Advanced Topics in Communications II (ELCN 456)

© Samy S. Soliman

EECE Department - Cairo University, Egypt
Zewail City - University of Science and Technology, Egypt

Email: samy.soliman@cu.edu.eg
Website: http://scholar.cu.edu.eg/samysoliman

Credit Hours System

Transmission Systems

Transmission Impairments

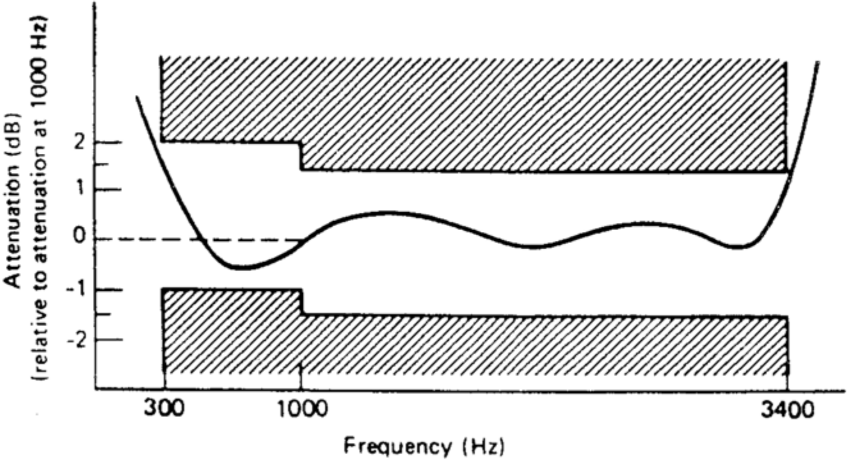
Transmission Impairments

- The basic building block for transmission is the telephone channel or voice channel.
- Voice channel implies spectral occupancy
- There are three basic impairments regarding the voice channel
  - **Attenuation distortion**
  - **Phase distortion**
  - Noise
- Additionally, there are
  - Echo
  - Singing
  - Level

1- Attenuation Distortion

- Signal over a voice channel suffers from distortion
  Output signal is not an exact replica of the input
- One form of distortion is attenuation distortion
  - Imperfect amplitude-frequency response
  - Can be avoided if all frequencies within the bandpass have exactly same loss (or gain)
  - In reality, some frequencies are attenuated more than others
  - For example, on loaded wire-pair systems, higher frequencies are attenuated more

1- Attenuation Distortion

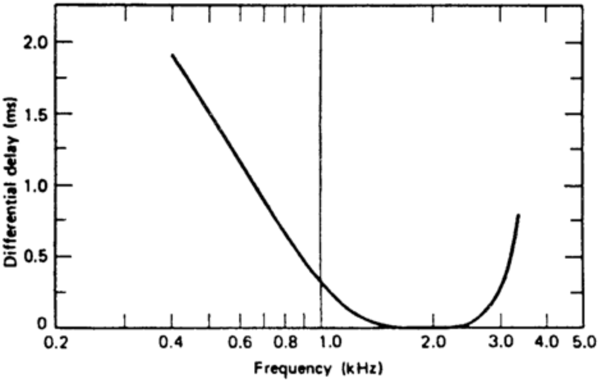


2- Phase Distortion

- Non-linear phase shift
- **Delay:** finite time a signal takes to pass the total extension of a voice channel or any network
- Propagation time is different for different frequencies
- Wavefront of one frequency arriving before the wavefront of another in the passband
- Modulated signal will not be distorted if the phase shift changes uniformly with frequency
- If the phase shift is nonlinear with respect to frequency, the output signal is distorted compared to the input

2- Phase Distortion

- Velocity of propagation varies with frequency because of the electrical characteristics associated with the network
- In a voice channel, velocity of propagation increases toward band center and decreases toward band edge



2- Phase Distortion: EED

- If the phase-frequency relationship over a band is not linear, distortion will occur in the transmitted signal
- This phase distortion is often measured by **envelope delay distortion (EDD)**, which occurs when the rate of change of phase shift with frequency over the necessary BW is not constant
- Mathematically, envelope delay is the derivative of the phase shift with respect to frequency
- EDD equals the maximum difference in the derivative over any frequency interval
- EDD is always a difference between the envelope delay at one frequency and that at another frequency of interest in the band.

Voice vs Data

EDD has little effect on speech, however, for data transmission, it is a bottleneck for data rate.

3- Noise

- Undesired signals in the communication circuit
- Noise reduction is probably the most important single consideration in communication transmission
- Major limiting factor in system performance
- Noise is broken down into four categories:
  - Thermal noise
  - Intermodulation noise
  - Crosstalk
  - Impulse noise

3.1- Thermal Noise

- Occurs in all media and communication equipment, including passive devices (devices that do not produce energy, e.g. resistors)
- Occurs due to random electron motion and is characterized by a uniform distribution of energy over the frequency spectrum
- The average of this energy distribution is called **white noise**
- Every equipment element as well as transmission medium contributes thermal noise if the temperature of that element or medium is above absolute zero
- Sets the lower limit of sensitivity of a receiving system

- Directly proportional to bandwidth and temperature. Thus, the amount of thermal noise to be found in 1 Hz of bandwidth is

$$P_n = k \times T \quad \mathrm{W/Hz}$$

- At room temperature,

$$\begin{aligned} P_n &= 4 \times 10^{-21} \ \mathrm{W/Hz} \\ &= -204 \ \mathrm{dB/Hz} \\ &= -174 \ \mathrm{dBm/Hz} \end{aligned}$$

- For a band-limited system (i.e., a system with a specific bandwidth)

$$P_n = kTB \quad \text{W}$$

- For a system with a noise bandwidth, B, measured in hertz and whose noise temperature is T we obtain

$$P_n = -228.6\ \text{dB} + 10\log_{10} T + 10\log_{10} B \quad \text{W}$$

3.2- Intermodulation Noise

- Common in digital communication systems
- Signals from two independent channels inter-modulate each other to form a product that falls into a separate band of frequencies
- Symptom: background noise
- Sources:
    - Non-linear characteristics of electronic circuits result in products of signals components.
    - Inter-modulated signals have spectral components at higher frequency bands
    - These bands may be reserved for other useful signals

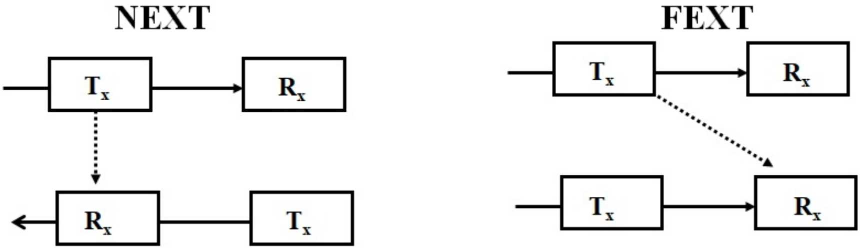
3.2- Intermodulation Noise

- Mixing possibilities when passing F_1 and F_2 through a non-linear device
  - Second-order products: $F_1 \pm F_2$
  - Third-order products: $2F_1 \pm F_2$, $F_1 \pm 2F_2$
  - Forth-order products: $2F_1 \pm 2F_2$, $F_1 \pm 3F_2$, $\cdots$
- The coefficients indicate the first, second, or third harmonics
- IM noise results from either a non-linearity or a malfunction that has the effect of non-linearity

3.3- Crosstalk

- Unwanted coupling between signal paths.
- Three causes:
  - Electrical coupling between transmission media, such as between wire pairs
  - Poor control of frequency response (defective or poor filter design)
  - Non-linear performance in analog (FDM) multiplex systems
- There are two types of crosstalk:
  - **NEXT** is more troublesome, when transmitters and receivers are close. The signal in the Tx line is strong while it is weak in the Rx line. Twisting wire pairs reduces the NEXT
  - **FEXT** is significant when transmitting on multiple pairs in the same direction in the same time, e.g. Ethernet cables

3.3- Crosstalk



- Near end crosstalk is the greatest impairment
- Received crosstalk varies with
  - The volume of the disturbing talker
  - The loss from the disturbing talker to the point of crosstalk
  - The coupling loss between the two circuits under consideration
  - The loss from the point of crosstalk to the listener

3.4- Impulsive Noise

- Noncontinuous, irregular pulses or noise spikes of short duration, broad spectral density, relatively high amplitude (high energy)
- Symptoms: sharp sound clicks
- **Internal sources:** relay contacts, poor wrapped or poor soldered twisted pairs
- **External sources:** atmospheric static voltage, electric machines, microwave interferences

Voice vs Data

- Impulse noise degrades telephony only marginally
- Can seriously degrade data error performance
- 1 ms impulse destroys 64 bits of 64 Kbps bit rate

4- Echo

Level considerations

SNR: Voice vs Data
Measuring

- Echo is the return of a talker's voice
- It is most annoying to the talker himself/herself
- It can also be an annoyance to the listener
- It is a reflection of the voice signal caused by an impedance mismatch in the balance circuit

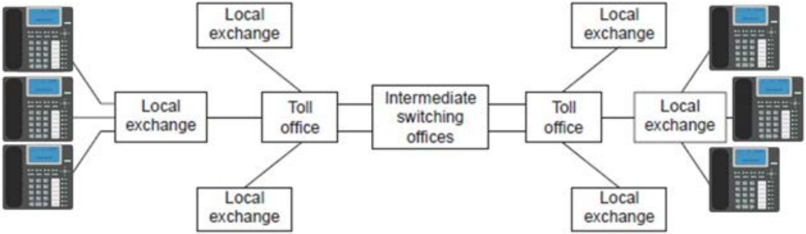
5- Singing

- Excessive echo
- Singing is the sustained oscillations due to positive feedback in amplifying circuits
- Circuits that sing overload multiplex equipment particularly FDM equipment

Transmission Systems

Transmission Arrangement

Transmission System Structure

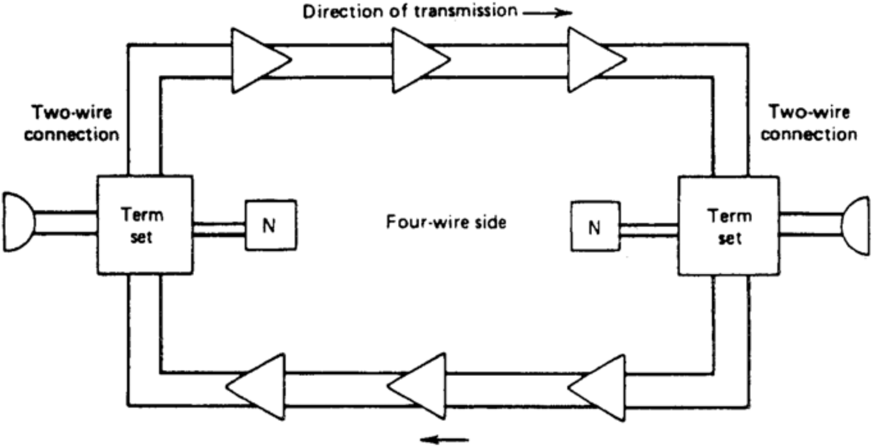


The simple arrangement of the two wire and four wire transmission.

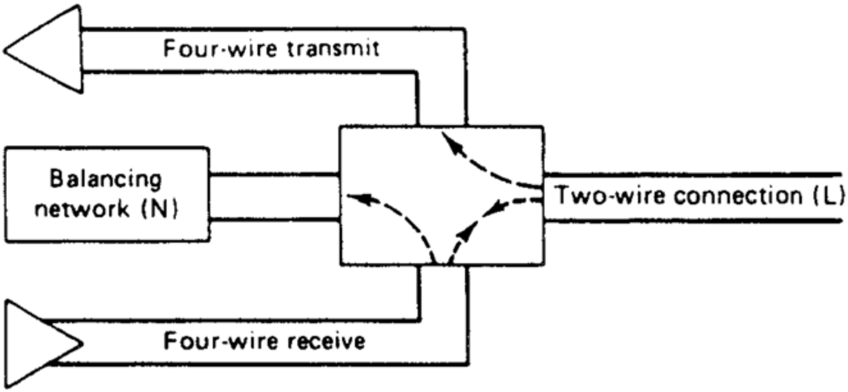
2-Wire and 4-Wire Transmission

- Transmission modes: Simplex, Half-Duplex and Full-Duplex
- For short distances, two-way communication is possible on a single pair of wires (bi-directional transmission).
- Problems occur however when amplification (in the past) or digital regeneration (nowadays) is needed.
- Amplifiers or regenerators in the network are uni-directional
- A **Hybrid Transformer** is used to convert a 2-wire circuit at the phone/terminal end to a 4-wire system in the switching network

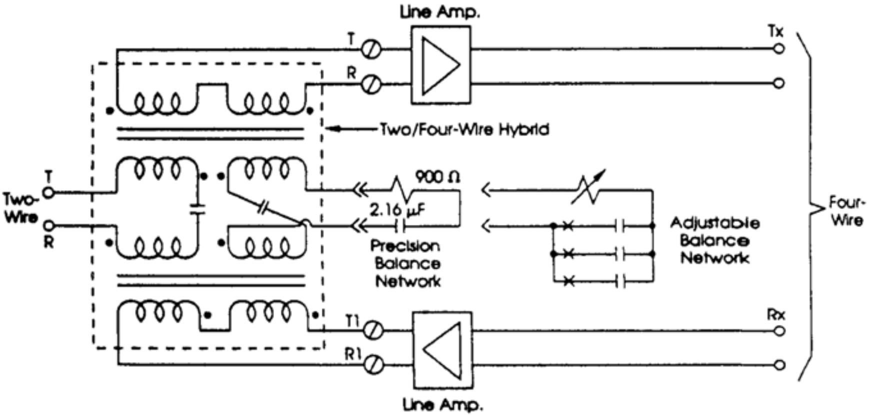
2-Wire and 4-Wire Transmission



Hybrid Transformer



Hybrid Transformer



Hybrid Transformer

- Hybrid **Dissipation Loss** The level of the signal (loss) in one (hybrid) 4w leg that will be transferred to the other 4w leg. It is estimated as the power, which amounts to 3dB.
- **Insertion loss**, due to an insertion of a passive element in the network is estimated at 0.5 dB
- The total loss is there fore 3.5 dB

Hybrid Transformer

- Balance network has a balance impedance of Z_N
- If $Z_N = Z_L$, then half the signal goes to the line and half goes to the balance network with little or no coupling (reflection) to the local receiver.
- But by design, we use $Z_N \neq Z_L$ to create sidetone.
    - Reflections from the CO return to the telephone set.
    - Talker hears his/her own voice.
    - Useful because acts (almost subconsciously) as a signal to the talker that the line is live.
    - No sidetone makes the line feel dead and unnatural (IP telephony often sounds like this since there's no sidetone).
- Balance Return Loss (BRL)

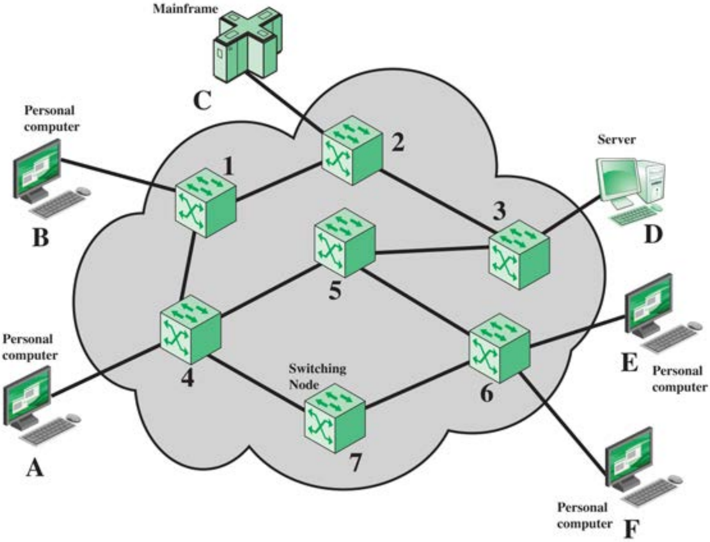
$$BRL \triangleq 20 \log_{10} \left(\frac{Z_N + Z_L}{Z_N - Z_L} \right) \quad \text{dB}$$

Switching Systems

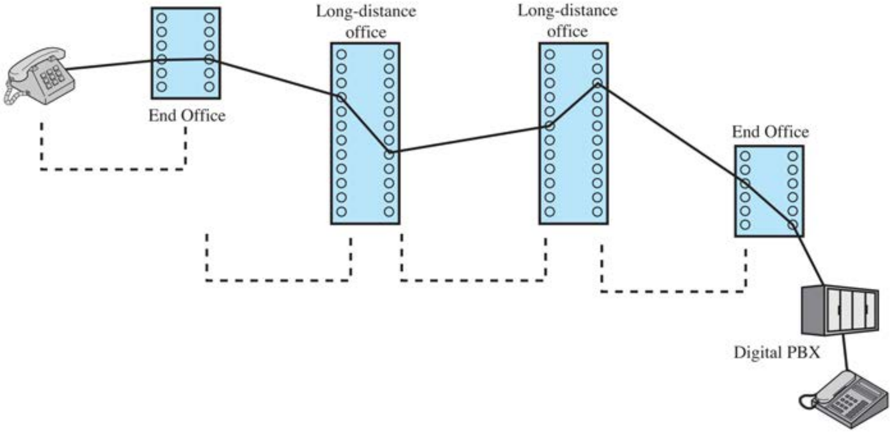
Switching in Telecommunication

- Establishes a path between two specified terminals
- Can be done in public or private networks
- Commercial switching satisfies the following requirements
  - A user should be able to communicate with any other user
  - Connection time is not critical, but has to be relatively small compared to holding time or conversation time
  - The probability of completion of a call is also not critical but should be high ($\sim 99\%$)
  - The user expects/assumes privacy. Usually does not specifically request it, nor, except in special cases, can it be guaranteed
  - The primary mode of communication for most users will be voice (or the voice channel)

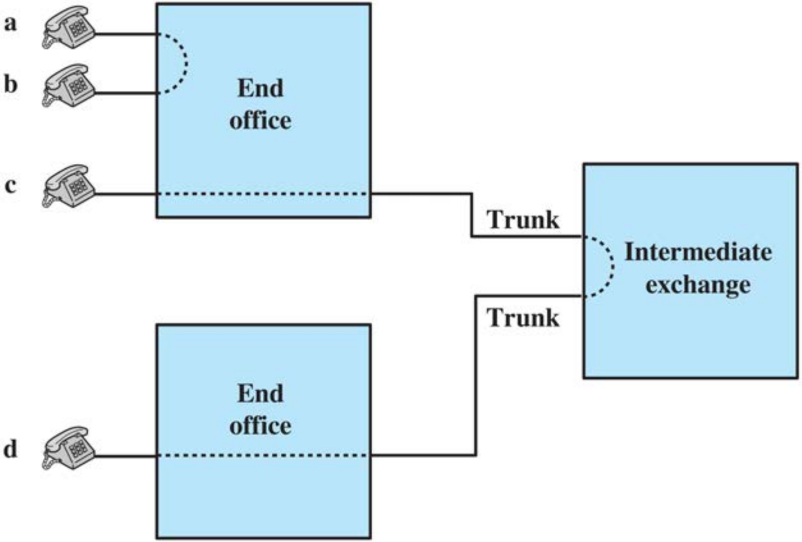
Switching in WANs



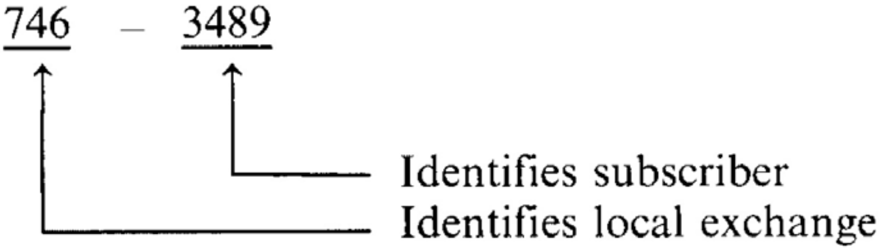
Switching in PSTN



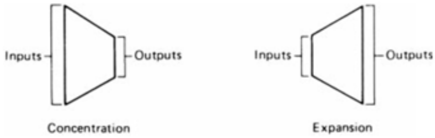
Switching in PSTN



Numbering

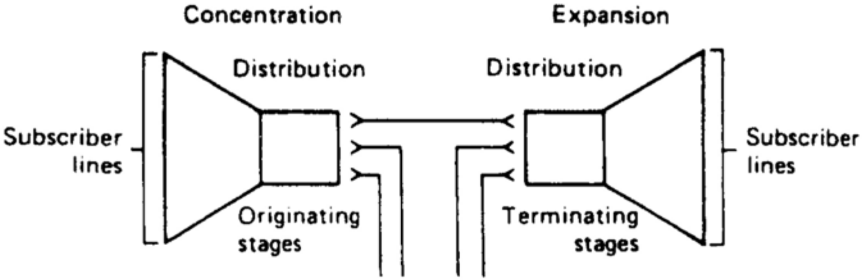

746 – 3489
Identifies subscriber
Identifies local exchange

Concentration and Expansion

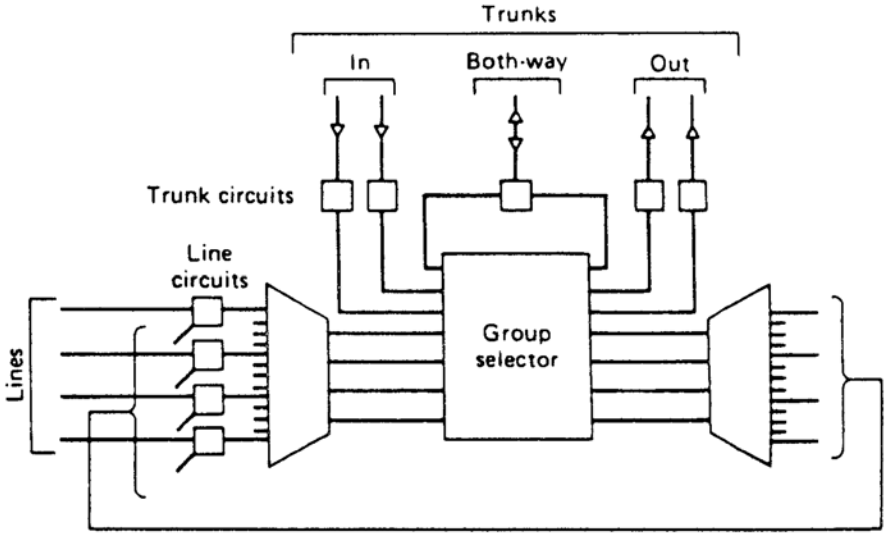


- Concentration is a key concept to the design of switching
- A local switching exchange concentrates traffic to reduce the number of switching paths or links within the exchange and the number of trunks connecting this local exchange to other exchanges
- A switch also performs the function of expansion to provide all subscribers served by the exchange with access to incoming trunks and local switching paths

Distribution Functions



Switch Functions



Switch Reliability

- The telecommunication system must be very reliable. System reliability is expressed as

$$R = \frac{\text{uptime}}{\text{uptime} + \text{downtime}}$$

- During uptime the system is operating satisfactorily. Usually, R is expected to be 99.999%
- The system unavailability is expressed as

$$U = 1 - R = \frac{\text{MTTR}}{\text{MTTR} + \text{MTBF}}$$

where,
MTTR = the mean time to repair
MTBF = the mean time between failures

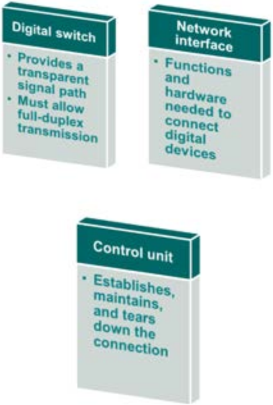
Techniques to increase reliability

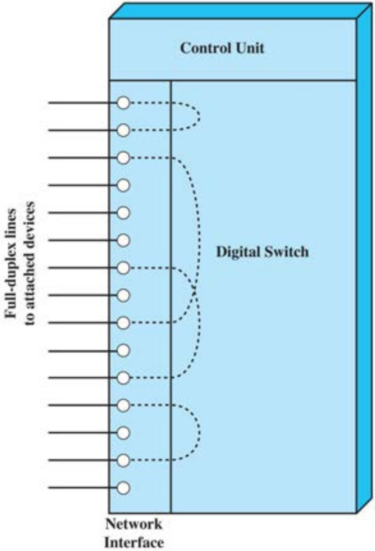
- **Duplicated units:** duplicated common control units, registers and processors, connected directly together and share data.
- **Standby units:** one unit is active, the rest are standby. Connected indirectly through secondary storage.
- **Load sharing:** both units are active and handle half of the calls on statistical basis.
- **Spare units (Line Replacement Units):** stored on-site for immediate repair of failed components.

Switching Systems

Digital Switching

Main Switching Functions





Main Switching Functions

Digital Switch

The heart of a modern system is a digital switch. The function of the digital switch is to provide a transparent signal path between any pair of attached devices. The path is transparent in that it appears to the attached pair of devices that there is a direct connection between them. Typically, the connection must allow full-duplex transmission.

Main Switching Functions

Network Interface

The network interface element represents the functions and hardware needed to connect digital devices, such as data processing devices and digital telephones, to the network. Analog telephones can also be attached if the network interface contains the logic for converting to digital signals. Trunks to other digital switches carry TDM signals and provide the links for constructing multiple-node networks.

Main Switching Functions

Control Unit

The control unit performs three general tasks. First, it establishes connections. This is generally done on demand, that is, at the request of an attached device. Second, the control unit must maintain the connection. Because the digital switch uses time division principles, this may require ongoing manipulation of the switching elements. Third, the control unit must tear down the connection, either in response to a request from one of the parties or for its own reasons.

Space Division

- Speech paths are physically separated
- Time-division switching permits a single path to be used by many calls separated in the time domain
- Digital speech
- Frame concept (address!, data)
- Analogy with routers in data networks
- Voice over IP

Blocking or Non-Blocking

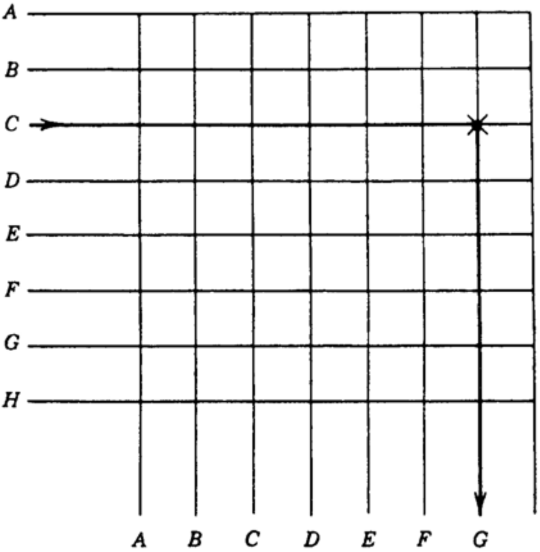
Blocking

- May be unable to connect stations because all paths are in use
- Used on voice systems because it is expected for phone calls to be of short duration and that only a fraction of the phones will be engaged at any one time

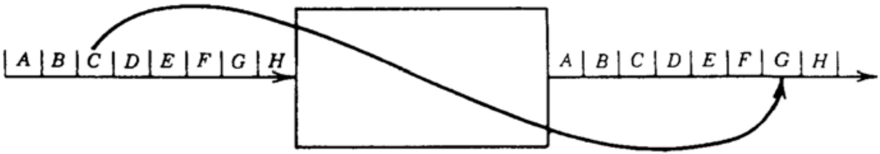
Non-Blocking

- Permits all stations to connect at once
- Grants all possible connection requests as long as the called party is free
- When using data connections terminals can be continuously connected for long periods of time so nonblocking configurations are required

Space Division



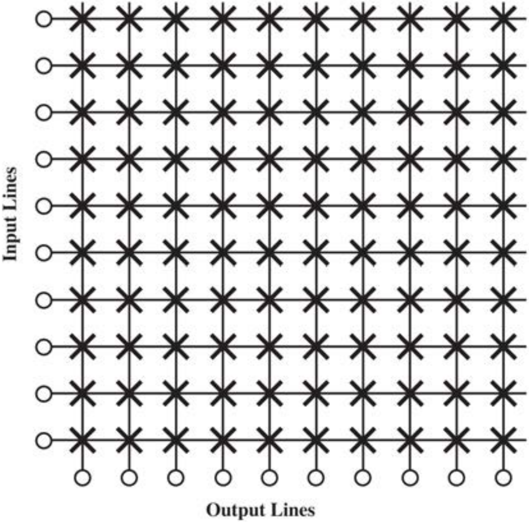
Time Division



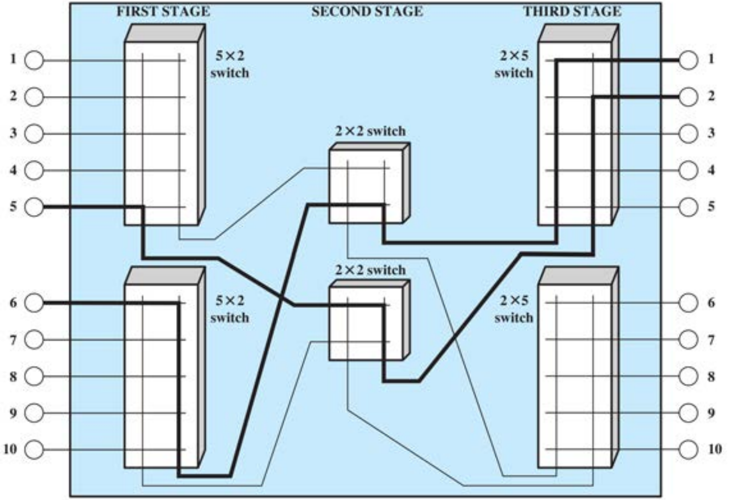
Advantages of PCM Switching

- Cost
  - Fewer cross-points
  - Smaller size
  - Easier to achieve full availability
- Technically
  - Regenerative
  - Noise-resistant
  - Compatibility with other digital devices
  - Lossless; no insertion loss

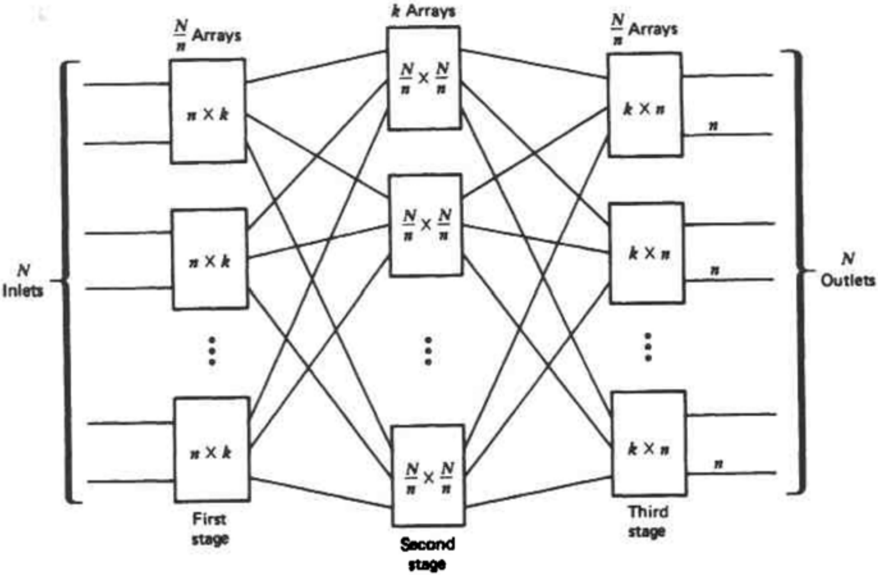
Switching Design



Switching Design



Switching Design



Switching Design

It can be shown that a switch is nonblocking if

$$k = 2n - 1$$

where,
k = number of intermediate stages
n = number of inputs/outputs af each of the first/last stages

Approaches of PCM Switching

Two Functional Elements

- Time Switch
- Space Switch

Time Switch = Time Slot Interchanger (TSI)

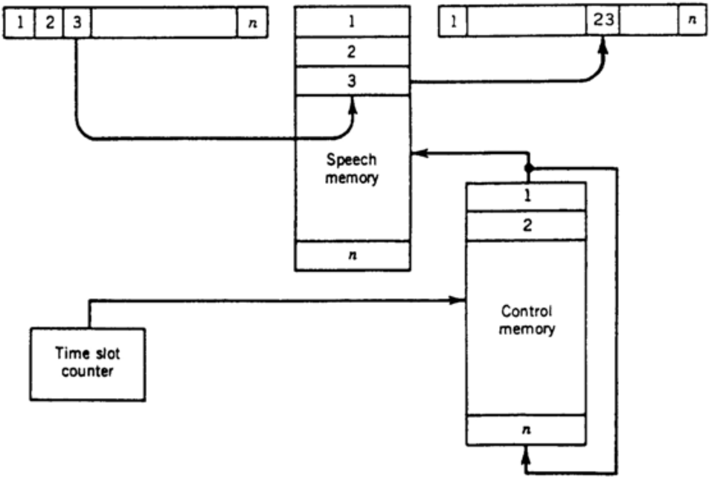
- Since the caller and the called share time slots differently, each at their end, we need to manage this difference
- TSI involves moving the data contained in each slot from the incoming bit stream to an outgoing bit stream, with a different time-slot arrangement (storage)
- **Three basic building blocks** of the time switch
  - Memory for speech
  - Memory for control
  - Time-slot counter or processor
- Two choices for time switching
  - **Sequential Input Random Output**
  - **Random Input Sequential Output**

Time Switch = Time Slot Interchanger (TSI)

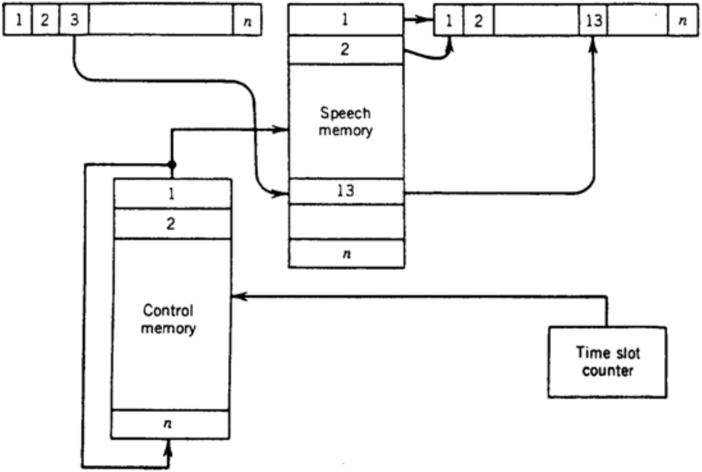
- The input lines of N devices are passed through a synchronous time division multiplexer to produce a TDM stream with N slots
- To create a full-duplex connection, the incoming data in a slot must be stored until the data can be sent out on the correct channel in the next TDM frame cycle
- The TSI introduces a delay and produces output slots in the desired order. The output stream of slots is then demultiplexed and routed to the appropriate output line
- Because each channel is provided a time slot in each TDM frame, whether or not it transmits data, the size of the TSI unit must be chosen for the capacity of the line, not for the actual data rate
- TSI is a simple, effective way to switch TDM data. However, the size of such a switch, in terms of the number of connections, is limited by the amount of latency that can be tolerated. The greater the number of channels, the greater the average delay that each channel experiences

Time Switch = Time Slot Interchanger

Sequential Input Random Output



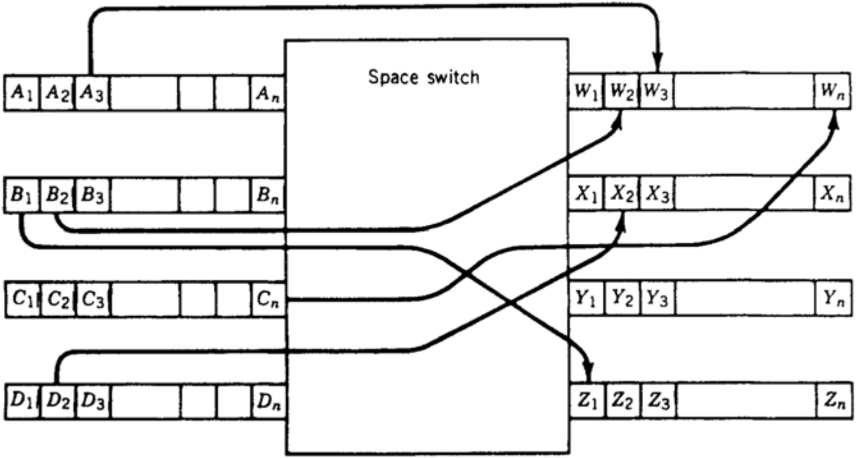
Random Input Sequential Output



Space Switch

- Consists of a cross-point matrix that allows the switching of time slots in the spatial domain
- The matrix consists of M input horizontals and N output verticals with a logic gate at each cross-point

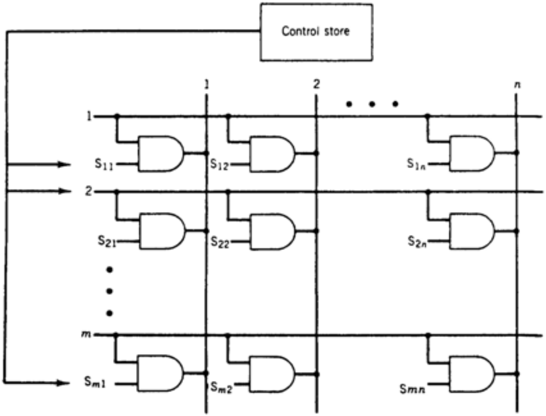
Space Switch



Space Switch

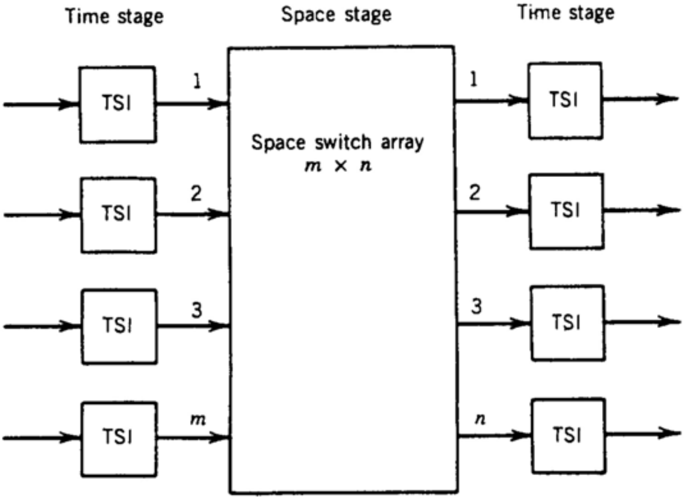
- The matrix consists of M input horizontals and N output verticals with a logic gate at each cross-point
  - If $M = N$, the switch is non-blocking
  - If $M > N$, the switch concentrates
  - If $M < N$, the switch expands
- The space array does not switch time slots as does a time switch
- Maximum capacity during any time-slot interval (simultaneous calls) $= \cdots$
- When a TSI is added $\cdots$

Space Switch

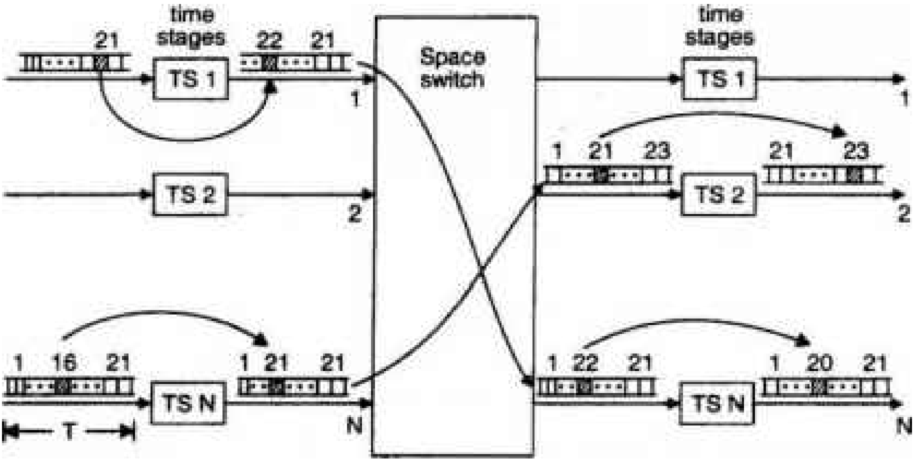


For a given time slot, the appropriate logic gate is enabled and the time slot passes from the input horizontal to the desired output vertical

Time-Space-Time



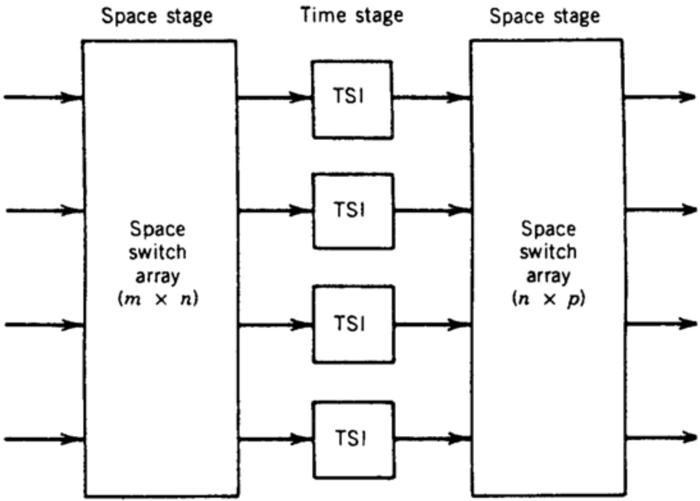
Time-Space-Time



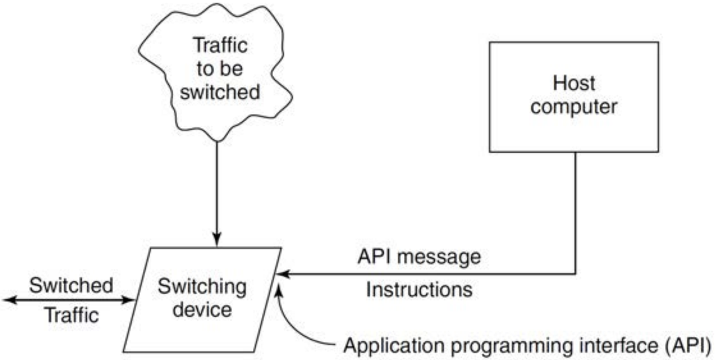
Time-Space-Time

- The space stage is considered a multiplier of the call-handling capacity
- **Blocking** in the overall switch occurs if there is no internal space-stage time slot during which the inlet and the outlet time-stages are idle

Space-Time-Space

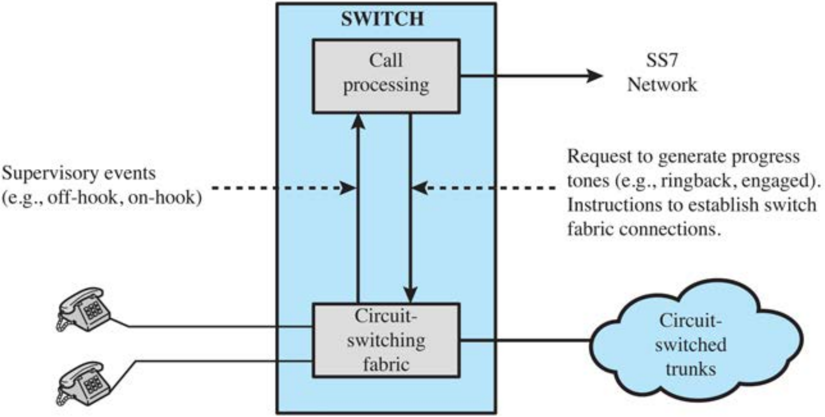


Programmable Switching



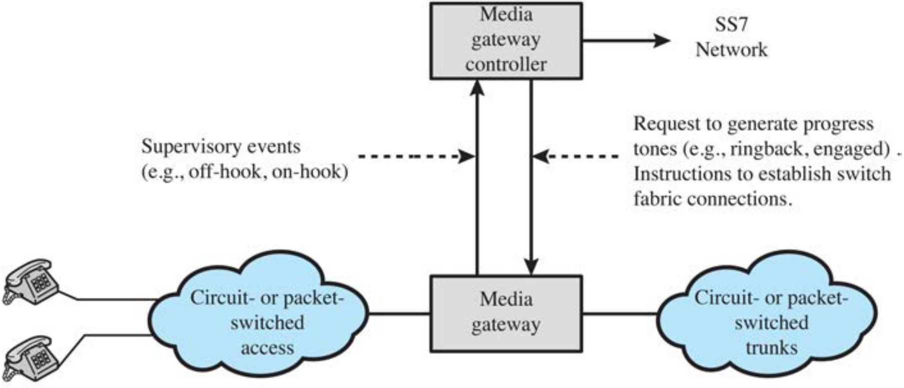
- Previously, telecommunication switches (e.g., 5ESS) were based on large, proprietary solutions
- Programmable switching is based on the open and distributed client-server computing model

Traditional Circuit Switching



- A softswitch is a general-purpose computer running specialized software
- Softswitches cost significantly less than traditional circuit switches
- A softswitch can convert a stream of digitized voice bits into packets. This opens up a number of options for transmission, including the increasingly popular voice over IP approach.
- In any telephone network switch, the most complex element is the software that controls call processing. This software performs call routing and implements call processing logic for hundreds of custom-calling features.
- Typically, this software runs on a proprietary processor that is integrated with the physical circuit-switching hardware.

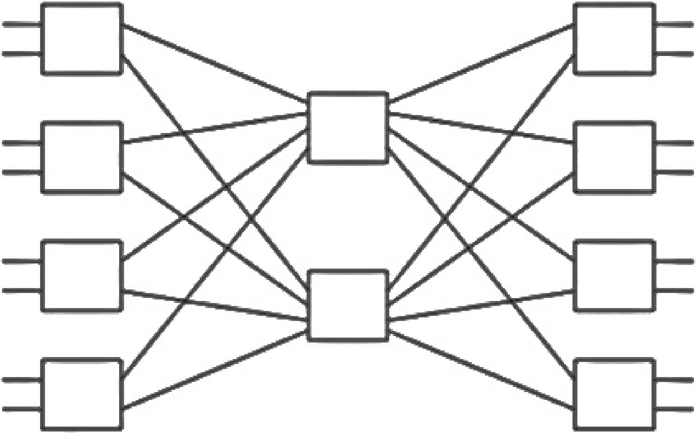
Softswitch Architecture



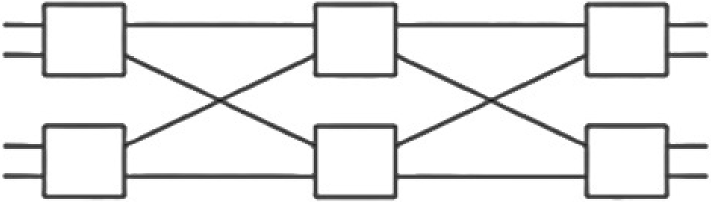
Softswitch Architecture

- A more flexible approach is to physically separate the call processing function from the hardware switching function. In softswitch terminology, the physical switching function is performed by a **media gateway (MG)** and the call processing logic resides in a **media gateway controller (MGC)**
- The MG and MGC are distinct entities and may be provided by different vendors
- To facilitate interoperability, ITU-T has issued a standard for a media gateway control protocol between the MG and MGC: **H.248.1 (Gateway Control Protocol)**

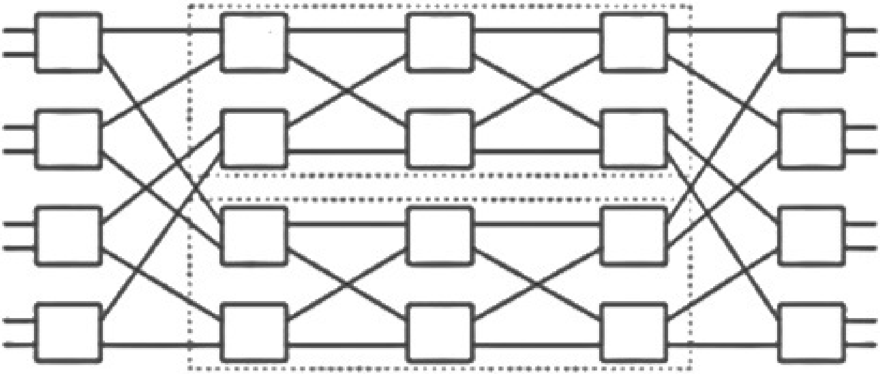
(2,2,4) Clos Network



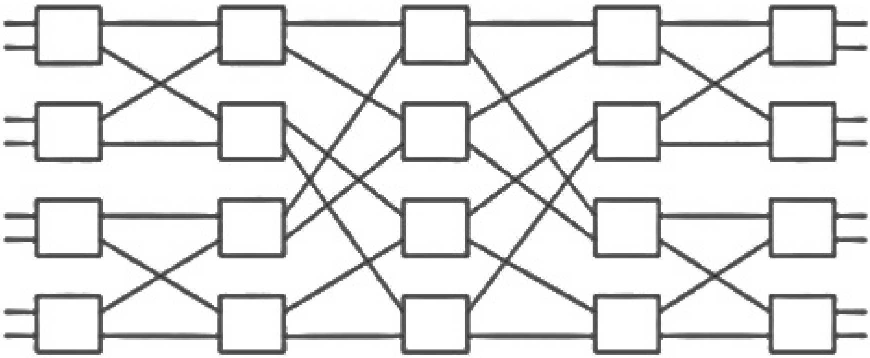
(2,2,2) Clos Network



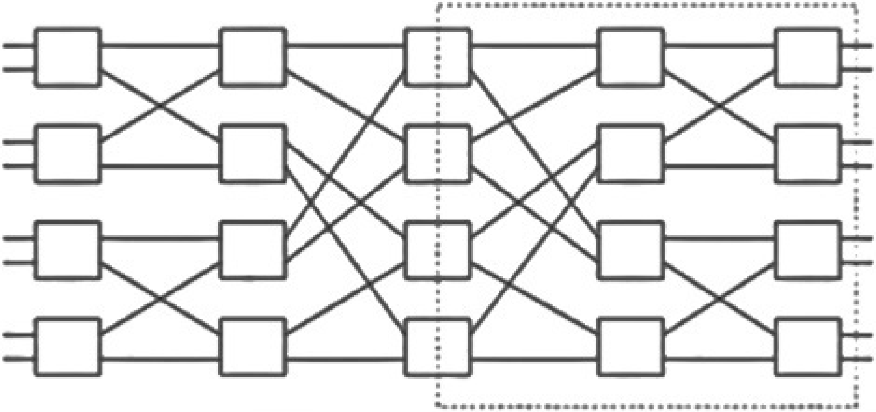
Data Centers: Fat Tree



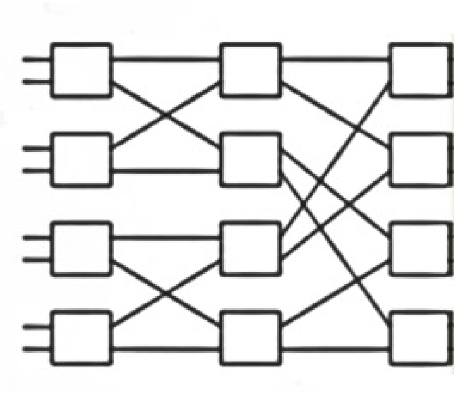
Data Centers: Fat Tree



Data Centers: Fat Tree

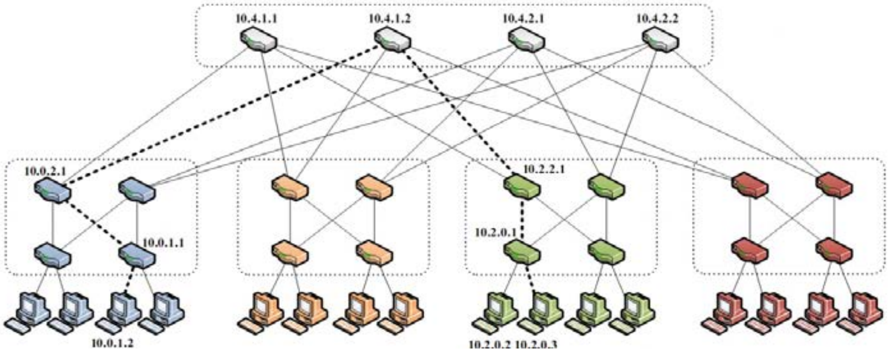


Data Centers: Fat Tree



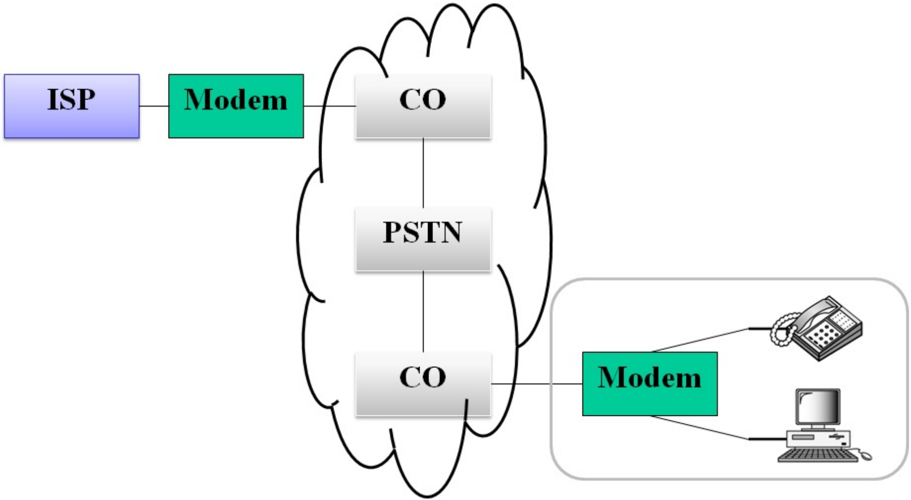
Data Centers: Fat Tree

FatTree-Based Data Center Architecture



Digital Subscriber Line

Voiceband Modem



Digital Subscriber Line (DSL)

- DSL was developed to provide higher-speed access to the Internet
- DSL is a promising technology for high-speed digital communication over the existing local loops
- DSL is a set of technologies: ADSL, VDSL, HDSL, and SDSL
- The set is often referred to as xDSL

Asymmetric Digital Subscriber Line (ADSL)

- ADSL provides higher speed (bit rate) in the downstream direction than in the upstream direction
- Asymmetric
- The designers of ADSL specifically divided the available bandwidth of the local loop unevenly for the residential customer
- The service is not suitable for business customers who need a large bandwidth in both directions

ADSL: Using Local Loops

- ADSL uses existing local loops
- ADSL reaches data rates that were not achieved with traditional modems
- Twisted-pair local loop is actually capable of handling bandwidths up to 1.1 MHz
- The filter installed at the central office where each local loop terminates limits the bandwidth to 4 kHz (sufficient for voice communication)
- If the filter is removed, the entire 1.1 MHz is available for data and voice communications

ADSL: Adaptive

- The BW value 1.1 MHz is just the theoretical bandwidth of the local loop
- Factors such as the distance between the residence and the switching office, the size of the cable, the signaling used, etc, affect the bandwidth
- Thus, ADSL uses an adaptive technology that tests the condition and bandwidth availability of the line before settling on a data rate
- The data rate of ADSL changes based on the condition and type of the local loop cable

ADSL: Using DMT

- The standard modulation technique for ADSL is called the Discrete Multi Tone (DMT) technique
- It combines QAM and FDM. There is no set way that the bandwidth of a system is divided. Each system can decide on its bandwidth division
- Typically, an available bandwidth of 1.104 MHz is divided into 256 channels
- Each channel uses a bandwidth of 4.312 kHz

ADSL: Using DMT

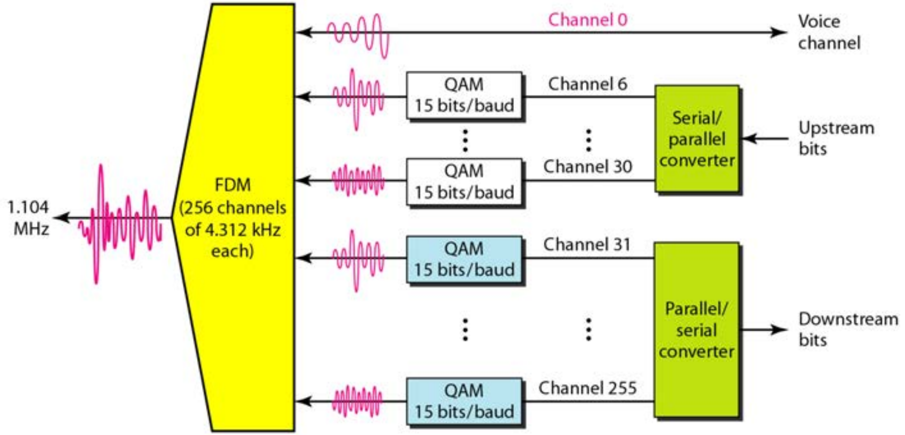
Bandwidth allocation:

- Channel 0: is reserved for voice communication.
- Channels 1 to 5: are not used and provide a gap between voice and data communication
- Channels 6 to 30 (25 channels): are used for upstream data transfer and control. 1 channel for control and 24 channels for data
- Channels 31 to 255 (225 channels): are used for downstream data transfer and control. 1 channel for control and 224 channels for data

ADSL: Using DMT

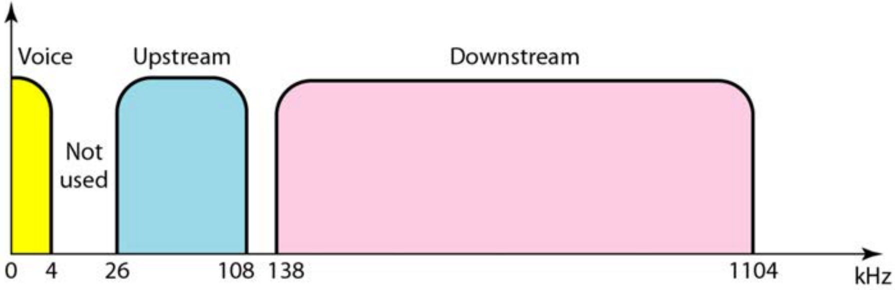
- If there are 224 channels, we can achieve up to $224 \times 4000 \times 15 = 13.4$ Mbps
- However, the data rate is normally around $8 \sim 9$ Mbps because some of the carriers are deleted at frequencies where the noise level is large
- In other words, some of channels may be unused

ADSL: DMT

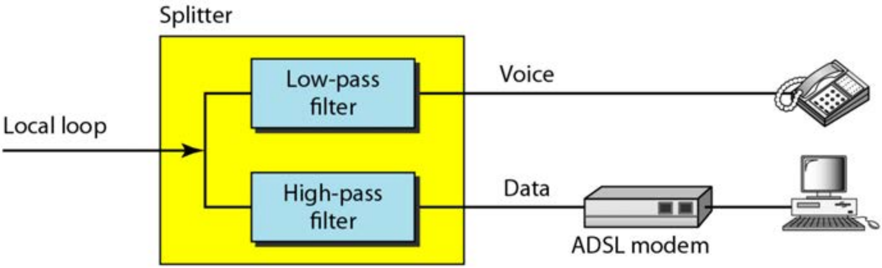


Channel 0
Voice channel
QAM 15 bits/baud
Channel 6
Serial/ parallel converter
Upstream bits
QAM 15 bits/baud
Channel 30
1.104 MHz
FDM (256 channels of 4.312 kHz each)
QAM 15 bits/baud
Channel 31
Parallel/ serial converter
Downstream bits
QAM 15 bits/baud
Channel 255

ADSL: Spectrum



ADSL: Customer Site

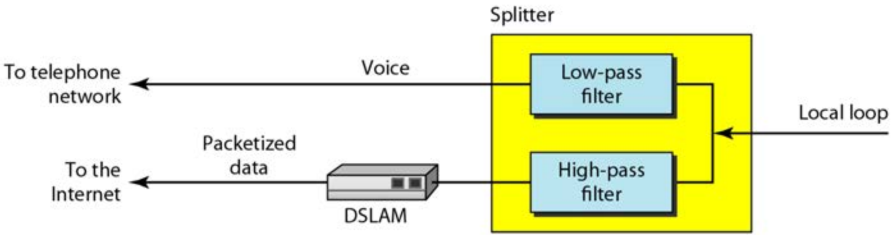


ADSL: Customer Site

- The local loop connects to a **splitter** which separates voice and data communications
- The **ADSL modem** modulates and demodulates the data, using DMT
- It also creates downstream and upstream channels
- The splitter needs to be installed at the customer's premises
- The voice line can use the existing telephone wiring in the house
- A data line needs to be installed

DSLAM: Digital Subscriber Line Access Multiplexer

It packetizes the data to be sent to the Internet



DSL: Other Technologies

Technology	*Downstream Rate*	*Upstream Rate*	*Distance (ft)*	*Twisted Pairs*	*Line Code*
ADSL	1.5–6.1 Mbps	16–640 kbps	12,000	1	DMT
ADSL Lite	1.5 Mbps	500 kbps	18,000	1	DMT
HDSL	1.5–2.0 Mbps	1.5–2.0 Mbps	12,000	2	2B1Q
SDSL	768 kbps	768 kbps	12,000	1	2B1Q
VDSL	25–55 Mbps	3.2 Mbps	3000–10,000	1	DMT

Thank You

Questions?

samy.soliman@cu.edu.eg

http://scholar.cu.edu.eg/samysoliman