists for the duration of the connection.

**Time Division (TD) system:** Each connection is made over the same path in space, but in different instants in time.

**Digital Switching Systems:**

While reed-electronic exchanges were being developed, TDM transmission was being introduced for trunk and junction circuits in the form of pulse-code modulation (PCM). If time
division transmission is used with space division tandem switching as shown in fig (a) it is necessary to provide demultiplexing equipment to demodulate every channel to audio before switching and multiplexing equipment to retransmit it after switching.

**CROSSBAR EXCHANGE**

In the late 1930’s and throughout 1940’s, AT & T introduced various versions of the crossbar switches. This crossbar switch basically consists line link frames trunk, link frames and common control equipments. With crossbar switches and common control equipments, the crossbar exchange achieves full access and nonblocking capabilities. Active elements called crosspoints are placed between input and output lines. In common control switching systems, the switching and the control operations are separated. This permits a particular group of common control circuits to route connections through the switching network for many calls at the same time on a shared basis. The unique features of the crossbar switches are

(i) Common control allows the customer and the switch to share the common equipments used to process the call.
(ii) Wire logic computer allows specific routine functions of call processing to be handwired into the switch.
(iii) Flexible concentration ratios allows the system designer to select the appropriate ratio for a specific switch based on customer mix in a specific location.

(iv) Crossbar switches are easier to maintain because the switch have significantly fewer moving parts than strowger switching system.

**Basic principle.** The fundamental concept of crossbar switching is that it uses common control networks. The common control networks enables the exchange to perform event monitoring, call processing, charging, operation and maintenance. The common control also facilitates uniform numbering of subscribers in a multiexchange area like big cities and routing of calls from one exchange to another via some intermediate exchanges. The common control method of switching overcomes the disadvantages of step-by-step switching. The common control makes no call processing until it receives entire number. It receives all the number, stores, and then establishes connection.

**Crossbar switching matrix.** The basic crossbar matrix requires at least $M \times N$ sets of contacts and $M + N$ or less activators to select one of the contacts. Fig. 4.10 illustrates the $3 \times 4$ crossbar switching. It contains an array of horizontal and vertical wires (shown as a solid line). Both wires are connected to initially separated contact points of switches. Horizontal and vertical bars (shown as dotted lines) are mechanically connected to these contact points and attached to the electromagnets.

When both horizontal and vertical bars connected to the electromagnet are activated, the contact of the intersection of the two bars will close together. Thus the contact is made and continues to hold. When the electromagnets are deenergized both horizontal bar and vertical bars are released from the contact. In order to prevent the catching of different crosspoint in the same circuit, a procedure is followed to establish a connection. Accordingly, horizontal bar is energised first and then vertical bar is energised to make contact or in reverse. But while removing contact horizontal bar is deenergized first and then the vertical bar is deenergized. The crossbar switch is known as a non-blocking crossbar configuration. It requires $N^2$ switching elements for $N$ subscribers. Thus for 100 subscribers, 10000 crosspoint switches are required. Hence, crossbar is economic only for small private exchanges requiring small switches. For connecting and releasing the subscriber, the select magnet and bridge magnet should be energised and deenergised respectively. External switch must decide which magnet to
operate. This is called marker. A marker can control many switches and serve many registers. Thus, even a large exchange needs few markers. In Ericsson ARF system, groups of 1000 subscribers are served by a line switch network controlled by the two markers.

**Diagonal crosspoint matrix.** A diagonal matrix for 5 subscriber is shown in Fig. 4.11. The number of crosspoints are reduced to \( N (N-1)/2 \), where \( N \) is the number of subscribers. It is also called triangular matrix or two way matrix.

![Fig. 4.11. Diagonal crosspoint matrix.](image)

The diagonal crosspoint matrix is fully connected. When subscriber \( c \) initiates a call, his horizontal bar is energised first and then the appropriate bar. The diagonal crosspoint matrix is nonblocking configuration. The difficulty is that the failure of a single switch will make some subscribers inaccessible.

**Blocking Configurations.** By blocking configuration the crosspoint switches required can be reduced significantly. Fig. 4.12. shows the two stage matrices. Fig. 4.12. shows that there are now four paths between input and output in Fig. 4.12 (a) and four paths between any of the stations in Fig. 4.12 (b). For the rectangular matrices with \( N \) inputs and \( N \) outputs, the number of switches is now \( 2N^2 \) compared to \( N^2 \) for the single stage. Here, the random failure of a limited number of switches will not preclude connections.

![Fig. 4.12. Two stage matrices.](image)
Multistage switching. The single stage structures are called non-blocking and the multistage crosspoints are called blocking. Many of the limitations of the single stage matrix can be remedied by using a multistage structure. In order to produce longer switches a two stage link system of primary and secondary switches is used. Fig. 4.13 shows a two stage link network called line frame.

![Fig. 4.13. Two stage link network.](image)

The Fig. 4.13 shows twenty switches of size $10 \times 10$ used to connect 100 incoming trunks to 100 outgoing trunks. The links between primary and secondary are arranged systematically. The link 29 connects the outlet of 9 of primary switch 2 and inlet of 2 of secondary switch 9. The marker sets up a connection between incoming and outgoing trunk only when both are found to be free. This is called conditional selection.

4.5.1. AT & T No. 5 Crossbar System

This system was developed by the Bell Telephone Laboratories and brought into service in 1948. This system is especially suitable for isolated small cities and for residential areas on the fringes of large cities. When the percentage of calls connected to subscribers in the same office is relatively high, No. 5 crossbar system is useful. Improvements and added features have widened the applications of the No. 5 equipment. It is presently being used in almost all areas including metropolitan business exchanges and rural centres of about 2000 lines or more.
The basic structure of the No. 5 crossbar system is shown in Fig. 4.14. It consists of line link frame, trunk link frame and common control equipment. The No. 5 system employs a single switching train to handle incoming, outgoing or switch through. Also, the connection of the subscriber to the dial register circuit is also made through this switching train. Subscriber lines and incoming trunks terminate on the line link frames, trunks and originating registers termination on the trunk link frames. The line link and trunk link frames are interconnected by “junctors” which give each link frame access to all of the trunk link frames.

**Line link frames.** The basic line link frame is a 2 bay frame work with each bay mounting ten 200 point, 3 wire switches. The ten switches on one bay are used as combined line and junctor switches and provide terminations for 100 junctors and 100 lines. The ten switches on the other bay are line switches which provide terminations for 190 additional lines and ten “no test” verticals used to obtain access to busy lines. Thus a line link frames provides 290 line terminations and 100 junctor terminations.

A feature of this line link frame is that the same frame can serve customers who have various classes of service. Like coin telephone, emergency line facility, hot line facility, a maximum of thirty classes of service can be served on a frame.
Junctors. Each line link frame has 100 junctor terminations which are used to connect to all the trunk link frames in the office. The number of junctors in a group depends on the number of trunk line frames in the office. For example, in an office with eight trunk line frames and sixteen line link frames, each junctor group contains either twelve or thirteen junctors.

Trunk link frames. The trunk link frame is made up of trunk switches, junctor switches and relays for marker access to the frame. Trunks and originating registers, which register the called number are connected to the trunk switches. The trunk links run from vertical to vertical, the junctors being connected to the horizontals of the junctor switches and the trunks to the horizontals of the trunk switches. Thus, the trunk is accessible to all the junctors on the frame but only to either, the left or right junctors on one channel test.

Common control equipments: The common control equipments used in AT & T crossbar system are originating and incoming registers, markers, translators, senders and connectors. These equipments are explained briefly below.

Marker. It is the most active part of common control equipment. All the markers and their associated equipment serves up to a maximum of 20,000 members make a marker group. There are three types of markers. The combined marker performs dialtone, allotting the jobs between markers. The dialtone marker is used exclusively on dialtone jobs. Completing marker performs all the other jobs. The principal functions of the marker are to respond demands for dialtone, determine the proper route, establish connection, determine the class of service, recognize the status of the connection etc.

Outgoing registers. It furnish dialtone to subscribers and record the digits that are dialed, and then the called number is transmitted from register to marker. The originating circuit may be assigned to seize the pretranslator after either the second or third digit has been dialed.

Pretranslator. The pretranslator determines, how many digits the register should expect before seizing a marker. A pretranslator can be placed in the outgoing register. For complex Evaluation of Telecommunication Switching Systems numbering plans, a separate pretranslator circuit is provided. The pretranslator determines how many more digits should be dialed and instructs the register, the time it must wait to make connection to marker.

Outgoing Sender. The marker transfers the required digits of the called number to a sender which is connected to an outgoing trunk. The sender type is based on the switching system used. In crossbar No. 5 office, four different types of outgoing senders provided are Dial pulse (DP), Multi frequency (MF), Reventive pulse (RP) Panel call indicator (PCI) This four types of outgoing senders and intermarker group senders may be located on one sender link frame.

Connectors. It is used for interconnecting two equipment elements for short interval of time. If more than one type of equipment originate action toward another type, the connector is named according to both the originating and terminating action:

Important features of No. 5 crossbar system:
(i) The use of precious metal, non-sliding contacts results in noise free conversations.
(ii) Various options of charging methods such as AMA or message resister and coin.
(iii) Provision of toll and tandem switching features with the same common control equipment as is used for local traffic.
(iv) Good trouble shooting procedures and additional features like eleven digit capacity, alternate routing, code conversion, marker pulse conversion etc.
(v) Improved distribution of usage over various equipment units by means of rotating sequence and memory circuits.

**DIGITAL SWITCHING SYSTEMS**

**Purpose of Analysis**

The reliability of digital switching systems is becoming increasingly important for users of telephone services. Currently most Internet access takes place through digital switching systems. Almost all electronic money transfers depend on the reliability of digital switching systems. The federal government requires that all network outages exceeding 30 minutes be reported to the Federal Communications Commission (FCC). The Bell Operating Companies require that the outage of digital switches not exceed 3 minutes per system per year.

**Basic Central Office Linkages**

During the analysis of a digital switching system, it is helpful to define the extent of a central office (CO) and its linkages to other facilities. Figure 1.1 shows a typical central office along with some important facilities. Familiarity with this setup is essential to better understand various operations that may impact the overall reliability of a digital switching system. The following relate to the basic linkages of a typical central office:

**Main distributing frame (MDF)**

Location where all lines and other related links are cross-connected to a central office switch also referred to as the line side of a switch. The MDF is probably extensive part of a CO. All lines from subscribers terminate in the MDF. The MDF has two sides: a vertical and a horizontal. The subscriber cables terminate on the vertical side. The wiring from the digital switching system referred to as line equipment terminates on the horizontal side. Based on the assignment of subscribers to line The word "CO" or "switch" for Central Office will be used ,wires are connected between the vertical (cable pair) and the horizontal (line equipment pair).
Trunk distributing frame (TDF).
Location where all trunks and other related links are cross-connected to a central office switch, also referred to as the trunk side of a switch. The TDF is usually smaller than the MDF. All trunk cabling from different locations terminates in the TDF. The TDF has two sides: a vertical and a horizontal. The trunk cables terminate on the vertical side. The wiring from the digital switching system, referred to as trunk equipment, terminates on the horizontal side. Based on the assignment of cable to trunk equipment, the vertical cable pair are connected to the horizontal trunk equipment pair. The assignment process for trunks to trunk equipment is usually automated.

Power plant.
A combination of power converters, battery systems, and emergency power sources which supply the basic -48- and +24-V direct-current (dc) power and protected alternating-current (ac) power to a CO switch or a group of switches. These should not be confused with the power distributing frames in the central offices that provide special voltage conversions and protection for the CO.

Carrier facilities.
Facilities which provide carrier or multiplex transmission mode between central offices and with other parts of the telephony network. These facilities typically employ coaxial cables (land or
undersea) and radio and satellite systems. The carrier facilities usually terminate on the TDF for cross connection to the digital switching system.

**Digital X-connect.**
Digital cross-connect provides automatic assignments and cross-connection of trunks to digital switching systems. It can be considered a small switching system for trunks.

**Special services.**
Those services which require special interfaces or procedures to connect central office facilities to a customer, eg., data services and wireless services.

**1.2.3. Outside Plant versus Inside Plant**
Most of the telephone companies classify their telephone equipment as Outside plant or inside plant. This classification becomes important during the analysis of a switching system, since indirectly it defines the extent of a CO and consequently the scope of analysis. As shown in Fig. 1.1 and explained above, any element of telephony equipment outside the CO box, such as MDF and carrier systems, is classified as outside plant. CO equipment, such as central processors, switching fabric, and tone generators, are considered inside plant.

**Switching System Hierarchy**

Figure 2.2 also shows the different classes of switching system in the North American network:
- **Local exchange (class 5).**
  It is also referred to as the *end office (EO)*. It interfaces with subscribers directly and connects to toll centers via trunks. It records subscriber billing information.

- **Tandem and toll office (class 4).**
  Most class 5 COs interface with the tandem offices. The tandem offices primarily switch trunk traffic between class 5 offices; they also interface with higher-level toll offices. Toll operator services can be provided by these offices.

- **Primary toll center (class 3).**
  The class 3 toll center can be directly served by class 4 or class 5 offices, depending upon the trunk deployment. In other words, if the normal number of trunks in these offices are exhausted, then traffic from lower-hierarchy offices can home into a class 3 office. Class 3 offices have the capability of storing, modifying, prefixing, translating, or code-converting received digits as well as finding the most efficient routing to higher-level toll offices.

- **Sectional toll center (class 2).**
  It functions as a toll center and can home into class 1 offices.

- **Regional toll center (class 1).**
  It functions as a toll center and can home into international gateway offices.

- **International gateway.**
  These offices have direct access to international gateway offices in other countries. They also provide international operator assistance.

  - The advantage of the hierarchical network is that it provides an efficient way of searching for a path through the network.
  - The disadvantage is that if the primary sectional, or regional toll center goes down, then large areas of North America can become inaccessible.

The following table shows approximate numbers of end offices and toll centers in North America.

<table>
<thead>
<tr>
<th>Class</th>
<th>Type</th>
<th>Number in1977</th>
<th>Number in1982</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>End office</td>
<td>19,000</td>
<td>19,000+</td>
</tr>
<tr>
<td>4</td>
<td>Toll and tandem office</td>
<td>1,300</td>
<td>925</td>
</tr>
<tr>
<td>3</td>
<td>Primary toll center</td>
<td>230</td>
<td>168</td>
</tr>
<tr>
<td>2</td>
<td>Section toll center</td>
<td>67</td>
<td>52</td>
</tr>
<tr>
<td>1</td>
<td>Regional toll center</td>
<td>12</td>
<td>10</td>
</tr>
</tbody>
</table>

  - These figures show that the number of class 5 COs is increasing while the number of toll centers is decreasing.
This switching hierarchy and the classification of offices are covered here to emphasize that just analyzing the reliability of a digital switching system may not solve the problem of overall network reliability.

However, to the analyst who understands the interconnection of digital switching systems, it is clear that every part of a switching network must be analyzed to fully appreciate the impact of network reliability.

**Evolution of Digital Switching Systems**

The evolution of digital switching systems as background to understand the current architecture of modern digital switching systems.

For instance, the control structure, call handling, alternate routing, billing, etc., all evolved from earlier crossbar switching systems.

1. **Stored Program Control Switching Systems**

With the advent of software-controlled central processors, the control of switching functions was programmed into memory and actions were executed by the controlling processor.

The early versions of electronic switching systems had temporary memory for storing transient-call information and semi permanent memories that carried programming information and could be updated.

A *stored program control (SPC)* switching system, shown in Fig. 1.3, depicts a simplified view of a telephony switch.

![Diagram of a telephony switch](Figure 1.3. Basic control structure of a central office)
The basic function of an SPC system is to control line originations and terminations and to provide trunk routing to other central or tandem offices.

The SPC system also provided control of special features and functions of a central office, identified here as ancillary control.

The intelligence of an SPC system resided in one processor, and all peripherals were controlled by this single processor. These processors were duplicated for reliability.

A modern digital switching system employs a number of processors and uses distributed software and hardware architectures.

Control of the maintenance functions of the modern digital switching system also evolved from earlier SPC systems.

These systems depended heavily on a single processor to conduct all maintenance functions of the switch.

Most of the modern digital switching systems employ a separate processor for maintenance functions. The maintenance functions of a digital switching system are so important.

2. Digital Switching System Fundamentals

Extend the basic concept of SPC switching systems to modern digital switching systems. Many basic elements of the digital switching system already exist in the SPC switching system.

A switching system is called digital when the input to and output from the switching system network can directly support digital signals.

A digital signal can be defined as coded pulses that can be used for signaling and control.

However, analog signals can still be processed through the digital switching system via analog-to-digital (A/D) or digital-to-analog (D/A) converters. This presents a very simplistic view of a digital switching system.

The evolution to digital switching from analog switching is shown in Figure 1.4a to d. Figure 14a shows a typical analog switch with analog lines and trunks. This figure also shows the line side and trunk side of a switch.

The basic function of a switching system is to switch lines and trunks. Many other advanced switching functions are handled by digital switching systems.
However, the main objective of digital switching systems is to switch subscribers and trunk facilities. Figure 1.4b shows the next step in the evolution of digital switching. This phase uses analog lines and analog trunks but employs A/D and D/A converters for digital processing of calls. Digitized signals are sent through the switch.

Figure 1.4c shows the next step in this process, in which digital switches can "talk" to other digital switches via digital trunks while simultaneously supporting analog lines and trunks.

Figure 1.4d shows the ultimate, an all-digital linkage. In this arrangement, there are no analog lines or trunks involved; all communication between digital switches is via digital signaling. This plan assumes that all incoming lines coming to a CO are digital and that all outgoing trunks are digital as well.

![Figure 2.4. Digital switch evolution](image)

- In some applications, switching from digital trunk to digital trunk is indeed performed. But we still live in an analog world, and lots of conversion from analog to digital signals is performed in many applications.

- Currently, the telecommunications industry is moving in the direction in which video, audio, and telephony services will all be combined and switched through digital switching systems. Obviously this will require lots of conversions. One form of switching not shown in Fig. 2.4 is optical switching.
the future of telephony switching will be optically based. Optical switching systems will provide high-speed, large-bandwidth switching.

Currently, many of the "pure" optical switches are under development, and many advances have been made in this area.

In the case of optical switching, electrical/optical (E/O) and optical/electrical (O/E) conversions will be required. Fiber-optic-based trunks and lines will be utilized, and signals with very wide bandwidths will be switched.

3. Building Blocks of a Digital Switching System

Since the object of analyze digital switching systems, first a basic digital switching system model is developed, and then is expanded gradually throughout to cover most of the important functions associated with a modern digital switching system.

The development of this digital switching system model is described in four stages. The first stage looks at the very basic kernel of a digital switching system, with the switching matrix, which is called switching fabric, since not all switching systems use a matrix arrangement for switching.

The switching fabric switches lines and the trunks under the control of a central processor and network controller.

The second stage of this development introduces the concepts of line and trunk modules.

The third stage introduces the notion of interface controllers and distributed processing.

The fourth stage presents a high-level design of a digital switching system equipped with service circuits.

Stage 1.
Stage 1 of conceiving a digital switching system is shown in Fig. 1.5a. At this stage, all inputs and outputs to a digital switching system are defined. In this particular case, which is a simple one, only lines and trunks are defined. Clearly, there can be many types of lines and trunks.

Their design specification must be defined and their reliability assessed at this stage. The line and trunk sides of the digital switching system are shown separately. As mentioned earlier, this is only a convention and does not mean that trunks appear on one side of the network and lines on the other.

The central processor controls the network controller, which in turn controls the switching fabric. For the time being, regard the switching fabric as a "switched" path through the CO.
Stage 2.

- Stage 2 of digital switching system design is shown in Fig.2.5b. The concept of line modules (LMs) and trunk modules (TMs) is introduced here. The line and trunk modules are the building blocks of a modern digital switching system, and conceptually they represent some lines or trunks grouped together on circuit packs, termed line or trunk equipment, and connected to the switching fabric through a controlling interface.

- Modern digital switching systems use various schemes to terminate lines on the line module. Some digital switching systems allow termination of only one line on one line module, while others allow termination of multiple lines on a single line module.

- If a line module becomes defective, this may impact a number of lines if the line module carries multiple lines. However, if a piece of line equipment becomes defective; the line can easily be assigned new line equipment if the LM carried multiple pieces of line equipment.

- Similar schemes are used for trunks on trunk modules. In a modern digital switching system, line and trunk modules are designed to be modular, which in simple terms means that a number of these units can be added on an as-needed basis without reengineering the system.

- This allows for easy growth and offers flexibility in offering new services. The impact of these design ideas on system reliability and on digital switching system operation is explored.
Stage 3.

- This stage is depicted in Fig. 2.5c. The concept of distributed processing in a digital switching system environment is developed here. Notice the replacement of the network controller in Fig. 1.5fc by network control processors in Fig. 1.5c and the addition of an interface controller for LMs and TMs.

- The task of controlling the switching fabric is usually assigned to a series of network control processors that control a part of the switching fabric and a group of LMs and TMs.

- The central processor controls the actions of the network control processors. This type of architecture is very flexible and allows the construction of different sizes of central office by increasing the number of network control processors.

- For instance, a small central office could be constructed by using just one network control processor, while a configuration of several network control processors could be employed for a larger central office.

- Naturally, the processing capacity of the network control processors and of the central control processor and network size also play an important role in determining the ultimate size of a central office.
Stage 4.

- As shown in Fig. 2.5c, stage 4 of the digital switching system design may appear to be the final stage of a digital switching system model, but it is not. In reality, it is only an initial model of a digital switching system which is needed to develop a more detailed model.

- This basic model introduces the *duplicated* scheme now commonly used in modern digital switching systems. Since telephony processing is a nonstop process requiring high reliability, a duplicated scheme for processing units and associated memory units is almost mandatory.

- This basic conceptual model also shows the attachment of interface controllers and service circuits to the line and trunk modules.

- The interface controllers allow interfacing and control of LMs and TMs through the network control processors. The purpose of the service circuits is to provide dial tone, ringing, and other associated functions.

- In a modern digital switching system, each line or trunk module or a group of modules can be attached to service circuits.

![Diagram](image-url)
Basic Call Processing

This section describes some basic types of calls that are usually processed through a digital switching system:

- Intra-LM calls
- Inter-LM calls
- Incoming calls
- Outgoing calls

Intra-LM Calls.

- When a customer dials from a telephone that is connected to a specific line module and calls another customer who is also connected to the same line module, this type of call is classified as an intra-LM call.

- A call path for this type of call is shown in Fig. 1.6a. The off-hook (line origination request) condition is detected by the line module, and service circuits are attached to supply a dial tone to the calling customer.

- Many other functions are performed before a dial tone is given to a calling customer; The line module's request for a path through the switching fabric is processed by the interface controller, which in turn works with the network control processor to make a path assignment.
Consequently, a path is established through the switching fabric for the called line, and a service circuit is attached to ring the line. Again, many other functions are performed before ringing is applied to the called customer; Since this is an intra LM call, the same line module will be involved in controlling the origination and termination of a call.

This very simplified explanation is offered here for introductory purposes only. Later chapters go into far greater detail in explaining various functions such as digit reception, digit translation, and tests that are performed before a call is completed.

**Figure 2.6a.** Calls within a line module

**Figure 2.6b.** Calls outside a line module
Inter-LM Calls.

- The workings of an inter-LM call are similar to those of an intra-LM call, except that the terminating line equipment is located in another line module. Figure 1.6 & shows interconnections for such a call. There are some subtle differences in how an inter-LM call is handled versus an intra-LM call.

Outgoing Calls.

- When a LM processes a call which has terminating equipment outside the CQ the LM requests a path through the switching fabric to a trunk module via the interface controller.

- The interface controller works with the network control processor to establish a path to an outgoing trunk. Once a path is established through the switching fabric, the TM connects a service circuit for controlling the call to the called CO or a tandem office.

- Functions such as out pulsing and multi frequency (MF) signaling are provided by the trunk service circuits. An outgoing call from an originating office is an incoming call to a terminating office. Figure 1.6c shows the paths of incoming and outgoing calls.

Incoming Calls.

- When a TM detects an incoming call, it attaches service circuits to control the call and requests a path through the switching fabric from the interface controller and network control processor.
Once a path is found through the switching fabric to a LM that has the terminating line/service circuits are attached to ring the called telephone. This also provides functions such as audible ringing to the calling line. Use Fig. 1.6c to visualize this simple connection of an incoming call.
UNIT 3: TELECOMMUNICATIONS TRAFFIC

Introduction, Unit of traffic, Congestion, Traffic measurement, Mathematical model, lost call systems, Queuing systems.

6 Hours

TEXT BOOKS:


Introduction:

In case of telecommunication systems, it is required to design the system in accordance with the number of calls that are in progress at any point of time and the total number of subscribers that are connected to the network. Teletraffic engineering involves the design of the number of switching equipment required and the number of transmission lines required for carrying telephone calls.

In tele traffic engineering the term trunk is used to describe any entity that will carry one call. The arrangement of trunks and switches within an exchange is called it’s trunking.

We can check the number of calls in progress at different intervals of time for a whole day and then tabulate the results. If a graph is plotted taking the number of calls in progress on y-axis and the time of the day on x-axis the graph would look like this:-

![Graph showing the number of calls in progress throughout the day](image.png)
The maximum number of calls occurs between 8:00 and 10:00 am for this particular exchange. This hour which corresponds to the peak traffic of the exchange is called the busy hour.

The busy hour varies for different exchanges and the teletraffic curve also varies for different exchanges from what is shown in the fig 1.

Exchanges in which offices and business establishments predominate usually have a busy hour between 10:00 and 11:00 am. Residential exchanges have a busy hour normally between 4:00 and 5:00 pm.

**The limit of traffic:**

The teletraffic intensity or simply the traffic is defined as the average no. of calls in progress. The unit of traffic is erlang (named after the Danish pioneer in teletraffic A.K.Erlang). It is a dimensionless quantity.

On a group of trunks, the average number of calls in progress depends on both the no. of calls which arrive and their duration. The duration of a call is called it’s holding time because it holds the trunk for that time.

Consider a holding time T for a group of 3 trunks:

![Diagram of traffic on 3 trunks](image)

Fig. 2
Example of 1 erlang of traffic carried on 3 trunks

Figure 2(a) shows 1 erlang of traffic resulting from one truck being busy for the holding time T. Figure 2(b) shows 1 erlang of traffic resulting from two trunks with each trunk being busy for 50% of the time T. Figure 2(c) shows 1 erlang of traffic being carried by three trunks with each of the trunks being busy for 33.33% of the time T.

Sometimes the traffic is also expressed in terms of hundreds of call seconds per hour (CCS).

1 erlang = 36 CCS

Mathematically traffic can be represented by the following equation:

\[ A = \frac{Ch}{T} \]  \hspace{1cm} (1)

where A=traffic in erlangs
C=average number of calls arriving during time T
h=average holding time
From eqn 1, if $T=h$, $A=C$. Thus traffic in erlangs can be defined as mean number of calls arriving during a period equal to the mean duration of the calls (average holding time).

A single trunk cannot carry more than one call, therefore $A \leq 1$ for a single trunk. This is called the occupancy of the trunk. The occupancy of the trunk is also the probability of finding the trunk busy.

**Congestion:**

Normally in a telecommunication system, the installed equipment will be enough to carry the busy hour traffic and not the entire traffic that can be generated by the subscribers since the probability of every subscriber making a call simultaneously is negligible. In such a design a situation might arise where all the trunks of the system are busy. The system will not be able to accept any further calls. This state is known as congestion.

There are two things that could happen to a call that encounters congestion depending upon the design of the exchange:

1) The call will be unsuccessful i.e. lost. Such a system is called a *lost call system*.

2) The call will wait in a queue until a trunk frees up. Such calls are delayed and not lost. Such systems are called *delayed systems* or *queued systems*.

**GOS-Grade of Service (B):**

The proportion of calls lost or delayed due to congestion is a measure of the service provided. For a lost call system the grade of service is given by,

\[
B = \frac{\text{number of calls lost}}{\text{number of calls offered}} = \frac{\text{traffic lost}}{\text{traffic offered}}
\]

The traffic carried by a lost call system will always be less than the traffic offered.

Traffic offered = $A$ erlangs

Traffic lost = $AB$ erlangs

Traffic carried = $A(1-B)$ erlangs

(2)

**Note:** Larger the Grade of service worse is the service given. Ideally $B=0$.

**Traffic measurement:**

It is essential to keep a record of the traffic that is offered to a telephone exchange in order to upgrade the system capacity as and when required.

Initially the number of calls used to be measured manually. Later automatic traffic recorders were installed in automatic exchanges. In modern SPC systems, a separate sub-program keeps count of the traffic generated.

**Mathematical model:**

A mathematical model needs to be developed in order to study telecommunications traffic. Such a model is based on two assumptions:

a) pure chance traffic

b) statistical equilibrium

a) The assumption of pure chance traffic means that call arrivals and call terminations are independent random events. It also implies that the number of sources generating calls is
very large. Since call arrivals are independent random events, the occurrence of calls is not affected by previous calls, therefore traffic is sometimes called memoryless traffic.

The number of call arrivals in a given time $T$ has a Poissonian distribution given by,

$$P(n) = \frac{\mu^n}{n!}e^{-\mu} \quad (3)$$

where $x$ is the number arrivals in time $T$

$\mu$ is the mean number of call arrivals in time $T$

i. The intervals $T$ between calls arrivals are intervals between independent random events and these intervals have a negative exponential distribution,

$$P(x>t) = e^{-\mu T} \quad (4)$$

where $T$ is the mean interval between call arrivals

ii. The call durations, $T$ are intervals between independent random events (call termination). Therefore the call durations also have a negative exponential distribution.

$$P(T>t) = e^{-\mu h} \quad (5)$$

where $h$ is the average holding time

b) Statistical equilibrium means that the generation of traffic is a stationary random process i.e. the probabilities do not change for the period being considered. Consequently the mean number of calls in progress remains constant.

![fig 3. State transition diagram for N trunks](image)

The state transition diagram is shown for a group of N trunks. The total number of states that N trunks can have is $N+1$. The number of calls in progress varies randomly and lies between 0 and N. The state transition diagram shown is called a simple Markov chain. The probabilities $P(0)$, $P(1)$, .... are called the state probabilities and the $P_{j,k}$, $P_{k,i}$ are called transition probabilities of the Markov chain. In case of statistical equilibrium these probabilities will have a fixed value and they will not change.

Using Markov chains we can proceed to prove that if call arrivals has a Poissonian distribution, then the calls in progress will also have a Poissonian distribution:

**Proof:**

Consider a small interval of time $\delta t$ such that the probability of two or more things happening in this interval is very small. The events that could occur in $\delta t$ are,

a) one call arrives with probability $P(a)$

b) one call ends with probability $P(e)$

c) no change occurs with probability $1-P(a)-P(e)$
From equation 1, the mean number of calls arriving in the holding time \( h \) is \( A \). The mean number of calls arriving in \( \delta \) is \( A \delta/t/h \) and this represents the probability of a call arriving in \( \delta \).

\[
P(a) = A \delta/t/h
\]

If the number of calls in progress is \( k \), then an average of \( k \) calls are expected to terminate in \( h \), the average holding time. The average number of call terminations in \( \delta \) is \( k \delta/t/h \) and this represents the probability of a call being terminated in \( \delta \).

\[
P(e) = k \delta/t/h
\]

If number of calls in progress is \( j \), then the probability of a call arriving causing a transition to \( k \) busy trunks \( P[j\rightarrow k] \) is given by \( P(j).P(a) \)

\[
P[j\rightarrow k] = P(j)A \delta/t/h
\]  

If number of calls in progress is \( j \), then the probability of a call arriving causing a transition to \( k \) busy trunks \( P[j\rightarrow k] \) is given by

\[
P[k\rightarrow j] = P(k).k \delta/t/h
\]  

From the assumption of statistical equilibrium we have \( P[j\rightarrow k] = P[k\rightarrow j] \)

\[
P(k) = A/k P(j)
\]

\[
P(1) = A/1 P(0); P(2) = A/2 P(1) = A^2/(1.2) P(0)
\]

In general

\[
P(x) = (A^x/x!) P(0)
\]

It is assumed that the number of sources is infinitely large i.e.

\[
\sum_{x=0}^{\infty} P(x) = 1 \Rightarrow \sum_{x=0}^{\infty} (A^x/x!) P(0) = 1
\]

\[
\Rightarrow e^A P(0) = 1 \Rightarrow P(0) = e^{-A}
\]

\[
P(x) = (A^x/x!) e^{-A}
\]

This is a Poissonian distribution.

Lost call systems:

Our aim is to find the GOS (B) of a lost call system that is offered traffic of \( A \) erlangs and has \( N \) outgoing trunks. Erlang worked out a solution to this problem based on the following assumptions:

i. Pure chance traffic – implies call arrivals and call terminations are independent random events.

ii. Statistical equilibrium - implies probabilities remain unchanged for the period being considered.

iii. Full availability – all incoming calls can be connected to any outgoing trunk that is free.

iv. Calls that encounter congestion are lost which is the basis on which lost call systems are classified.

If there are \( x \) calls in progress, then from equation 8,

\[
P(x) = (A^x/x!) P(0)
\]  

Where \( 0 < x < N \), where \( N \) is the total number of trunks

\[
\sum_{x=0}^{N} P(x) = 1 \Rightarrow \sum_{x=0}^{N} (A^x/x! P(0) = 1
\]

\[
P(0) = 1/(\sum_{x=0}^{N} (A^x/x!)
\]

Substituting the value of \( P(0) \) in equation 10, we get

\[
P(x) = (A^x/x!) \sum_{k=0}^{N} A^k/k!
\]
This is called the first erlang distribution. When \( x=N \), \( P(N) \) is the probability that a call encounters congestion i.e. the GOS of the network. It is represented by \( E_{1,N} \)

\[
B = E_{1,N} = (A^N/N!) \div \sum_{k=0}^{N} A^k/k!
\]  

(12)

This formula is also called erlang’s lost call formula. \( E_{1,N} \) can also be calculated by an iterative formula given by

\[
E_{1,N}(A) = (A \cdot E_{1,N-1}(A)) \div (N + A \cdot E_{1,N-1}(A))
\]

Traffic performance:

If there is an increase in traffic, then there must be a proportional increase in the number of trunks. The occupancy of a large group of trunks is higher than a smaller group of trunks and therefore more the number of trunks, greater the efficiency.

Concentrators: Since large groups of trunks are more efficient, it is always better to concentrate traffic through a single group having a large number of trunks rather than a large number of low trunk groups. The function of a concentrator is to connect a large number of low trunk groups to a single group containing a large number of trunks.

However the penalty that one has to pay for higher efficiency is the GOS deteriorates more rapidly for a large group of trunks for traffic overloads as compared to a small group of trunks.

Lost call systems in Tandem:

A large number of loss systems maybe connected in tandem and it is necessary to know the GOS of the entire system. Consider a system having two links with GOS \( B_1 \) and \( B_2 \). From equation 2 traffic offered to second link

\[
A_2 = A(1-B_1)
\]

Traffic reaching destination  = \( A_2(1-B_2) = A(1-B_1)(1-B_2) \)

= \( A(1+B_1B_2-B_1B_2) \)

Let overall GOS be \( B \).

\[
A(1-B) = A(1-(B_1+B_2-B_1B_2))
\]
Digital Switching System

\[ B = B_1 + B_2 - B_1 B_2 \quad B_1, B_2 \ll 1 \]

If \( B_1, B_2 \ll 1 \), then \( B_1 B_2 \) is negligible.

\[ B = B_1 + B_2 \]

In general for an \( n \) link connection

\[ B = \sum B_k \]

\( k=1 \)

**Delayed systems or queuing systems:**

**Second erlang distribution**

In queuing systems, the trunks present in the systems are called *servers*. Erlang’s solution to queuing systems is based on the following assumptions:

i. Pure chance traffic

ii. Statistical equilibrium

iii. Full availability

iv. Calls that encounter congestion are stored in a queue until a server becomes free.

Such a system is also called a M/M/N system.

If \( x \) is the total number of calls in a queuing system, then there are two cases:

i. \( x \leq N \) where \( N \) is the number of servers in the system and

ii. \( x = N \).

If \( x \leq N \):

No calls will be in queue and the probability of \( x \) calls is given by,

\[ P(x) = (A^x / x!) P(0) \quad \text{for } 0 \leq x \leq N \quad (12a) \]

If \( x = N \):

The probability of a call arriving in a short duration \( \delta t \) is \( P(a) = A \delta t / h \)

The probability of transition from \( x-1 \) calls to \( x \) calls in duration \( \delta t \) is given by,

\[ P(x-1 \rightarrow x) = P(x-1) A \delta t / h \quad (13) \]

Since all the \( N \) servers will be busy, the probability of a call terminating during \( \delta t \) is given by

\[ P(e) = N \delta t / h \]

The probability of transition from \( x \) to \( x-1 \) calls is given by

\[ P(x \rightarrow x-1) = P(x) N \delta t / h \quad (14) \]

For statistical equilibrium,

\[ P(x \rightarrow x-1) = P(x-1 \rightarrow x) \]

\[ P(x) N \delta t / h = P(x-1) A \delta t / h \]

\[ P(x) = (A / N) P(x-1) \quad (15) \]

But

\[ P(N) = (A^N / N!) P(0) \]

\[ P(N+1) = (A^{N+1} / (N+1)!) P(0) \]

\[ P(N+2) = (A^{N+2} / (N+2)!) P(0) \]

In general for \( x = N \)

\[ P(x) = (A^x / (N^x N!)) P(0) \]

\[ P(x) = (N^x N! / (A N^x)) P(0) \quad (16) \]

If the length of the queue is assumed to be infinite,

\[ \sum_{x=0}^{\infty} P(x) = 1 \]

\[ \sum_{x=0}^{\infty} P(x) = \text{infinite} \]
\[ 1/P(0) = \sum_{k=0}^{\infty} \frac{A^k}{k!} + \frac{N^N}{N!} (A/N)^N \sum_{k=0}^{N-1} (A/N)^k \]

where \( k = x - N \)

Since \( A/N \leq 1 \), \( \sum_{k=0}^{N-1} (A/N)^k = [1-A/N]^{-1} \)

\[ P(0) = [\frac{NA^N}{N!(N-A)} + \sum_{x=0}^{\infty} \frac{A^x}{x!}]^{-1} \] (17)

Thus \( P(x) \) for a queuing system is given by equations 12(a) and 16 where \( P(0) \) is defined by equation 17.

**Probability of delay:**

The probability that there are \( Z \) calls in the system where \( Z \geq N \) is given by,

\[ P(x \geq Z) = \sum_{x=z}^{\infty} P(x) \]

\[ = \frac{N^N}{N!} P(0) \sum_{k=0}^{\infty} (A/N)^x \]

\[ = \frac{N^N}{N!} P(0) (A/N)^z \sum_{k=0}^{\infty} (A/N)^k \]

where \( k = x - z \)

\[ P(x \geq Z) = \frac{N^N}{N!} (A/N)^Z [1-A/N]^{-1} P(0) \] (18)

If there are more than \( N \) calls in a system, then any further incoming calls will have some delay. The probability of delay \( P_D = P(x \geq N) \)

From 17 we have,

\[ P_D = P(x \geq N) = \frac{N^N}{N!} (A/N)^N [1-A/N]^{-1} P(0) \]

\[ = A^N/N! (N/N-A) P(0) \]

\[ = E_{2,N} (A) \] (19)

This formula is known as Erlang’s delay formula.

**Finite queue capacity:**

A practical system will never have an infinite queue. Thus when the queue gets full, the incoming calls are no longer stored and they are lost. If the queue can hold only \( Q \) calls, then \( x \leq Q + N \).

\[ 1/P(0) = \sum_{k=0}^{N-1} \frac{A^k}{k!} + \frac{N^N}{N!} (1-(A/N)^{Q+1})/(1-A/N) \]

The loss probability \( P(x \geq Q+N) \) is given by

\[ P(x \geq Q+N) = \frac{N^N}{N!} (A/N)^Q N/N.A \ P(0) \]

\[ = (A/N)^Q P_D \] (20)

\( Q \) can be designed in order to maintain a low loss probability. When queues are connected in tandem, their delays are cumulative. Each queue can be considered as independent for calculating their delays. The total delay of the entire system will be the sum of delays of individual stages.

The second erlang distribution and the first erlang distribution are related by the following formula:

\[ E_{2,N} = (N/(N-A)) E_{1,N(A)} \] (21)

Important solved examples from Flood:
1) During busy hour a company makes 120 outgoing calls of average duration 2 minutes and receives 200 incoming calls of average duration 3 minutes. Find
   a) Outgoing traffic
   b) Incoming traffic
   c) Total traffic

**Solution:**

from eqn 1, \( A = \frac{C \cdot h}{T} \), \( T=60 \) min (busy hour)

a. Incoming traffic = \( \frac{120 \times 2}{60} = 4 \) E
b. Outgoing traffic = \( \frac{200 \times 3}{60} = 10 \) E
c. Total traffic = \( 10 + 4 = 14 \) E

2) During busy hour a single customer line receives 3 calls and makes 3 calls of average duration 2 minutes. Find occupancy of trunk.

**Solution:**

Occupancy of single trunk = probability of finding trunk busy = \( A \)

\( A = \frac{6 \times 2}{60} = 0.2 \) E

3) During busy hour, 1200 calls were offered to a group of trunks and 6 calls were lost. The average call duration (holding time) was 3 minutes. Find
   a. traffic offered
   b. traffic lost
   c. traffic carried
   d. grade of service
   e. total duration of periods of congestion

**Solution:**

From 1, \( A = \frac{C \cdot h}{T} \)

a. traffic offered = \( \frac{1200 \times 3}{60} = 60 \) E
b. traffic lost = \( \frac{6 \times 3}{60} = 0.3 \) E
c. traffic carried = \( \frac{1194 \times 3}{60} = 59.7 \) E
d. grade of service = \( B = \frac{6}{2000} = 0.003 \) E

4) On an average one call arrives every 5s. During a period of 10s, what is the probability that
   a. no call arrives
   b. one call arrives
   c. two calls arrive
   d. more than two calls arrive

**Solution:**

We have \( P(x) = \frac{\mu^x}{x!} \cdot e^{-\mu} \) here \( \mu=2 \)

a. \( P(0) = \frac{2^0}{0!} \cdot e^{-2} = 0.135 \)
b. \( P(1) = \frac{2^1}{1!} \cdot e^{-2} = 0.270 \)
c. \( P(2) = \frac{2^2}{2!} \cdot e^{-2} = 0.270 \)

d. \( P(\geq 2) = 1 - P(0) - P(1) - P(2) \)
\[
= 1 - 0.135 - 0.270 - 0.270 \\
= 0.325
\]

5) A group of 5 trunks is offered 2E of traffic. Find
   a. grade of service
   b. probability that only 1 trunk is busy
   c. probability that only 1 trunk is free
   d. probability that atleast 1 trunk is free

Solution:
a. \( \text{GOS B} = E_{1, N}(A) = \frac{2^5/5!}{\sum_{k=0}^{5} A^k/k!} = 0.2667/7.2667 = 0.037 \)
b. \( P(1) = \frac{2}{7.2667} = 0.275 \)
c. \( P(4) = \frac{16/24}{7.2667} = 0.0917 \)
d. \( P(x<5) = 1 - P(5) = 1 - B = 1 - 0.037 = 0.963 \)

6) A group of 20 trunks provide a GOS of 0.01 when offered 12E of traffic. How much is the
   GOS when
   a. 1 trunk is added to the group
   b. 1 trunk is out of service

Solution:
From the recursive formula for \( E_{1, N}(A) \)
\[
E_{1, N}(A) = \frac{A E_{1, N-1}(A)}{N + A E_{1, N-1}(A)}
\]
a. \( E_{1,21}(12) = \frac{12E_{1,20}(12)}{21 + 12 E_{1,20}(12)} \)
\[
= 12 \cdot 0.01/(21+12 \cdot 0.01) \\
= 0.0057
\]
b. \( E_{1,20}(12) = \frac{12 E_{1,19}(12)}{20 + 12 E_{1,19}(12)} \)
\[
= 0.017
\]

Note: this example shows that greater is the number of trunks, lower is the Grade of service and thus the service provided is better.

Another interesting point in traffic performance:

In many switching systems, trunks in a group are selected by means of a sequential search. (selector hunter systems in Strowger automatic switching systems).
A call is not connected to trunk no.2 unless trunk no.1 is busy, it is not connected to trunk no.3 unless trunk no.1 and trunk no.2 are busy. Calls finding the last choice trunk busy are lost.
As a result, the first choice trunk has the highest occupancy as compared to the other trunks. The GOS of a single trunk offered A erlangs of traffic is given by,
\[ E_{1,1}(A) = \frac{A}{A+1} = B \]
The traffic lost by 1\textsuperscript{st} trunk = traffic overflowing into 2\textsuperscript{nd} trunk
\[ AB = A \cdot E_{1,1}(A) = A \cdot \frac{A}{A+1} = A^2 / (1+A) \]
Traffic carried by 1\textsuperscript{st} trunk = A - A^2 / (1+A) = A / (1+A)

In general, we can say the traffic carried by k\textsuperscript{th} trunk = traffic lost from first k-1 trunks – traffic lost from first k trunks
\[ = A \left[ E_{1,k-1}(A) - E_{1,k}(A) \right] \]

7) If sequential search is employed for a group of 5 trunks offered 2E of traffic, how much traffic is carried by,
   a. first choice trunk
   b. last choice trunk

Solution:
   a. traffic carried by 1\textsuperscript{st} choice trunk = A / (A+1) = 2/3 = 0.667E
   b. \[ E_{1,4}(2) = \frac{16/24}{7.2667} = 0.095 \]
      Traffic carried by last choice trunk= 2[0.095-0.037]=0.12E
UNIT 4: SWITCHING SYSTEMS

Introduction, Single stage networks, Gradings, Link Systems, GOS of Linked systems.

6 Hours

TEXT BOOKS:


Introduction

A basic requirement for constructing switching systems (or telephone exchanges) is to design switching networks having greater number of outlets than the switches from which they are built. This can be done by connecting a number of switching stages in tandem.

Single stage network:

Single stage network can also be constructed by multiplying banks of M uniselectors or one level of a group of M two-motion selectors each having N outlets.

Photonic switches use optoelectronic devices as crosspoints to make connections between optical fiber trunks. Cross bar switch gives full availability; no calls lost unless outgoing trunks are congested.

Number of simultaneous connections made is M (if M < N) and N (if N < M). The switch contains MN crosspoints. If M=N, the number of crosspoints is \( C_1 = N^2 \). Thus cost (number of crosspoints) increases as the square of size of switch. Whereas efficiency (proportion of crosspoints) \( N/N^2 = 1/N \) decreases inversely with N. It is uneconomic to use single stage network for large number of inlets and outlets. E.g. a switch with 100 inlets and outlets requires 10000 crosspoints. Only 1 pc of these can be in use at any time.

Switches for making connections between large numbers of trunks are therefore constructed as networks containing several stages of switches. Operation of crosspoint at co-ordinates (j,k) to connect inlet j to outlet k thus performs the same function as operating
crosspoint \((k,j)\) to connect inlet \(k\) to outlet \(j\). So half the crosspoints are redundant and thus can be eliminated.

This results in the triangular crosspoint matrix shown in figure.

![Triangular Crosspoint Matrix](image)

Triangular crosspoint matrix for connecting both way trunks
Number of crosspoints required is \(C_1 = \frac{1}{2}N(N-1)\)

Triangular switches are not found in telephone switching systems because both way trunks are not used. Triangular switches are not popularly used as the trunks are operated on a one way basis to facilitate supervision. For example ringing tone and ringing current are sent over separate one way trunks depending on whether a customer’s line is calling or being called.

**Grading:**

**Principle:**
For a route switch or concentrator, it is not necessary for each incoming trunk to have access to every outgoing trunk. It is adequate if each incoming trunk has access to sufficient number of trunks on each route to give required grade of service. This is *limited availability*. The number of outgoing trunks to which an incoming trunk can obtain connection is called *availability* and corresponds to outlet capacity of switches used.
The above figure shows 20 trunks on an outgoing route to which incoming trunks have access by means of switching giving an availability of only 10. In the figure, the outlets of switches are multiplied together in two separate groups and 10 outgoing trunks are allocated to each group. If total traffic offered by incoming trunk is 8E, each group of outgoing trunk is offered 4E traffic and will provide a GOS better than 0.01.

This arrangement in figure is not a very efficient design as for 8E only 15 trunks are required.

If traffic offered to two groups of incoming trunks is random, peak loads will seldom occur simultaneously in two groups. Efficiency can therefore be improved through mixing traffic by interconnecting multiples of two groups so that some of the outgoing trunks are available to both groups of switches.

If switches search sequentially for free outlets, the latter choice outlets carry least traffic, so it is desirable to connect latter choice trunks to both groups of selectors.

In this arrangement, the first six outlets are in two separate full availability groups, the last four outlets are common to both groups and carry traffic that overflows when the first six outlets of either group are busy. This arrangement gives a GOS of 0.01 with 16 trunks.
This arrangement requires only one extra outgoing trunk (for same GOS).

The technique of interconnecting multiples of switches is called grading. An interconnection of trunks based on this principle is called grading.

A grading enables a single switching stage to provide access to a number of trunks greater than the availability (i.e. the outlet capacity) of switches but not exceeding it by an order of magnitude.

A grading provides poorer GOS than a full availability group for same number of trunks. Some lost calls occur even when there are free outgoing trunks, when these trunks are in part of grading which is not accessible to group of selectors containing the incoming trunk requiring connection. These gradings are called O’Dell gradings. In Progressive gradings, the switches hunt over the outlets sequentially from a fixed home position.

**Design of progressive gradings:**

In order to from a grading, the switches having access to the outgoing route are multiplied into a number of separate groups known as graded groups. On early choices, each group has access to individual trunks and on late choices, trunks are common. Since the traffic decreases with later choices of the outlet, the number of groups connected together increases from individual connections on the early choices through partial commons to full commons on the late choices.

In designing a grading to provide access to N outgoing trunks from switches having availability k, the number of graded groups g has to be decided. If all the choices were individual trunks, we would have N=gk. If all the choices were full commons, N=k. since the grading contains a mixture of individuals, partial commons and full commons, then k<N<gk . A reasonable choice for N is N = ½ gk .

The number of groups is thus chosen to be: \( g = \frac{2N}{k} \)
Since the grading must be symmetrical, g should be an even number. So the value of g obtained is rounded up to the next even integer.

It is now necessary to decide how the gk trunks entering the grading are to be interconnected to N outgoing trunks. For a two-group grading, there is only one solution. If the number of columns of singles is ‘s’ and the number of commons is c, then:

Availability = k = s + c
Number of trunks = N = 2s + c
Therefore, s = N - k and c = 2k - N

If the grading has more than two groups, there is no unique solution. It is necessary to choose from the possible solutions the best one, i.e. the grading with the greatest traffic capacity. There should be a smooth progression on the choices from individuals to partial commons, from smaller partial commons to larger partial commons and from partial commons to full commons.

**Traffic capacity of gradings:**

In an ideal grading, the interconnections would ensure that each outgoing trunk carried an identical traffic load. Thus if total traffic A is carried by N trunks, the occupancy of each trunk is A/N. Each call has access k to trunks (where k is the availability), and the probability of all the k trunks being busy is

\[ B = \left(\frac{A}{N}\right)^k \]

The number of trunks required to carry A erlangs with a GOS of B is given by:

\[ N = AB^{-1/k} \]

This is *Erlang’s ideal grading formula.*

**Link system:**

Grade of service of a link system depends on the way the system is used. We may classify these uses as follows:

- **Mode 1:** Connection is required to one particular free outgoing trunk
- **Mode 2:** Connection is required to a particular outgoing route but any free trunk on that route may be used
- **Mode 3:** Connection may be made to any free outgoing trunk

Concentrator operates in mode 3, Route switch operates in mode 2 and Expander operates in mode 1.
Two stage networks:

N incoming trunks
N outgoing trunks
Primary switches have n inlets
Secondary switches have n outlets
So number of primary switches or secondary switches \((g)\) = number of outlets per primary or secondary switch
\[ g = \frac{N}{n} \]
Number of crosspoints per primary switch = number of crosspoints per secondary switch
\[ = gn = N \]
Total number of crosspoints \((C_2)\) = number of switches \(x\) crosspoints per switch
\[ C_2 = 2gN \]
\[ = \frac{2N^2}{n} \]
Number of links = number of primary switches \(x\) number of secondary switches
\[ = g \times g \]
\[ = g^2 \]
\[ = \left(\frac{N}{n}\right)^2 \]
Number of crosspoints varies as \(1/n\); number of links varies as \(1/n^2\)
If \(n\) is large, to make crosspoints less, then number of links will decrease.
Let number of links be equal to the number of incoming and outgoing trunks
i.e. \[ g^2 = N \]
substitute \(g = N/n\)
then \[ N^2/n^2 = N \]
or \(n = \sqrt{N} \)
Total number of crosspoints is \(C_2 = 2N^2/\sqrt{N} = 2N^{3/2} \)
The 2 stage network shown has the same number of incoming trunks and outgoing trunks.
A concentrator has more incoming trunks than outgoing trunks. An expander has more outgoing trunks than incoming trunks.
Consider a concentrator with \(M\) incoming trunks and \(N\) outgoing trunks \((M>N)\)
Each primary switch has \(m\) inlets and each secondary switch has \(n\) outlets.
Then
Number of primary switches = M/m
Number of secondary switches = N/n
Number of crosspoints per primary switch = mN/n
Number of crosspoints per secondary switch = nM/m
Total crosspoints = M/m (mN/n) + N/n (nM/m)
= MN (1/n + 1/m)

Total number of links = number of primary switches x number of secondary switches
= M/m x N/n
= MN/mn

Since the traffic capacity is limited by the number of outgoing trunks, there is no point in providing more links more links than N.

Therefore MN/mn = N
Or n = M/n

Total number of crosspoints C₂ = MN (m/M +1/m)
To minimize C₂, dC₂/dm = MN (1/M – 1/m²) = 0
Solving we get m = √M
But n = M/m = M/ √M =√M =m
Therefore n = m

Thus number of crosspoints is minimum when number of inlets per primary switch is equal to number of outlets per secondary switch.

C₂ = MN (1/n + 1/m)
= MN ( 1/√m + 1/√m)
= MN 2/√m
= 2N√m

m and n must be integers and factors of M and N respectively. Now if n = √N, then m = M/√N

**Multiple:**
An arrangement referred to as a multiple is used in connecting circuits to provide the various connections. If all the relays have the contact terminals on one side multiplied (duplicated) to a set of common leads, then the arrangement is called a ‘multiple’.

**Link:**
Two multiples may be joined back to back by a ‘common link’.
A circuit may reach the link by means of a multiple on a set of relays and then reach any one of the B circuits by a similar multiple on a second set of relays.

Thus link principle provides a means of positioning the amount of switching equipment according to the demand for simultaneous connections between two groups of terminal circuits.

Grading is obtained by the partial multiplying of the outlets of connecting networks when each network provides only limited availability to the outgoing group of trunks.

Other forms of grading:
- Homogenous grading
- Progressive grading
- O’Dell grading
- Transposed grading

Grade of service = ratio of number of lost calls to number of calls attempted
                  = probability of finding all the circuits engaged
3.5 Three stage networks:

There are total of N/n primary and tertiary switches. There is one link from each primary to each secondary switch and so is the case between secondary and tertiary switches. Any inlet on a primary switch has \( g_2 \) alternate paths (secondary switches to reach tertiary switches).

If the three stages have \( N \) incoming trunks and \( N \) outgoing trunks and has primary switches with \( n \) inlets and tertiary switches with \( n \) outlets, then:

- Number of primary switches \((g_1) = \frac{N}{n}\)
- Therefore, secondary switches have \( \frac{N}{n} \) inlets and outlets.

If the no. of primary-secondary links (A links) and secondary-tertiary (B links) are each \( N \), then the number of secondary switches is

\[
g_2 = N ÷ (\frac{N}{n}) = n = \text{no. of outlets per primary switch} = \text{no. of inlets per tertiary switch}
\]

No. of cross points in primary stage = \( n^2(\frac{N}{n}) = nN \)

No. of cross points in secondary stage = \( n (\frac{N}{n})^2 = \frac{N^2}{n} \)

No. of cross points per tertiary stage = \( n^2(\frac{N}{n}) = nN \)

and the total number of cross points = \( C_3 = N(2n + \frac{N}{n}) \)

By differentiating the above equation with respect to \( n \) and equating to zero, it can be shown that the number of cross points is a minimum when

\[
n = \sqrt{\frac{N}{2}}
\]

and then \( C_3 = 2\sqrt{2} \frac{N^{3/2}}{2} \frac{N^{3/2}}{2} = 2^{3/2}N^{3/2}C_1 \)

If a three stage concentrator has \( M \) incoming trunks and \( N \) outgoing trunks (\( M > N \)), its primary switches each have \( m \) inlets and its tertiary switches each have \( n \) outlets, then:

- No. of primary switches = \( M/m \)
- No. of tertiary switches = \( \frac{N}{n} \)
- If there are \( g_2 \) secondary switches, then:
  - Cross points per primary switch = \( m \) \( g_2 \)
  - Cross points per secondary switch = \( M/m \times N/n \)
  - Cross points per tertiary switch = \( g_2n \)

The total number of cross points is \( C_3 = \frac{M}{m} \times mg_2 + g_2 \times MN/mn + \frac{N}{n} \times g_2n \)

Since \( M > N \), let no. of A links = no. of B links = \( N \)

Therefore \( N = g_2 \frac{M}{m} = g_2 \frac{N}{n} \)

Hence \( g_2 = n \) and \( m = n \) \( M/N \)
Therefore \( C_3 = (M + N)n + \frac{N^2}{n} \)

Differentiating with respect to \( n \) to find a minimum gives

\[
m = \frac{M}{\sqrt{(M+N)}}, \quad n = \frac{N}{\sqrt{(M+N)}}
\]

\( C_3 = 2N/\sqrt{(N+M)} \)

To obtain an expander, \( M \) is exchanged with \( N \) and \( m \) with \( n \).

**Four stage networks:**

A four stage network can be constructed by considering a complete two stage network as a single switch and then forming a larger two stage array from such switches. It is necessary that one trunk (B link) be connected from each secondary switch of an incoming frame to a primary switch of an outgoing frame. These switches are connected to corresponding numbers on the two frames, thus facilitating marking of the network.

If a four stage network is constructed with \( N \) incoming and \( N \) outgoing trunks, with switches of size \( n \times n \), then \( N = n^3 \) and the total number of switches is \( 4n^2 \). Thus the total number of crosspoints is

\[
C_4 = 4n^2 \cdot n^2 = 4N^{4/3}
\]

The number of crosspoints per incoming trunk is \( 4N^{1/3} \).

**Grade of service:**

**Two-stage network:**

For a two stage network, let occupancy of the links be \( a \) and the occupancy of the trunks be \( b \).

For mode 1 (i.e. connection to a particular outgoing trunk) only one link can be used. The probability of this being busy is \( a \) and this is the probability of loss.

For mode 2 (i.e. connection to an outgoing route with one trunk on each secondary switch) any free link can be used. The probability of using a particular link is

\[
1 - \text{probability that both link and trunk are free} = 1 - (1-a)(1-b)
\]

But there are \( g \) paths available. Assuming that each being blocked is an independent random event, the probability of simultaneous blocking for all \( g \) paths is:

\[
B_2 = [1-(1-a)(1-b)]^g = [a + (1-a)b]^g
\]

where \( g \) is the number of secondary switches.

If connection be made to any outgoing trunk that is free (mode 3) then it is possible to make the connection unless all the outgoing trunks are busy. Thus if no. of incoming trunks, links and outgoing trunks are equal, then no calls can be lost. However this mode of operation is normally used with a concentrator. The number of incoming trunks is then much larger than the number of outgoing trunks, so the grade of service is given by

\[
B_3 = E_{1,N}(A) \quad \text{where } A \text{ is the total traffic offered.}
\]

**Three stage network:**

Let occupancy of links be ‘\( a \)’. Let occupancy of outgoing trunks be ‘\( b \)’.
Occupancy measures the extent to which a stage in a multistage network is occupied or is busy. Traffic on the network is measured in terms of the occupancy of the servers in the network. Erlang measure indicates the average no. of servers and therefore,

**Occupancy period = total traffic ÷ no. of servers of links**

For mode 1, the choice of a secondary switch determines the A and B links.

- Probability that both links are free = \( (1-a)(1-b) \)
- Probability of blocking = \( 1 - (1-a)(1-b) \)

However there are \( g_2 \) secondary switches,

- Probability that all \( g_2 \) independent paths is simultaneously blocked is
  
  \[ B_1 = \left[ 1 - (1-a)(1-b) \right] g_2 \]
  
  \[ = \left[ a + (1-a)b \right] g_2 \]

For mode 2,

- Probability of blocking for a particular trunk
  
  \[ = 1 - (1-B_1)(1-c) \]
  
  \[ = B_1 + (1-B_1)c \]

Therefore probability of simultaneous blocking for all \( g_3 \) independent paths is

\[ B_2 = \left[ B_1 + c(1-B_1) \right] g_3 \]

where \( g_3 \) is the no. of tertiary switches.

**Four stage networks:**

For a four stage network, let the occupancy of A links be \( a \), the occupancy of B links be \( b \), the occupancy of C links be \( c \) and the occupancy of outgoing trunks be \( d \).

For a connection from a given inlet on an input frame to a particular outlet on an output frame (i.e. mode 1), the call may use any primary switch in the output frame. This switch is connected by a B link to only one secondary switch in the particular input frame. From this switch there is only one A link to the primary switch of the given incoming trunk.

- Probability of this path being free is \( = (1-a)(1-b)(1-c) \)
- Therefore probability of this path being blocked is \( 1 - (1-a)(1-b)(1-c) \)
- Probability that all \( g_2 \) independent paths are simultaneously blocked is
  
  \[ B_1 = \left[ 1 - (1-a)(1-b)(1-c) \right] g_2 \]
  
  where \( g_2 \) is the no. of secondary switches in input frame = no. of primary switches in output frame.

**Application of graph theory to link systems:**

A graph is a collection of points known as nodes or vertices connected by lines called edges or arcs. Conventional representation shows switches, network graph focuses more on links without details of switches.

The representation of a switching network by means of a graph can therefore be simplified by drawing only the paths which can be used for making connections between one particular inlet-outlet pair. This graph is called the channel graph of the network.

An important property of the network which is displayed channel graph is its connectivity. This may be defined as minimum number of disjoint paths joining the non-adjacent vertices. The larger the value of connectivity, lower is the probability of blocks.
Channel graphs show how adequate connectivity is provided by adding a 3rd stage to the 2 stage network and a 4th stage to the partially interconnected 3 stage network.

Two stage network:

Fully interconnected three stage networks:

Partially interconnected three stage networks:

Four stage network:
UNIT: 5  TIME DIVISION SWITCHING

Introduction, space and time switching, Time switching networks, Synchronization.

4 Hours

TEXT BOOKS:


Space and time switching:

A tandem switching centre or the route switch of a local exchange must be able to connect any channel on one of its incoming PCM highways to any channel of an outgoing PCM highway. The incoming and outgoing highways are spatially separate, so the connection requires space switching.

A connection will occupy different time slots on the incoming and outgoing highways. Thus the switching network must be able to receive PCM samples from one time slot and re-transmit them in a different time slot. This is known as Time slot interchange or Time switching.

Space switches:

Cross point matrix connects incoming and outgoing PCM highways. Different channels of an incoming PCM frame may need to be switched by different cross points in order to reach different destinations. Crosspoint is a 2 input AND gate. One input is connected to incoming PCM highway and another to connection store that produces a pulse at required instants.

Figure below shows space switches with k incoming, m outgoing PCM highways carrying n channels. The connection store for each column of cross points is a memory with an address location for each time slot which stores the number of the cross point to be operated in that time slot. This number is written into the address by the controlling processor in order to set up the connection.

The numbers are read out cyclically in synchronism with incoming PCM frame. In each time slot, the number stored at corresponding store address is read out and decoding logic converts this into a pulse on a single lead to operate relevant cross point. Since a cross point can make a different connection in each of n time slots, it is equivalent to n cross points in a space division network.
**Time switches:**

Time switch connects an incoming n-channel PCM highway to an outgoing n-channel PCM highway. Since any incoming channel can be connected to any outgoing channel, it is equivalent to a space-division cross point matrix with n incoming and outgoing trunks.

Time slot interchange is carried out by means of two stores, each having a storage address for every channel of the PCM frame.

Speech store consists of data of each of the incoming time slots (i.e. its speech sample) at a corresponding address. Each address of the connection store corresponds to a time slot on outgoing highway. It contains number of time slot on incoming highway whose sample is to be re-transmitted in that outgoing time slot. Information is read into the speech store cyclically in synchronism with the incoming PCM system; however random access read out is used. The connection store has cyclic read out, but writing is non-cyclic.

To establish a connection, the number (X) of the time slot of an incoming channel is written into the connection store at the address corresponding to the selected outgoing channel (Y). During each cyclic scan of the speech store, the incoming PCM sample from channel X is written into address X. During each cyclic scan of the connection store, the number X is read out at the beginning of time slot Y. This is decoded to select address X of the speech store, whose contents are read out and sent over the outgoing highway.
Time switching introduces delay. If $Y > X$ the output sample occurs later in the same frame as the input sample. If $Y < X$, the output sample occurs in the next frame.

**Time Division switching networks:**

The figure below shows a *Space-Time-Space (S-T-S) switching network*. Each of the $m$ incoming PCM highways can be connected to $k$ links by cross points in the A switch, and the other ends of the links are connected to the $m$ outgoing PCM highways by cross points in the C switch. Each link contains a time switch. To make a connection between time slot $X$ of an incoming PCM highway and time slot $Y$ of an outgoing PCM highway, it is necessary to select a link having address $X$ free in its speech store and address $Y$ in its connection store. The time switch is set to produce a shift from $X$ to $Y$. 

![Fig. Time switch](image-url)
**Time-Space-Time (T-S-T) switching network:**

Each of the \( m \) incoming and \( m \) outgoing PCM highways are connected to a time switch. The incoming and outgoing time switches are connected by the space switch. To make a connection between time slot \( X \) of an incoming highway and time slot \( Y \) of an outgoing highway, it is necessary to choose a time slot \( Z \) which is free in the connection store of the incoming highway and the speech store of the outgoing highway. The connection is established by setting the incoming time switch to shift from \( X \) to \( Z \) setting the outgoing time switch to shift from \( Z \) to \( Y \) and operating the appropriate cross point at time \( Z \) in each frame.

**Bidirectional paths:**

PCM transmission systems use four wire circuits, it is necessary to provide separate paths for the send and receive channels. One way of doing this would be to provide a separate switching network for each direction of transmission. However this may be avoided by connecting the send highways of both incoming and outgoing circuits to one side of the switch and the receive highways to the other side as shown in the figure.
In an STS network, the same speech store address in the time switch may be used for each direction of transmission.

In a TST network, speech in the two directions must be carried through the space switch using different time slots.

**Concentrators:**

A concentrator connects to a PCM highway, a number of customers’ line units greater than the number of time slots on the highway. In a simple concentrator, the customers’ CODECS are all connected to the common highway and each may use any time slot. A codec is operated in the required time slot by means of a connection store.

Since a concentrator is connected to the route switch by a PCM highway, it may be located at a distance from the main exchange. The concentrator can be controlled by the central processor in the main exchange by means of signals sent over the PCM link. If PCM link between a remote concentrator unit and the main exchange fails, customers on the concentrator lose all service. Duplicate PCM links are provided.

The control functions of the concentrator may be enhanced to enable it to connect calls between its own customers if PCM link fails. Facilities must be added to receive and analyze address signals, generate tones and make cross-switch connections between customers’ lines. The unit is known as a *remote switching unit*.

**PBX (Private Business Exchange) Switches:**

A large PBX may use a switching network similar to that of a public exchange. However, a small PBX may only generate sufficient traffic for all its connections to be made over a single highway. All its parts, i.e. those for extension lines, exchange lines and the operators position have CODECS connected to a common highway as shown in the figure below.
The CODECS are operated in the required time slots by a connection store. In order to increase the line capacity of the PBX, the number of time slots on the common highway may be increased by using 8-bit parallel transmission instead of serial transmission.

**Digital cross-connect units:**

For a telephone call, a connection is made through a digital switching network at the start of a call and cleared down as soon as the call ends. However, a similar digital network may be used for semi-permanent connections. It is controlled manually from an operating terminal instead of automatically by the processor of an exchange. Such a switching network is called a *digital cross-connect unit*. It is sometimes called a slow switch in contrast to a fast switch used to connect telephone calls and connections made by a digital cross-connect unit are called nailed-up time slots.

Two functions that can be performed by digital cross-connect units are

- **Grooming**: In grooming, 64kbits/s channels on a common PCM bearer are separated for routing to different destination.
- **Consolidation**: In consolidation, channels on several PCM bearers that are not fully loaded are combined onto a smaller number of bearers thereby improving utilization of PCM systems.

**Grades of service of T-D switching networks:**

**S-T-S network:**

Mode 1: \( B_1 = [1-(1-b)^2]^k \)

Mode 2: \( B_2 = [B_1 + c(1-B_1)]^n \)

**T-S-T network:**

Mode 1: \( B_1 = [1-(1-b)^2]^n \)

Mode 2: \( B_2 = B_1 \)
Non-blocking networks:

Time division switching networks often have large values of connectivity and are therefore quasi non-blocking. Time division networks can also be strictly non-blocking. A time division switching network will be non-blocking in the strict sense if its equivalent space division network is strictly non-blocking.

A three stage space division network whose primary switches have n inlets and tertiary switches have n outlets is strictly non-blocking if there are 2n-1 secondary switches.

STS switch is made strictly non-blocking by providing 2m-1 time shifting links. TST switch is made strictly non-blocking by providing more time slots (64 instead of 32).

Synchronization:

Frame alignment:

If all exchange clock pulse generators are in perfect synchronism, there will be time differences between the starting instants of different PCM frames entering a digital exchange. To solve this problem, the line terminating unit of a PCM junction stores the incoming digits in frame-alignment buffer. Digits are read into this buffer at the rate, $f_a$, of the incoming line beginning at the start of each frame. They are then read out at the rate $f_b$ of the exchange clock, beginning at the start of the PCM frame of the exchange.

To cater to the maximum amount of misalignment between a digital line system and the exchange, the aligner must have a buffer capacity of at least one frame. This introduces delay additional to that caused by time switching. A frame alignment buffer caters perfectly to a constant misalignment.

However if the exchanges at the two ends of a line have slightly different clock frequencies, the contents of the buffer will change until it either overflows or empties. If the buffer overflows, its contents are erased so that it can start refilling. If the buffer empties completely, the contents of the previous frame are repeated to refill it. In either case, a complete frame is in error. This is known as frame slip. Of course, slip can also arise from malfunctions in switching or transmission systems.

Synchronization networks:

In a synchronous digital network, just one or two atomic reference clocks control the frequencies of the clocks of all the exchanges in the network. This is sometimes called despotic
control. For this purpose, a synchronizing network is added to PSTN in order to link the exchange clocks to the national reference standard.

The local clock in each exchange is provided by crystal oscillator whose frequency can be adjusted by a control voltage. This control voltage is derived from incoming digit stream on synchronizing link which is used to determine whether the exchange clock rate should be increased or decreased or left unchanged. Adjustments are made periodically as a single quantum increase or decrease. This ensures that exchanges maintain the same long term average frequency, although short term deviations may occur. This is known as mesochronous working.

Synchronizing links may be unilateral or bilateral. In first case, there is a master-slave relationship; the clock frequency of the exchange at one end of link is controlled solely by exchange at other end. In second case, there is a mutual relationship; each exchange influences the frequency of the other. The principles of these methods are shown in the figure below.
UNIT: 6: SWITCHING SYSTEM SOFTWARE

Introduction, Scope, Basic software architecture, Operating systems, Database Management, Concept of generic program, Software architecture for level 1 control, Software architecture for level 2 control, Software architecture for level 3 control, Digital switching system software classification, Call models, Connect sequence, Software linkages during call, Call features, Feature flow diagram, Feature interaction.

TEXT BOOKS:

Introduction
A modern digital switching system is quite complex. At this stage of digital switching evolution, most of the complexity comes from the software, which is much more complex and harder to manage than the hardware it controls. This chapter exposes some intricacies of the software that drives a digital switching system.

Scope
This chapter covers the basic software architecture of a typical digital Switch, classifies various types of software, describes a basic call model and software linkages that are required during a call, and discusses some basic call features.

Basic Software Architecture
A good understanding of the hierarchy of software currently employed by many modern digital switching systems is important. Most of today's digital switching systems employ quasi-distributed hardware and software architectures. The control structure of a digital switching system can usually be divided into three distinct levels. This chapter elaborates on the software employed in a hypothetical digital switching system at different levels of control. It shows levels of control along with some details of minimum software architectural functions that may be necessary for each level of control. From a digital switching system analyst's point of view, it is essential to understand the high level software architecture of a digital switch before attempting to analyze it. Low-level details are not essential, since the objective is to analyze the digital switch, not to design it. However, details on software engineering practices are essential for software analysis.
1. Operating Systems

Every digital switching system has an operating system as a part of its software architecture. An operating system (OS) may be defined as software that manages the resources of a computer system or controls and tasks other programs. Sometimes these programs may be referred to as control programs, supervisory programs, executive programs, or monitor programs. In theory there are different types of operating systems, classified as serial batch systems, multiprogramming systems, timesharing systems, and the real-time systems. The operating systems employed by digital switching systems are real-time operating systems. This type of OS is required for digital switching systems since the very nature of telephony processing demands execution of tasks in real time. Typically, the real-time operating system for the digital switching system interacts with different layers of applications necessary to support telephony features and functions. Since practically all modern digital switching systems use quasi distributed architecture, the processor or controller for each subsystem may even use different OSs than the central processor does.

![Figure 5.1 Basic software architecture of a typical digital switching system](image)

Therefore, it is conceivable for a digital switching system to employ more than one OS. Each subsystem may employ a different type of processor and therefore may employ different high-level languages for the development of its software. It is thus a challenge for the analyst to
understand the operational and developmental environment of a digital switching system. Details on a methodology that could aid the analyst in better understanding the complex software environment of digital switching systems.

**Kernel.**
The kernel or the nucleus of an operating system comprises those functions of an OS that are most primitive to the environment. It usually supports the following functions.
- Process control and scheduling
- Main memory management
- Input/output control of requests for terminals and buffers
- Domain protection of main memory read/write operations etc.

Most of the real-time operating systems that control digital switching systems use priority interrupt systems. These interrupts are serviced by the kernel based on the importance of an operation. Of course, the interrupt and similar hierarchical controls are system-specific, but most give highest priority to system maintenance interrupts, since this ensures proper operation of the digital switching system, followed by other types of interrupts required for call processing and other ancillary functions. Most digital switching systems employ kernels that reside in the main memory.

### 2. Database Management
The databases that are employed in digital switching systems are usually relational and sometimes distributed. In simple terms, distributed databases imply multiple databases requiring data synchronization. The relational database systems use the relational data model in which the relationships between files are represented by data values in file records themselves rather than by physical pointers. A record in a relational database is flat, i.e., a simple two dimensional arrangement of data elements. The grouping of related data items is sometimes referred to as a tuple. A tuple containing two values is called a pair. A tuple containing N values is called an N-tuple. A good example of a relational database system in a digital switching system is a database system that keeps cross-references of all directory numbers that are assigned to the line equipment of subscribers. When a particular subscriber goes off-hook, the line equipment is identified by the scanning program. The database is searched to find its associated directory number that identifies all characteristics of the line. In the hypothetical digital switching system developed for each network control processor (NCP) is assigned a group of subscribers. Therefore, each NCP has a replica of the subscriber database for all other NCPs. Depending on the type of call, a NCP may be required to route calls through other NCPs. To accomplish this, the database information for all NCPs needs to be distributed and always kept synchronized.

### 3. Concept of Generic Program
Most digital switching systems support the concept of generic program similar to release in the computer industry. However, a generic program can be a little more involved than release. In the early days of stored program control (SPC) switching systems, the generic program was more or
less the same for most telephone companies. Usually, the generic program contained all programs necessary for the switching system to function. It included all switching software, maintenance software, and specialized office data for the configuration of a central office (CO). The translation data were usually supplied by the telephone companies. However, now it is sometimes more difficult to define exactly what a generic program consists of. Most of the modern digital systems have modular software structure. They usually have base programs or core programs that control the basic functions of the digital switching systems. On top of these programs reside different features and special options. Generally, the performance of a generic program is tracked for software reliability. Therefore, it becomes very important for an analyst to identify the exact software components that constitute a generic program. The components of a digital switching systems software that are kept common for a specific market or a group of telephone companies can sometimes be used to identify the generic program. Usually this set of programs can be labeled as a generic, base, or core release for a digital switching system. In general, generic programs contain operating system(s), common switching software, system maintenance software, and common database(s) software for office data and translation data management.

4. Software Architecture for Level 1 Control

Level 1 is the lowest level of control. This level is usually associated with lines, trunks, or other low-level functions. Most of the software at this level is part of the switching software. As shown in Fig. 5.1, the interface controllers (ICs) are usually controlled by microprocessors and may have a small kernel controlling the hardware of the 1C. The ICs may have a small OS, labeled Operating System (Level 3) in Fig. 5.1. The function of this OS is to control and schedule all programs that are resident in the 1C. Most of the ICs have enough intelligence to recognize proper functioning of hardware and software. The 1C can also conduct diagnostics of lines and trunks or other peripherals connected to it. More extensive diagnostic routines may reside in the central processor or in some cases in the 1C itself. In either case, the central processor can run the diagnostic program itself or request a fault-free 1C to run it. The 1C will then run the diagnostics and forward the results to the central processor. The ICs may also be capable of local recovery. This means that in case of an 1C failure, the 1C could recover itself without affecting the entire digital switching system. The only effect will be on the lines and trunk or peripherals connected to the 1C undergoing a recovery process. Again, all this will depend on the design of the ICs and associated software. An analyst should be conversant with different types of design strategies that may be employed, since they will impact the reliability and functionality of the 1C.

5. Software Architecture for Level 2 Control

The intermediate or level 2 controls are usually associated with network controllers that may contain distributed databases, customer data, and service circuit routines. Obviously these functions are digital switching architecture dependent; many switching functions could be assigned at this level of control. In a quasi-distributed environment, the processors employed are usually of intermediate or mini size. The NCPs are usually independent of the central processor. As shown in Fig. 5.1, the NCPs usually have their own operating system, labeled Operating System (Level 2). This OS has a kernel that controls the hardware and
basic functionalities of the NCR. At this level of control, usually a resident database system maintains the translation data of subscribers and other software parameters required to control the telephony functions of the NCP. System recovery at this level of control is crucial, since a failure of a NCP may impact a number of ICs (dependent on the design) and a large number of lines, trunks, and peripherals. The NCPs should be capable of self-diagnosis, and since they are duplicated, they must be able to switch to a working backup. As mentioned in earlier chapters, the use of NCPs is design-specific. A design may call for a dedicated NCP to act as a control NCP for all other NCPs, or each NCP may be designed to operate independently. The recovery strategy in each case will be different. In the first case, where one NCP acts as the control NCP, the control NCP is responsible for system recovery for all other NCPs. In the second case, where there is no control NCP, the central processor is responsible for the recovery process of all NCPs. There could be all kinds of recovery strategies involved in the system recovery process at this level. The analyst needs to understand what type of recovery strategy is being used, in order to better assess the reliability of a digital switching system. Consider the function of the NCP. A subscriber goes off-hook, the IC receives an off-hook notification from the line module. The IC requests details on the subscriber, such as allowed features and applicable restrictions. The NCP queries its database for this information and passes it back to the IC. This type of action required by the NCP necessitates that the NCP maintain a subscriber database as well. This database is supposed to be managed and kept up to date with the latest information for each subscriber. This is shown as DBMS in Fig. 5.1 under level 2 control.

5.3.6. Software Architecture for Level 3 Control

The highest or level 3 control is usually associated with the central processor of a digital switching system. Normally these processors are mainframe type computers. Usually, the CP of a digital switching system provides all high level functions. These high-level functions include the management of the database system for office data, high-level subscriber data, software patch levels, feature control, and above all, system recovery in case of hardware or software failures. The main operating system of a modern digital switching system resides at this level and is labeled Operating System (Level 3) in Fig. 5.1. As mentioned earlier, this OS operates in real time and is multitasking (i.e., it can support more than one task at a time). This OS controls the database management system, switching software, recovery software, and all applications such as features, traffic management systems, and OS interfaces. Most CPs work in an active/standby mode. In this mode, one CP is always available to go into active mode if the active CP develops a fault. Indeed, there are different schemes for operating a redundant processor system to improve reliability and availability. However, for digital switching systems, the scheme most commonly employed is the one in which both processors execute instructions in a matched mode, and in case of a failure, the standby processor becomes active immediately. Other schemes are sometimes employed, such as hot standby, in which the standby processor is powered up and ready to take over the operation of an active processor. In this scheme, call processing can be impacted during the processor switchover. There is a third option, cold standby, in which the processor is not powered up, but can be brought on line in case of failure.
This scheme is not used for CPs but is sometimes employed for less critical peripherals. Most of the maintenance and recovery functions of a switch are also controlled from this level.

5.3.7. Digital Switching System Software Classification
A conceptual diagram of typical digital switching system software is shown in Fig. 5.2. The basic software functionality of a digital switching system can be divided into five basic elements, and other functions can be derived from these basic elements:
- Switching software
- Maintenance software
- Office data
- Translation data
- Feature software

Switching Software.
The most important layer of software for a digital switching system usually comprises
- Call processing software
- Switching fabric control software
- Network control software
- Periphery control software

Switch Maintenance Software.
This set of programs is used to maintain digital switch software and hardware. Examples of these types of programs include digital switch diagnostics, automatic line tests, system recovery, patching, and trunk tests.

![Figure 5.2. Classification of digital switch software](image-url)
The recovery software of a modern digital switching system is usually distributed among its subsystems, since most digital switches have a quasi distributed architecture. This strategy allows the system to recover more efficiently. In earlier SPC systems, the recovery scheme required the entire switching system to go down before it could be reinitialized to a working configuration.

A digital switching system may employ a large number of programs that are external to the operation of the digital switch, such as operational support systems (OSSs), operator position support, and advanced features (e.g., ISDN/SCP AIN). These are not shown in Fig. 5.2 as separate items, since they can be external to a digital switching system or may be implemented as a supported feature. Some parts of OSSs can even be viewed as part of digital switching system maintenance software.

The objective of Fig. 5.2 is to provide the analyst with a clear picture of the digital switch software. The objective of this chapter is to help the analyst better understand the software environment of a digital switch without getting distracted by functions that may not directly impact the reliability assessment of a class 5 digital switch. The importance of software tools such as compilers, assemblers, computer-aided software engineering tools, and methodologies that are needed to develop, produce, and maintain digital switching system software should not be ignored. They can impact the quality of software.

**Office Data.**

The generic program, as described earlier, requires information that is specific to a particular digital switch to operate properly. Digital switching systems have suffered outages due to wrong or improperly defined office data. The easiest way to visualize office data is by comparing them to your personal computer (PC). For the PC to operate properly, the OS has to know what type of color monitor the PC is equipped with, so that correct drivers are installed; the size and type of hard disk installed so that it can access it correctly; types of floppy disks/mouse; and CD ROM. Similarly, the office data of a digital switching system describe the extent of a central office (CO) to the generic program. However, the office data are much more involved and also define software parameters along with hardware equipment. Some common hardware parameters are:

- Number of NCP pairs in the CO
- Number of line controllers in the CO
- Maximum number of lines for which the CO is engineered
- Total number of line equipment in the CO
- Maximum number of trunks and types of trunks for which the CO is engineered
- Total number of trunks of each type in the CO
- Total number and types of service circuits in the CO such as ringing units, multifrequency (MF) receivers and transmitters, and dial-pulse (DP) receivers and transmitters. These are some examples of software parameters:
- Size of automatic message accounting (AMA) registers
- Number of AMA registers
- Number and types of traffic registers
- Size of buffers for various telephony functions
- Names and types of features supported

These types of parameters are digital switching system-specific and CO-specific. The parameters can literally number in the hundreds and are generated from engineering specifications of a CO.

**Translation Data.**
The translation data, also referred to as subscriber data, are subscriber-specific and are required for each subscriber. This type of data is generally generated by the telephone companies and not by the suppliers. In some cases, the suppliers may input translation data supplied by the telephone companies. However, the database and entry system for the translation data is supplied as part of the digital switching system software. Typical translation data may consist of:

- Assignment of directory number to a line equipment number
- Features subscribed to by a particular customer, such as call waiting, three-way calling, and call forwarding, etc.
- Restrictions for a particular customer, such as incoming calls only, no long-distance calls, certain calls blocked
- Three-digit translators that route the call based on the first three digits dialed
- Area-code translators that translate the call to a tandem office for 1+ call, which is followed by 10 digits
- International call translators that route the call to international gateway offices based on the country code dialed

Again, literally hundreds of translation tables are built for a CO before it can become functional. If the CO is a new installation, much of the information is provided by the traffic department of a telephone company. The data tables are generated in conjunction with the specification of a new CO. However, if the CO is a replacement for an earlier CQ then all existing data may be required to be regenerated in a different format for the new CO.

**Feature Software.**
As mentioned earlier, most features implemented in modern digital switching systems are offered through feature packages. Some of the feature packages are put in a feature group and are offered in a certain market or to a group of telephone companies. These features may be included in the base package of a generic release or, offered as an optional package. In either case, most of
the features are considered to be applications for a digital switch. They are engineered to be modular and can be added to a digital switch according to the requirements of the telephone company and associated CO. Some examples of feature packages are:
- Operator services
- Centrex feature
- ISDN basic rate
- STP extensions
- SCP database

Depending on the digital switching system, these feature packages can be extensive and large. The analyst of digital switch software should assess the extent of the feature package and its compliance with the requirements of telephone companies.

**Software Dependencies.**

Most telephony features of digital switching systems require specific office data and translation data for their operation. They depend on the generation of feature specific office data and/or translation data. These dependencies are, of course, design-specific. Similarly, the maintenance programs may require a set of specialized office data and/or translation data for testing various functionalities of a digital switching system. These relationships are shown as a software dependency in Fig. 5.2, and direct interactions of a generic program are shown as solid arrows.

**Call Models**

The concept of call models is an important one in the design of telephony systems. In its most basic form, the call model describes hardware and software actions that are necessary for connecting and disconnecting a call. Once a basic model for a particular type of call is established, features can then be designed to conform to a particular call model. A complex telephony system may invoke different call models for various types of calls.

Some elements of a basic call model is shown in Fig. 5.3. This model shows two basic states: connect and disconnect. This model by no means represents a complete call model for a digital switching system but is presented here to provide some basic concepts of call models and associated features.

**1. Connect Sequence**

The connect sequence consists of software routines that scan the line and detect request for originations. Once the line equipment informs the line scanning program that a line has gone off-hook and that this is a legitimate request for a dial tone, not a hit on the line, the off-hook detection program passes on the control to the test line program.
Figure 5.3. A basic call model

The function of the test line program is to test for the presence of false-ground, high-voltage, line cross, and other conditions that could be detrimental to the switching equipment. After successful completion of these tests, a dial tone is returned to the subscriber, signaling the customer to commence dialing. According to customer requirements, all this action needs to be completed in less than 3 seconds. The term slow dial tone is used if a switch takes more than 3 seconds to provide the dial tone due to heavy traffic conditions or hardware or software problems. Once the switch detects the start of dialing, the dial tone is removed, and the digit receiver is attached to the line equipment to receive the dialed digits. After the correct number of digits is received by the digit receiver, the switching fabric map is consulted, which tracks the status of all calls and available paths through the switching fabric. Network connect orders are then issued to establish a talking path through the switching fabric. After the completion of the path, the ringing service circuit is connected to the called party, and ringing is initiated. When the called party answers the call, the switching network map is updated and the automatic message accounting timing for billing the call is started.

2. Disconnect Sequence
The disconnect sequence is also shown in Fig. 5.3. The lines are constantly scanned for connects and disconnects. Once an on-hook or a disconnect is detected, the line is again tested for hazards and a disconnect switching network order is issued to "tear down" the call. Once this is accomplished, the switching network map is updated and the AMA or billing timer is stopped.

As mentioned earlier, the connect and disconnect scenarios mentioned are only two of the numerous sequence models that could be employed in processing a call through a digital switching system. In a typical digital switching system, a large number of call types exist, and they are all associated with various call models.
Software Linkages during a Call

The software linkages to these hardware subsystems will be discussed now. An example of possible software linkages required during a typical call is shown in Fig. 5.4. The line control programs scan the status of lines via the line modules and report the status to the network status program, which in turn works with the network control programs. The line control program also works with the line service circuit programs in providing dial tone, digit receivers, ringing circuits, etc., to the subscriber lines. The network control program orders a network connection through the switching fabric when a subscriber goes off-hook and completes the dialing of all digits for a call.

The call processing programs are usually responsible for call processing functions and interface with the feature programs, translation and office data, and automatic message accounting and maintenance programs. The maintenance program is responsible for system recovery, system diagnostics, backup, and other maintenance-related functions. All these functions are available during call processing.

Once the call processing program determines for the subscriber line the allowed features and attributes, it allows a call to be established through the switching fabric. The called subscriber may reside in the calling subscriber's digital switch or may be in another digital switch. If the called subscriber is not in the same digital switch, then an outgoing trunk is used to establish a connection to the other digital switch or tandem office.

Under this condition, the proper type of outgoing trunk is selected and assigned a proper trunk circuit for signaling and supervision. When the called subscriber answers the phone, a talking path is established through the switching network while the line and the trunks are constantly scanned for disconnect from either side. If the subscriber resides in the same digital switch, the special internal line and trunk circuits are used to complete and monitor the call. See Fig. 5.3 for a basic call model. If the called subscriber resides in the same digital switch, the call is classified as an intraoffice call; if the called subscriber resides outside the digital switch, the call is termed an interoffice call.
Figure 5.4. Software linkages required during a typical call

**Call Features**

The basic function of an end office digital switching system is to provide telephony services to its customers. In today's competitive environment, a feature-rich digital switching system has a competitive edge. Most of the basic features used in the North American market are defined in Bellcore's LSSGR requirements. These requirements are currently divided into the following categories:

- Residence and business customer features
- Private facility access and services X Attendant features
- Customer switching system features » Customer interfaces
- Coin and charge-a-call features
- Public safety features
- Miscellaneous local system features
- Interoffice features
- Call processing features
- Database services
- Data services
- System maintenance features
- Trunk, line, and special service circuit test features 1 Administrative features
- Cut-over and growth features
- Billing and comptrollers features

1. Feature Flow Diagrams
The features employed in a digital switching system are usually very complex, and flow diagrams can help one to understand their functionalities. A simplified flow diagram for one of the most commonly used subscriber features, call forwarding (CF), is shown in Fig. 5.5. This feature has three modes of operation:

**Feature Activation.**
The feature is activated when the customer goes hook and dials an activation code. The software checks for the correct validation code. If the activation code is wrong, the subscriber does not get the second dial tone. If the activation code is correct, the subscriber gets a second dial tone and is allowed to dial the call-forwarding telephone number. The call-forwarded subscriber line is rung once, and the number is recorded in the system memory for future use.

**Feature Operation.**
Now, suppose the subscriber receives a call on the line that has the CF feature activated. The system rings the called subscriber once and then forwards the call to a number previously recorded by the subscriber during feature activation.

**Feature Deactivation.**
This feature can be deactivated when the subscriber goes off-hook and dials the deactivation code. If the code is valid, the CF number is removed; otherwise, the deactivation request is ignored. Note that this was a very simplified flow diagram for a feature. The actual flow diagrams for some of the features are far more complex.

2. Feature Interaction
One of the obvious problems that can arise owing to the existence of so many features on a single digital switching system is feature interaction. This can happen even in the most advanced and best-designed digital switches. One way to minimize this problem is to conduct regression tests on the software and related hardware. This subject is discussed in greater detail in chapter 6, which addresses software reliability and quality assessment issues.
UNIT: 7: MAINTENANCE OF DIGITAL SWITCHING SYSTEMS

Introduction, Scope, Software maintenance, Interface of a typical digital switching system central office, System outage and its impact on digital switching system reliability, Impact of software patches on digital switching system maintainability, Embedded patcher concept, Growth of digital switching system central office, Generic program upgrade, A methodology for proper maintenance of digital switching system, Effect of firmware deployment on digital switching system, Firmware-software coupling, Switching system maintainability metrics, Upgrade process success rate, Number of patches applied per year, Diagnostic resolution rate, Reported critical and major faults corrected, A strategy improving software quality, Program for software process improvement, Software processes improvement, Software processes, Metrics, Defect analysis, Defect analysis.

8 Hours

TEXT BOOKS:


Introduction

After the digital switching system is installed, switch maintainability becomes an important consideration. This chapter introduces some basic information that is needed to assess the maintainability of a central office (CO).

Scope

This chapter introduces typical interfaces that are utilized in maintaining central offices both remotely and locally. Topics essential to CO maintenance such as fault reports, software patches, and the software and hardware upgrade process, including firmware, are also covered.

Software Maintenance

The software industry spends almost 80 percent of its effort in maintaining software, but not enough research has been conducted to improve software maintainability. From the digital switching point of view, digital switch maintainability can be grouped into two broad categories:

- Supplier-initiated software maintenance:
  This consists of software maintenance actions needed to update or upgrade a generic release of a digital switch. These also include applications of "patches" or software corrections that are required to correct faults in an existing generic release.
- **Software maintenance by site owners:** These are routine maintenance actions that must be performed by the owners of a digital switch to keep it operational. Examples could be routine diagnostics, updating of translation tables, and addition of lines and trunks to a digital switch.

### Interfaces of a Typical Digital Switching System Central Office

Most of the common interfaces needed for a digital switching system central office are shown in Fig. 7.1. The maintainability of a CO depends on satisfying the needs of all these and other interfaces. A group of COs is usually assigned to a switching control center (SCC), in the Bell Operating Companies environment, but local maintenance personnel are also involved in maintaining COs. The next level of maintenance is assigned to the electronic switching system assistance center (ESAC) in parallel with the maintenance engineers. Maintenance engineers are not involved with daily maintenance but oversee resolution of recurrent maintenance issues. The ESAC organization usually controls generic upgrades, patching, operational trouble reports (OTRs), and interfaces with the supplier's regional technical assistance centers (RTACs) and technical assistance centers (TACs) to solve unusual and difficult maintenance problems. Note that this is only a typical arrangement and will vary with telephone companies and switching system products. But most telephone companies support different levels of digital switch maintenance. These other departments interact with a digital switch:

![Organizational interfaces of a typical CO](image-url)

**Figure 7.1.** Organizational interfaces of a typical CO
- **Engineering support:**
  This department writes specifications for a new digital switch and engineers' additions to the existing CO. This department also interfaces with the supplier's engineering department, CO plant department, and traffic department with the objective of issuing accurate engineering specifications for a new digital switch installation or addition.

- **Billing center:**
  The billing center is responsible for processing automatic message accounting (AMA) or billing tapes from a CO to produce customer bills. Currently, billing information can also be transmitted directly to the billing center.

- **Security:**
  This department provides security services for the digital switching system to prevent unauthorized entry and fraudulent use of the telephone service.

- **Special translation support:**
  This group provides support in establishing unusual translations for COs that provide special services for large corporations with complete call routings, trunk translations, etc.

- **Trunk and line assignment:**
  This group's main function is to assign lines and trunks to a digital switch's line equipment and trunk equipment, respectively. It also maintains database of line and trunk assignments.

- **Coin bureau:**
  Usually, coin equipment is maintained by a separate department since coin telephones employ different instruments and often different operators. Special coin collection signals and special line translators are also employed. However, the department works through SCCs and ESACs to correct any coin-related problems.

- **Customer bureau:**
  This department is usually the single point of contact for telephone customers with requests for telephone connection, disconnection, reconnection, and telephone problems. It usually works through the trunk and line assignment groups and the SCCs.

- **Traffic department:**
  The main responsibility of this group is to model and study telephony traffic through a digital switch. It recommends the addition and removal of trunks in a CQ based on the dynamics of traffic patterns. The group also interfaces with the engineering support group concerning trunk estimates necessary for the installation of a new digital switch.
System Outage and Its Impact on Digital Switching System Reliability

Digital switch outages represent the most visible measure of switching system reliability and affect maintainability. Various studies have been conducted to better understand the causes of digital switch outages. Traditionally, the causes of outages have been classified into four categories:

- **Software deficiencies.**
  This includes software "bugs" that cause memory errors or program loops that can be cleared only by major initialization.

- **Hardware failure.**
  This relates to simplex and/or duplex hardware failures in the system which result in a system outage.

- **Ineffective recovery.**
  This category includes failure to detect trouble until after service has been impaired and failure to properly isolate a faulty unit due to a shortcoming of the software and/or documentation.

- **Procedural error.**
  In short, these are "cockpit" or craft errors which have caused loss of service. Examples may include inputting wrong translation data or taking incorrect action during repair, growth, and update procedures. Based on earlier studies of outage performance, an allocation of 3 minutes per year of total system downtime has been made to each of the above categories.

The most important finding in the switching system outage study was that over 40 percent of outages were caused by procedural errors directly related to digital switch maintainability issues. To reduce digital system outage, a concerted effort is required in all four categories mentioned above. However, this chapter focuses on the reduction of system outages by proper digital switch maintenance, since currently this is the highest contributing category. The next few subsections elaborate on areas that need to be studied to improve digital switching system maintainability.

**Impact of Software Patches on Digital Switching System Maintainability**

The frequency of generic releases for a large digital switching system is usually limited to a few times a year; however, some digital switching systems are beginning to deploy new releases more often. In between these releases all software corrections are incorporated via patches. Patches are a "quick fix" or program modification without recompilation of the entire generic release. In the case of real-time operational systems, it is usually difficult to install patches since the digital switching system works continuously and patches have to be applied without bringing the system down.
1. Embedded Patcher Concept

The concept of a resident patcher program for digital switches has evolved over the last 15 years or so. In first-generation digital switches, field patching was performed by hard writing encoded program instructions and data at absolute memory locations. This technique, though viable, created many problems in the operation of a digital switch. Under this hard write/read concept, mistakes were made in applying the wrong data to wrong addresses, patching incompatible generic releases, and applying patches that were out of sequence. Embedded patcher programs that operate as software maintenance programs and reside in digital switches have alleviated some of these problems.

Proper design specification of digital switching functions, coupled with exhaustive regression testing of software-hardware interfaces, could go a long way in reducing the number of patches in the field. However, the current state of digital switching software requires large numbers of patches needing excessive maintenance effort by the owners of digital switching systems.

Growth of Digital Switching System Central Offices

Most digital switching systems need to be upgraded or "grown" during their lifetimes. This process represents a major effort for maintenance organizations such as SCCs and ESACs. A digital switch may be upgraded in software or hardware, and sometimes in both. The complexity of upgrading a digital switch comes from its nonstop nature, real-time operational profile, and the complexity of software and hardware involved. The exact upgrade process for each digital switch is usually documented by the supplier, and it should be well studied to ascertain its impact on switch operation before, after, and during the upgrade process. Criteria for successful upgrades should be well documented and the results recorded after each upgrade attempt.

1. Generic Program Upgrade

The operational profile of a digital switching system requires that a minimum amount of system downtime be incurred when a new generic release is installed in an operational switch. Usually this process varies among suppliers, and a thorough analysis of this procedure is needed. The most important aspect of a generic program upgrade process is not the upgrade process itself, but how a digital switch is prepared to accept a new release. At least the following points need to be covered in the method of procedure (MOP) along with other detailed items that are specific to a digital switch and a CO:

- Time line for the entire upgrade process
- Availability of the switch during that period a Dumping of existing data tables that need to be repackaged with the new release
- Verification of old tables with new tables to ensure that all old functionalities are supported in the new release
- The synchronization of hardware availability and software upgrade if hardware upgrade is included along with software upgrade
- Establishment of software patch levels for the upgrade process a Supplier support before, during, and after the upgrade of the generic release
A Methodology for Reporting and Correction of Field Problems

In the digital switching environment, the internal and external (field) reporting of faults usually follows a similar scheme. A very simplified problem reporting system is shown in Fig. 7.2. Fault reports from various sources such as testing/first office application failures, operational (CO) failures, and failures observed during the upgrade process are sent to a fault-reporting database. This database can be used to record and assign fault report numbers, fix priorities (e.g., critical/major, and minor), and track time required to fix. The formal problem report can then be captured by fault report metrics and forwarded to the module owner for correction. Depending on the type of fault, the module owner can decide to fix the problem in the current generic program with patches or to postpone it for compiled correction in the next generic program. The fault reporting metrics can then be used to record correction history. These metrics can also be enhanced to break down the causes of failures and aid in root-cause analysis of faults.

![Figure 7.2. A simplified problem-reporting system](image)

Diagnostic Capabilities for Proper Maintenance of Digital Switching Systems

Effective diagnostic programs and well-thought-out maintenance strategies play a very important role in the proper maintenance of digital switching systems with reduced maintenance cost. Most of the COs will not stock large amounts of circuit packs because of the prohibitive cost, but will use a centralized location where all types of spares are stored and maintained. Most COs are also remotely managed via SCCs and ESACs which require that the digital switching systems maintenance programs support remote diagnostics as well as provide high-accuracy diagnostic results. In some of the remote sites, it may take hours before a maintenance crew can make any circuit pack changes. In the past, switching systems employed a large number and types of circuit packs, and diagnostic capabilities were of great importance. Although modern digital switching systems are using a smaller number of circuit packs, the importance of proper diagnostics has not diminished, since a single high-density circuit pack impacts many functionalities of a digital switch. Therefore, it is imperative in the overall evaluation of a digital switch that the diagnostic capability of a switch be considered an item of high importance.
Effect of Firmware Deployment on Digital Switching Systems

The recent trend toward distributed processing in digital switching systems has resulted in increased use of firmware. The impact of firmware on digital switching system reliability and maintainability can be substantial. Most intelligent subsystems in digital switching systems require resident nonvolatile object code for the purpose of booting or bringing the system on-line after a loss of power or a system failure. These semiconductor memory types are often referred to as firmware devices. The term firmware is often used to include the program code stored in the device.

For telecommunications applications, firmware can be defined as executable code or data which are stored in semiconductor memory on a quasi-permanent basis and require physical replacement or manual intervention with external equipment for updating. With the trend toward distributed architecture in digital switching systems, the use of microprocessor controllers embedded throughout the system has increased dramatically.

As a result, typical digital switching systems may have 20 to 30 percent of their program code embedded in firmware (some digital cross-connect systems and subscriber carrier systems have 100 percent of their program code embedded in firmware). Most present-day switches incorporate many call processing functions on the line cards, and these line cards can perform many switching functions by themselves. These line cards are capable of detecting line originations, terminations, basic translation, service circuit access control, etc. Most programs which provide these functions are firmware-based. Many vendors choose this arrangement since firmware-based programs require no backup magnetic media and provide local recovery of line service with minimal manual intervention.

While the semi permanent code storage aspect of firmware provides a necessary function, it requires physical replacement or manual intervention with external equipment for updating. The updating process may involve erasing and/or Programming equipment or special commands and actions from a host system for updating electrically erasable/programmable firmware devices. During the updating process, the switching system controllers may be required to operate in simplex (without redundancy). The updating process for firmware can have a significant impact on the operational reliability of a switching system, particularly if firmware changes are frequent.

1. Firmware-Software Coupling

The basic notion of "coupling" between firmware and software evolved slowly in the telecommunications industry. Telephone companies became aware of the importance of firmware in digital switches when the companies were required to change a large number of firmware packs upon the release of new software updates. The need to change significant numbers of firmware packs as part of generic updates has created a number of problems, including these:

- Increased simplex times for switches during the firmware update process
- Increased switch downtimes due to system faults while in simplex
mode, required initializations for firmware changes, insertion of defective firmware circuit packs, and damaged circuit packs due to electrostatic discharge (ESD)

- Increased maintenance problems due to procedural errors
- Delays in the upgrade process because of shortages of correct versions of firmware packs
- Increased incompatibility problems between firmware and operational software

A measure of coupling between firmware and software can be established as the ratio of firmware circuit packs, which are changed in conjunction with a generic or major software change, to the total number of firmware circuit packs in the system. A low ratio indicates a "loose" coupling between firmware and software, and a high ratio indicates "tight" coupling. An historical study of the frequency of changes and the associated ratios can be used to assess the degree of coupling between firmware and software. Industry requirements [5] seek decoupling between firmware and software as far as possible. They state, "To reduce the frequency of firmware changes in the field, firmware should be decoupled as far as possible from other software. The extent of coupling should be documented. A list of coupled firmware and the firmware's function should be provided.

Switching System Maintainability Metrics

A metric-based methodology for assessing maintainability of digital switching systems is presented next. Figure 7.3 shows a set of sample metrics with arbitrary scores.

1. Upgrade Process Success Rate

The first metric shown in Fig. 7.3 assesses the upgrade process. As an example, if the upgrade process for a digital switching system is successful only 40 percent of the time, a score of 0 is given, a score of 5 is given for success rates over 90 percent. Note that the scores shown here represent a sample guideline. A thorough understanding of the upgrade process for a particular digital switching system is necessary before one can generate scores as shown in Fig. 7.3. Important questions as to what constitutes a successful upgrade process, the impact of customer cooperation during the upgrade process, and the time required for the upgrade process need to be considered in measuring the success of an upgrade process.
2. Number of Patches Applied per Year

As mentioned earlier, a large number of patches impact digital switching system reliability and maintainability. Therefore, the number of patches applied to a system per year is a good indication of system maintainability. An arbitrary sample-scoring example is shown in Fig. 7.3. Some important questions need to be addressed. Is a patch generated for every software-correcting fault, or are a number of faults corrected with each patch? Are the CO personnel involved in screening and applying patches to their switches, or does the supplier do it automatically? These types of questions will be helpful in generating a comprehensive set of metrics for patching. Figure 7.3 shows a situation in which a single fault generates a single patch and the CO personnel are involved in patching the switch. The example shows that if the number of patches is greater than 600, then a score of 0 is entered for that particular switch; if there are 100 patches or fewer, then a score of 5 is entered; and so on. Note that these numbers are arbitrary and are not intended to replace any existing requirements.

3. Diagnostic Resolution Rate

In a modern digital switching system, it is extremely important that the diagnostic programs correctly determine the name and location of a faulty unit, down to the circuit pack level. Therefore, diagnostic programs should have good resolution rates, and this capability becomes more important when the CO is not staffed, the diagnostic is conducted remotely, and a technician is dispatched with correct circuit packs. Repair times that were used in Markov models will depend on the accuracy of diagnostic programs. A less accurate diagnostic program will require additional diagnostic runs for identifying defective circuit packs, thus increasing repair times. An arbitrary example is shown in Fig. 7.3, which assigns a value of 0 if the diagnostic program can pinpoint defective circuit packs with an accuracy with 45 percent or less and 5 if the diagnostic accuracy is over 95 percent. Again, this is just an arbitrary example. Much
detailed knowledge of the digital switch needs to be acquired before this metric can be accurately generated and used.

4. Reported Critical and Major Faults Corrected

Clearly fault reporting and fault correction play a very important role in maintaining a digital switch. There are some strong industry guidelines in this area. For example, refer to Bellcore's Reliability and Quality Measurements for Telecommunications Systems [6], which requires that all critical faults be fixed within 24 hours and all major faults in 30 days or fewer. The example shown in Fig. 7.3 establishes a score of 0 if critical faults were not corrected in 6 days or fewer and 5 if the critical faults were corrected within 1 day. Similarly for major faults a 0 score is entered if the major faults are not corrected in 55 days or more and a score of 5 for 30 days or fewer.

A Strategy for Improving Software Quality

A strategy for improving digital switching system software quality is shown in Fig. 7.4. It is based on a process metric, defect analysis, and a continuous-improvement program. The importance of a good measurement plan cannot be overemphasized in the arena of software process improvement. A good example of software metrics is Bellcore's In-Process Quality Metrics and the field metric is Bellcore's Reliability and Quality Measurements for Telecommunications Systems [6]. These two measurement systems are used extensively in the United States by the telecommunications industry and are now being implemented in Europe. However, the methodology described here is independent of any measurement system, but depends on measurement systems that control software processes and field failures.

Let us consider this methodology in detail. Figure 7.4 shows five distinct processes. We begin at the top.

1. Program for Software Process Improvement

This represents the heart of the system. Software processes for the digital switching system are usually large, complex, and multilocational. These processes must be formalized (i.e., documented) and base lined by putting them under a configuration management system. This will allow tracking of any changes to the process and help the process administrator to better understand the impact. A process change does not always improve a process, but a continuous improvement program (CIP) always does. The CIP strategy can vary greatly for different processes, projects, or products. The suggested strategy in this section assumes that the processes can be instrumented. The inputs to the improvement process are the thresholds established for different metrics. These thresholds are used to observe the impact of changes on all processes. A set of new thresholds is fed to the metric system when the process is changed, enforcing tighter thresholds when required. This feedback process is implemented continuously to improve the quality of the software process.
2. Software Processes

The software processes shown in Fig. 7.4 relate to the software metrics discussed below. These include

1. Software development process
2. Software testing process
3. Software deployment process
4. Software maintenance process

- **Software development metrics:**
  These metrics define measurements related to the life-cycle phases of a software development process. Typical life-cycle development phases include the software requirements process, high-level design, low-level design, and software coding. These metrics measure the effectiveness of these processes.

- **Software testing metrics:**
  Software testing metrics measure the effectiveness of the software testing process. Typical measurements include the number of test cases planned versus the number of cases executed, testing effectiveness, coverage, etc., applicable to all test life cycles. For digital switching systems the test life cycles can include unit testing, integration testing, feature testing, regression testing, and system testing.

- **Software deployment metrics:**
  These metrics are collected during the deployment of a release in the CO. The most effective metrics in this category are the application success metrics and the number of patches applied at
the time of deployment. On occasion, during the application of a new release to a digital switch, the upgrade process may fail; this type of information needs to be collected to improve the upgrade process. The number of patches applied during the deployment process also must be minimized.

- **Software maintenance metrics:**
These metrics are collected once the release is installed. The most important metrics are the number of software patches applied, number of defective patches found, and effectiveness of diagnostic programs.

- **Customer satisfaction metrics:**
These metrics are collected from the customers of the digital switching systems. Examples are billing errors, cutoffs during conversation, slow dial tone, and other digital switch related problems.

4. Defect Analysis

The defect analysis is a base process for this strategy. It drives the continuous improvement program. There are some well-defined methodologies for defect analysis [8], and the objective here is not to define a new one. This strategy can function with any type of defect analysis methodology. After a release becomes functional in the field, it will eventually experience failures. Field failures are usually classified according to severity. Field failures that cause system outages are classified as critical, followed by less severe ones as major or minor.

A causal analysis of all failures especially critical and major ones is conducted first. After the analysis, the causes of failure are generally categorized as software, hardware, or procedural. In the next step, each failing category is expanded into subcategories. Since the strategy described here is for software processes, the hardware and procedural categories are not covered here. However, this strategy can be applied to hardware faults if the hardware development process can be mapped into life-cycle phases. Some procedural problems due to software procedures can be included in the sub categorization process.

**Analysis Example.**

Let us apply causal analysis to the hypothetical digital switching system developed for this book. Based on the software architecture of this digital switch, a software problem may have originated from

- Central processor software
- Network processor software
- Interface controller software
- Peripheral software (lines, trunks, etc.)

The next step is to identify the software subsystem that may have caused the problem:

- Operating system
- Database system
- Recovery software
- Switching software
- Application software (features, etc.)

Depending on the digital switching architecture, this sub categorization process can be long and complicated. However, once the classification of the field failures is completed and the failing software module is identified, a search is conducted to identify why this module failed and in which life-cycle phase. Usually, a patch is issued to correct the problem; however, the objective of this strategy is to fix the process so that this type of fault will not recur.

**Field Trouble Report.**

To better understand this strategy let us analyze the following trouble report:

- **Name of digital switch:** Digital switching system type, class 5
- **Location:** Any Town, United States
- **Type of failure:** Software
- **Duration of failure:** 10 minutes
- **Impact:** Lost all calls
- **Priority:** Critical

**Explanation:** During heavy traffic period on Monday January 1, at 9 a.m., the digital switching system lost all call processing. An automatic recovery process initialized the system. The system recovered in about 10 minutes. Yesterday night, some patches were added to correct some feature X problems. Feature X was deactivated as a precaution.

**Typical Analysis.**

This trouble report indicates a problem in feature X. Analysis of the patch and any printout during the initialization process points to the application software of the central processor. The failing module can then be identified. Further analysis of the defective module could identify the life-cycle phase by the following possibilities:

- **Requirements phase** (The requirement was incorrectly captured, causing the design and code to be defective.)
- **Design phase** (Captured requirement was correct, but the translation of requirements to design was wrong, causing defective code.)
- **Code phase** (Captured requirement was correct, translation of requirements to design was correct, but the written code was defective.)
- **Test phase** (Captured requirement was correct, translation of requirements to design was correct, written code was correct, but the testing phase did not detect the problem.)

Assume, for this particular case, that causal analysis identifies the failure as being in the test phase. Looking at the result of the causal analysis and the problem report, we see that the problem seems to be "traffic-sensitive," indicating lack of testing with high-traffic load. A good test methodology for digital switching system software should check each feature under a realistic traffic condition before it is released. All metrics that measure the effectiveness of testing should include testing with high traffic as an input data point. The testing effectiveness threshold can now be made tighter to improve testing effectiveness. All documents related to feature testing will be changed to show enhanced traffic test requirements.
This completes the corrective feedback loop for this trouble report. Similar corrective loops need to be implemented for all trouble reports requiring process correction and improvement. This strategy enhances the software processes continuously.
UNIT: 8: GENERIC OF DIGITAL SWITCHING SYSTEMS


6 Hours

TEXT BOOKS:


Introduction

Different hardware and software components of the digital switch were described, and the system was analyzed. This chapter extends the functionalities of the hypothetical digital switch to elucidate the "overall" hardware and software architectures of a typical class 5 switch. It is important for the reader to comprehend the functionalities of a digital switching system at various levels of the hardware and software architecture.

Scope

This chapter creates a generic digital switching system and its hardware and software architectures. Typical calls through the switch are traced to reveal the functionalities of an operational digital switching system. A system recovery strategy for the hypothetical digital switch and essential items in a digital switch analysis report also are covered.

Hardware Architecture

The hardware architecture of a hypothetical digital switch is shown in Fig. 8.1. This hypothetical digital switching system is based on quasi-distributed control architecture. Note that the architecture of a working digital switching system is very complex with many subsystems. It can be covered only in a technical specification of a product, and not in a textbook of this type.

1. Central Processor

A typical digital switching system usually employs a central processor (CP) as the primary processor, and it is always duplicated. Its function is to provide system wide control of the switching system. It usually supports secondary processors, shown in Fig. 8.1, as network control processors (NCPs). The CP usually controls high-level functions of the switch and supports operation, administration, and maintenance (OA&M) functions. When critical faults occur in the switching system, usually the CP controls the system recovery process. The CP also
maintains subscriber and office data. The billing system for the switch is usually supported by the CP.

Figure 8.1. Generic switch hardware architecture

2. Network Control Processors

The network control processors are the secondary processors. Usually, their purpose is to provide call processing functions and assist in setting up a path through the switching fabric. Since most digital switching systems switch calls via a time-space-time (TST) path for call connection, this hypothetical switch is assumed to do the same. The secondary processors are usually duplicated; and depending on the desired size of the class 5 central office, a digital switch may employ a number of such processors. These processors usually interface with the interface controllers (ICs) and provide medium-level call processing support.

Generally, the secondary processors like the NCPs are associated with particular ICs. Usually a NCP keeps track of all calls that are controlled by its IC and associated paths assigned for such calls. Usually the NCP interfaces with the CP or other NCPs to update call paths on a regular basis, so that other NCPs can get a "global" view of all calls.

3. Interface Controllers

Most digital switching systems employ a processor-based controller that acts as a concentrator of all incoming lines or trunks. These controllers use time multiplexed output to the NCPs and
provide time-switching (T switch) functions. The number of such controllers in a switch depends on the engineered size of the central office (CO).

4. Interface Modules
Different types of modules are employed in a digital switching system. Most common are the line modules (LMs) and the trunk modules (TMs). Depending on the design objectives of a digital switching system, a line module may terminate a single line or scores of lines. Most digital switching systems employ smart line cards that are processor-driven and can perform most basic call-processing functions, such as line scanning, digit collection, and call supervision. The trunk modules interface different types of trunks to the digital switching system. Most digital switching systems employ special modules to connect ISDN and other digital services to the switch. They also employ specialized module interfaces to provide enhanced services such as AIN and packet switching. The number and types of modules deployed in a digital switching system are dependent on the engineering requirements of a class 5 switch.

5. Switching Fabric
Most digital switching systems employ at least one space or S switch. The concentrators in the ICs are usually time or T switches. The S switch is usually accessible to all NCPs. In some cases, the switching fabric is partitioned for use by different NCPs. In either case, a dynamic image of the entire network usage/idle status for the switching fabric is maintained by the CP of the digital switching system.

Software Architecture
This section covers a typical organization of digital switching system software.

1. System-Level Software
Most digital switching systems employ some system-level software. Software at this level is normally a multitasking operating system (OS) and is based on a duplex mainframe computer. The function of the OS is to control each application system (AS) deployed by the digital switching system. Basic software systems for a digital switch can be classified as

- Maintenance software
- Call processing software
- Database software

2. Maintenance Software
For details on digital switching system maintenance and associated software functions.

3. Call Processing Software
Based on the architecture of the digital switching system, the call processing program can be divided into three levels:
- High level includes call processing functions that require support from a central processing unit or a central database. Examples are special feature routing/specialized billing, office data (OD), and translation data.
- Medium-level functions usually reside in the network processing units. Software supports routine call processing functions such as establishing a path through the switching fabric, verifying a subscriber, and maintaining a call map. These are referred to as network software in Fig. 8.2.

- Depending on the architecture of the digital switching system, many low-level functions are shared between the interface controllers and the line modules. These functions may be line scanning, digit collection, attaching service circuits, or call supervision. These are referred to as controller or peripheral software in Fig. 8.2.

4. Database Software
The contents of the database software can vary greatly between digital switching systems, and within a switching system product, a switch may be engineered to provide different functions. Most digital switching systems employ a database system to record office information, system recovery parameters, system diagnostics, and billing information.

![A generic switch software architecture](image)

**Figure 8.2.** A generic switch software architecture

**Recovery Strategy**
The following is a possible recovery strategy for the hypothetical digital switching system developed for this book. An effective recovery strategy for this digital switch could be based on
a three-level scheme. These schemes can be based on the three control levels developed for this
digital switch:

**Level 1 Initialization (INIT 1)**
This is considered the lowest level of initialization for the digital switch. This level of recovery
initializes all components that function at level 1 control (see chapter 2). It is controlled and
directed by the interface controllers which control line modules, trunk modules, and peripheral
modules (PMs).
This INIT 1 recovery could be directed specifically to initialize defined line modules, defined
trunk modules, and defined peripherals. This recovery strategy selectively initializes lines,
trunks, or peripherals based on the severity of the problem. This recovery can be called local
recovery, since it can initialize peripherals locally without impacting the operation of the entire
digital switching system.

**EXAMPLE**
After a thunderstorm, a technician in a digital CO found 17 LMs, 5 TMs, and 2 PMs hung up
(nonoperational). This was causing a partial outage and other operational difficulties. In this type
of situation, it is appropriate for the technician to conduct a direct local recovery of these
modules. Manual restoral would take too long. This type of recovery will have minimal impact
on the rest of the digital switching system and will bring the digital switching system to normal
operation by the low-level initialization of the digital switch.

**Level 2 Initialization (INIT 2).**
This type of recovery can be considered as a middle-level initialization for all components that
function at level 2 control. This INIT 2 recovery could be directed specifically for initializing a
specified network control processor and a group of network control processors. Because of the
distributed architecture of this hypothetical digital switching system, each NCP controls a
number of ICs. The ICs in turn control the line, trunk, and peripheral modules. If a NCP breaks
down and the backup NCP cannot switch to active mode cleanly or if a duplex failure of a NCP
pair occurs, then the operation of all ICs connected to the NCPs will be impacted. Under this
condition, two types of recovery strategies need to be considered. If the problem is due to a
NCP's switching from active mode to standby mode and the "switch" is not "clean," then the
connected ICs may help to stabilize connections by running an INIT 1 initialization on the lines,
trunks, and peripherals. If that does not help, then an INIT 2 needs to be run to initialize the NCP
and associated ICs with connected LMs, TMs, and PMs. If the problem is due not to processor
switching, but to a hard duplex failure in the NCP pair, then an INIT 2 needs to be run
immediately. This will naturally impact all the connected ICs and associated LMs, TMs, and
PMs. A multiple-NCP strategy will require initialization of a number of NCPs. Initialization of
all NCPs would require a level 3 initialization.

**EXAMPLE**
The maintenance personnel tried to switch a NCP with its redundant side after the diagnostics for
the NCP failed. The NCP switch was not successful, and the digital switch lost all calls
controlled by the NCP. A situation like this requires an INIT 2 initialization. This is considered a partial outage.

**Level 3 Initialization (INIT 3)**

This is the highest level of initialization for the digital switch. This level of initialization functions at level 3 control. This INIT 3 recovery could be directed specifically for initializing the central processor (CP) and all network control processors. This is the highest level of initialization, and it is run when the redundant CPs fail or the CP switch is not successful and the digital switching system cannot fully function with defective CPs. Under this initialization scheme, the recovery program tries to identify the problem with the last known good CP. It also seeks a "minimum" configuration for it to function. Since it cannot function fully, it will function with a reduced number of NCPs or no NCP at all, depending on the severity of the problem. Lower load or no load on the system will allow the CPs to be diagnosed effectively. Once the CP is fixed, the system will then run the INIT 2 process to synchronize all NCPs and bring them up on-line. This level of initialization will cause a total system outage.

**EXAMPLE**

A digital switching system starts experiencing slow dial tone, and after a time it runs an automatic INIT 2 initialization. This clears the slow-dial-tone problem, but the problem returns after a few minutes. The digital switch then starts taking repeated INIT 2's. At this stage, the technician initiates an INIT 3, which clears the problem. This type of condition usually occurs because of software corruption in the CP, and an initialization normally clears it. A thorough root-cause analysis of this type of outage needs to be conducted and the robustness of the system improved.

**Manual Recovery**

When repeated use of INIT 3 does not recover the system, manual recovery of the digital switch becomes essential. Under manual recovery, the generic program with the last known good office data and selected subscriber data is loaded in the digital switch. Then manual diagnostics or specialized diagnostics are used to recover the digital switch. This type of manual recovery scheme is digital switch-specific, but the basic idea is as follows:

- Bring up the system with manual effort since automatic runs of INIT 1, INIT 2 and INIT 3 failed to bring the system back on-line.
- The current generic program and data may be corrupted; the system is updated with last known good generic program and data.
- Special diagnostic programs and techniques are needed to identify the Problem.

**A Simple Call through a Digital Switching System**

A flowchart for a typical call through a typical digital switching system is shown in Fig. 8.3. Most digital switching systems follow a similar scheme. However, note that not all digital switching systems may follow exactly the call connection sequence shown in the flowchart, but these high-level functionalities are usually covered. Details of different types of calls are given in
chapter, and the software linkages required during a call are covered in chapter 5. The basic steps necessary to complete a simple call are as follows:

1. Detect off-hook condition.
2. Identify customer's line.
3. Test customer's line.
4. Provide dial tone to customer.
5. Provide digits analysis of dialed number.
6. Establish a path between the calling customer and the called customer.
7. Ring the called customer.
8. Detect answer and establish cut-through path.
9. Supervise both lines for disconnect.
10. Detect on-hook condition and disconnect.
Figure 8.3. A simple call flowchart
Figure 8.4. Calls within the same interface controller

**Line-to-Line Intra-IC Call.**
Customer A calls customer B within the same interface controller (1C). See Fig. 8.4a.
When customer A goes off-hook to call customer B, the call origination request is detected by the line module. It sends a message to the interface controller which in turn sends a message to the network control processor. The NCP validates customer A's line. The interface controller attaches a digit receiver to the line and provides a dial tone to customer A. After the customer dials the first digit, the LM removes the dial tone from customer A's receiver. The dialed digits are then collected and sent to the central processor for digit analysis. If the dialed number is valid, the NCP assigns time slots for a call connection path between customer A and customer B. If the dialed number is incorrect, for instance, has a wrong prefix, is a partial dial, etc., an announcement or a tone is given to customer A. Customer B's line is checked for busy/idle status, and a power ringing is applied to customer B's line. An audible ringing is simultaneously applied to customer A's line. When customer B answers, a cut-through path through the switching fabric is provided via previously assigned time slots. The first leg of the call from customer A uses a T switch of the interface controller, the second leg uses an S switch through the switching fabric, and the third leg to customer B uses another T switch through the interface controller. This is a typical TST connection scenario that most digital switching systems use. If either customer disconnects, the LM detects the on-hook condition and idles the connection.
**Line-to-Trunk Intra-IC OGT Call.**
Customer A calls customer B, who is served by another central office (CO), and the outgoing trunk selected lies in the same interface controller (IC). See Fig. 8.4b. When customer A goes off-hook to call customer B, the call origination request is detected by the line module. It sends a message to the interface controller which in turn sends a message to the network control processor. The NCP validates customer A's line. The interface controller attaches a digit receiver to the line, and a dial tone is provided to customer A. After the first digit is dialed, the dial tone is removed from customer A's receiver. The dialed digits are then collected and sent to the central processor for digit analysis. If the dialed number is valid, the NCP assigns time slots for a path for the call between customer A and an outgoing trunk for customer B's CO or a tandem office. If the dialed number is incorrect, for instance, has a wrong prefix, an announcement or a tone is given to customer A. The terminating central office checks customer B's line for busy/idle status and applies a power ringing to customer B's line. An audible ringing is simultaneously applied to customer A's line. When customer B answers, a cut-through path through the switching fabric is provided via previously assigned time slots. As in line-to-line calls, each CO uses a TST connection. If either customer disconnects, the LM of either CO detects the on-hook condition and idles the connection. Call supervision is provided by the originating CO.

![Diagram of Line-to-Line Intra-IC Call](image1.png)

**Figure 8.5.** Calls between different interface controllers

**Line-to-Line Intcr-IC Call.**
Customer A calls customer B, who is located in another interface controller (IC). See Fig. 8.5a. This is the same as a line-to-line intra-IC call, except a path through IC-X and IC-Y is
established for the call. The coordination between the associated NCPs (that is/ NCP-X for IC-X and NCP-Y for IC-Y) is provided by the central processor.

**Line-to-Trunk Inter-IC Call.**
Customer A calls customer B, who is located in another central office, and a different interface controller is selected. See Fig. 8.5b. This is the same as a line-to-trunk intra-IC OGT call, except a path through IC-X and IC-Y is established. The coordination between the associated NCPs (NCP-X for IC-X and NCP-Y for IC-Y) is provided by the central processor.

**Trunk-to-Line Intra-IC IGT Call.**
Customer A is called by customer B, who is served by another central office, and the incoming trunk selected lies in the same interface controller. See Fig. 8.6a.

![Figure 8.6. Incoming calls to interface controllers](image)

The CO for customer B homes into customer A's CO directly or through a tandem office. It connects to customer A's CO via an incoming trunk (IGT). If the trunk and customer A's line are in the same interface controller, a path is established through the switching fabric to the line module of customer A. The associated NCP performs all time-slot assignments for the IGT and customer A's line. Line A is validated, and its idle/busy status is checked. A power ringing to customer A's line is applied by the IC, and an audible ringing is simultaneously transmitted to customer B's line via the IGT. When customer A answers, a cut through path through the switching fabric is provided via previously assigned time slots. As in line-to-line calls, each CO
uses a TST connection. If either customer disconnects, the LM of either CO detects the on-hook condition and idles the connection. Call supervision is provided by the originating CO.

**Trunk-to-Line Inter-IC IGT Call.**
Customer A is called by customer B, who is served by another central office, and the incoming trunk selected lies in a different interface controller. See Fig. 8.6b. This is the same as a line-to-trunk intra-IC IGT call, except a path through IC-X and IC-Y is established. The coordination between the associated NCPs (NCP-X for IC-X and NCP-Y for IC-Y) is provided by the central processor.

**8.7. Some Common Characteristics of Digital Switching Systems**
Most commercial digital switching systems in the North American network exhibit some common characteristics. They are described here at a high level and do not pertain to a particular switch. Chapter 10 provides some high level details on some major digital switching systems that are currently deployed in North America.

- **Dual capability.** Most digital switching systems covered, which are primarily class 5, can also have tandem/toll or class 4 capabilities.
- **Termination capability.** Most of the large digital switching systems can terminate approximately 100,000 lines or 60,000 trunks.
- **Traffic capacity.** In a distributed environment, this depends on the digital switch configuration, and it can go as high as 2,000,000 busy hour call attempts (BHCAs).
- **Architecture—hardware.** Most digital switching systems have a quasi-distributed hardware architecture (see chapter 2 for definitions), since they all maintain control of the switching functions through an intermediate processor. All digital switching systems employ multiple processor subsystems.
- **Architecture—software.** Most digital switching systems maintain a modular software design, sometimes through layering or through functionalities. They have operating systems under which application systems function. They all support database systems for office records, subscriber records, administration records, etc. They all have maintenance subsystems that support diagnostic and switch maintenance processes. They also support billing systems for subscribers such as the automatic messaging system.
- **Switching fabric.** Most digital switching systems utilize time-space-time (TST) mode for switching calls.
- **Remote operation.** Most digital switching systems have remote switching modules (RSMs) to support switching functions in a remote location. And most remote switching systems have standalone capabilities, so if the main switching system (host) goes down, the remote units can still switch local calls.

- **Advanced feature support.** Most digital switching systems can support advanced features such as ISDN, STP, SCf and AIN.

The telecommunications market is now demanding a marriage between telephony and cable television applications. This would change the nature of class 5 COs and would require
broadband switching. The use of Internet around the world is placing very high demand on class 5 CO provisioning requirements. Many Internet users now connect to their Internet providers through class 5 COs and keep the connection up for long periods. Most COs were not designed for such use. New types of interfaces may be required to identify such calls and route them through designated COs equipped to handle high holding times. The cost of provisioning COs will rise since most of the cost associated with equipping a class 5 digital switching system comes from customer interfaces such as line modules, trunk modules, and service circuits. The integration of voice, data, and full-motion video as required by the Internet and other services will need to be switched through a class 5 digital switching system. The use of ATM and optical links using SONET will dominate the switching markets of the future.

**Analysis Report**
The analysis report of a digital switching should at least contain the following sections.

1. **System Description**
   This section gives a high-level description of the digital switch being analyzed, with emphasis on:
   - **System overview**: Describe system-level functional blocks of the digital switch.
   - **Capacity**: Cover busy-hour call attempts of the digital switch for desired configurations.
   - **Hardware description**: Give a detailed description of all important hardware components of the digital switch required for desired configuration of equipment.
   - **Software description**: Describe the main software architecture of the digital switch with all major software components identified.
   - **Call processing**: Describe the flow of different types of calls through the digital switch.
   - **Features list**: Describe all base features (included with generic) and optional features that need to be obtained separately.
   - **System recovery strategy**: Describe different levels of system initialization and typical times for system recovery for each level of initialization.

2. **Operation, Administration, and Maintenance**
   This section gives a brief description of all maintenance features of a digital switch, with emphasis on:
   - **Database management**: Describe all databases that need to be managed, e.g., office database, translation database, and billing database.
   - **OSS interfaces**: Describe all types of operational support system interfaces.

3. **Reliability Analysis**
   This section is the most important, and it gives a brief description of the reliability models of the digital switch and includes overall reliability findings covering:
   - **Component failure rates**: Describe the component failure rates for different circuit packs used in the digital switch.
   - **System reliability**: Describe the results of hardware modeling of various subsystems of the digital switch.
- **Software reliability analysis**: Describe the results of the software analysis of the digital switching system software.

4. **Product Support**

This section describes the organizational structure and commitment of the organization to support the digital switching system after it is sold.

- **Technical assistance**: Describe different levels of technical support that the digital switching supplier provides and the escalation process and time limits within which the supplier will correct the fault.

- **Documentation**: List all documents that will be supplied to maintain the digital switching system and how often it will be updated.

- **Fault reporting system**: Describe a fault-reporting system that tracks all faults discovered by the operator of the digital switching system.

- **Training**: List all training courses available for telephone company personnel who will use and maintain the digital switching system.