Network Infrastructures

A.A. 2017-2018
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Telephone networks

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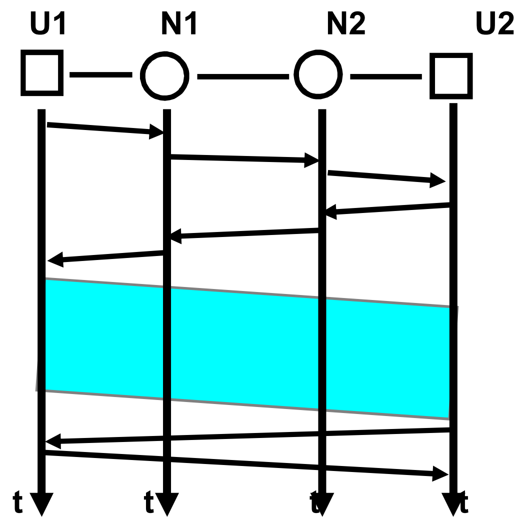
Circuit switching

- Opening
- Data transfer
- Closing



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Switching techniques

- Circuit switching
  - Resources allocated uniquely to a circuit
    - » Physical channel, time-slot in TDM frame
  - Connection oriented
    - » Need to open (and close) the circuit prior (after) data transmission
    - » Store state information on each circuit (stateful approach)
  - Address (unique for each user in the network) used only when opening the circuit, not carried in data
  - Data unit identified by position

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Switching techniques

- Circuit switching
  - Routing (choice of the best route) performed only when opening the circuit
    - Done through routing table lookup
  - Data forwarding
    - Through forwarding table look-up (one entry for each active circuit)
    - Static (always the same scheduling, unless circuits are closed or opened)

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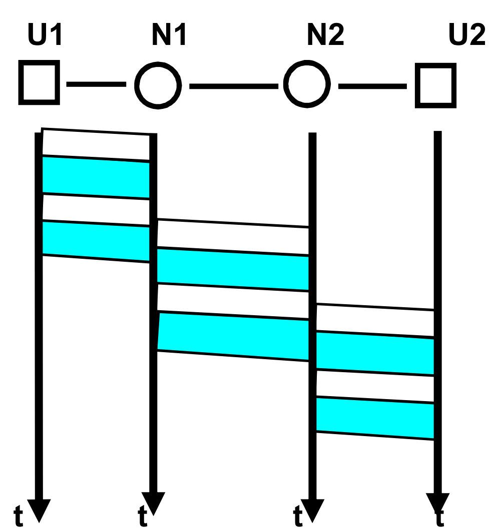
Packet switching



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Switching techniques

- Packet switching, with datagram service
  - Shared resources
    - » Ideally the full network is available to a single user
    - » Resources are shared with all other users
  - Connectionless
    - » Free to send data when available, no need to check network or user availability
    - » Stateless approach

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Switching techniques

- Packet switching, with datagram service
  - Each packet must carry the destination (and source) address
  - Data unit identified through source and destination addresses (unique for each pair of users in the network)
  - Routing and forwarding performed independently over each packet
    - » Through routing table look-up

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Telephone Network: What is It?

- Specialized to carry voice traffic
  - Aggregates like T1, SONET OC-N can also carry data
- Also carries
  - Telemetry, video, fax, modem calls
- Internally, uses digital samples
- Switches and switch controllers are special purpose computers
- Pieces:
  - » 1. End systems
  - » 2. Transmission
  - » 3. Switching
  - » 4. Signaling

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Telephone Network: What is It?

- Single basic service: two-way voice
  - low (not variable) end-to-end delay
  - guarantee that an accepted call will run to completion
- Endpoints connected by a ***circuit*****,** like an electrical circuit
  - Signals flow both ways (***full duplex***)
  - Associated with ***reserved*** bandwidth and buffer ***resources***

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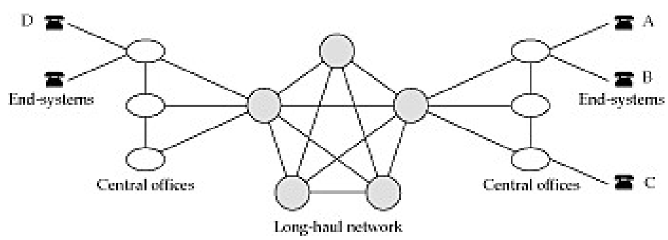
Telephone Network Design

- Fully connected core
  - simple routing
  - *telephone number* is a hint about how to *route* a call
    - » But not for 800/888/700/900 numbers: these are pointers to a directory that translates them into regular numbers
  - *hierarchically allocated* telephone number space



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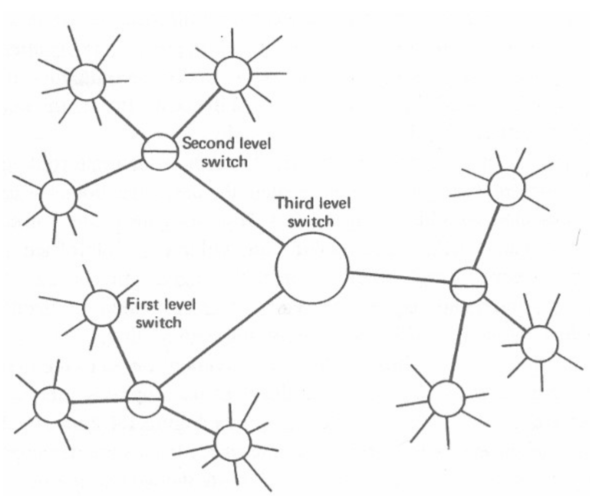
Telephone Network Design

- Three levels switching hierarchies



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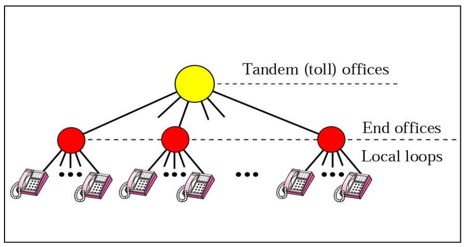
Telephone Network Design

- A local office (or end office) is a switching centre that connects directly to the customers' telephone instruments
- A tandem office is one that serves a cluster of local offices
- Finally, a toll office is involved in switching traffic over long-distance (or toll) circuits



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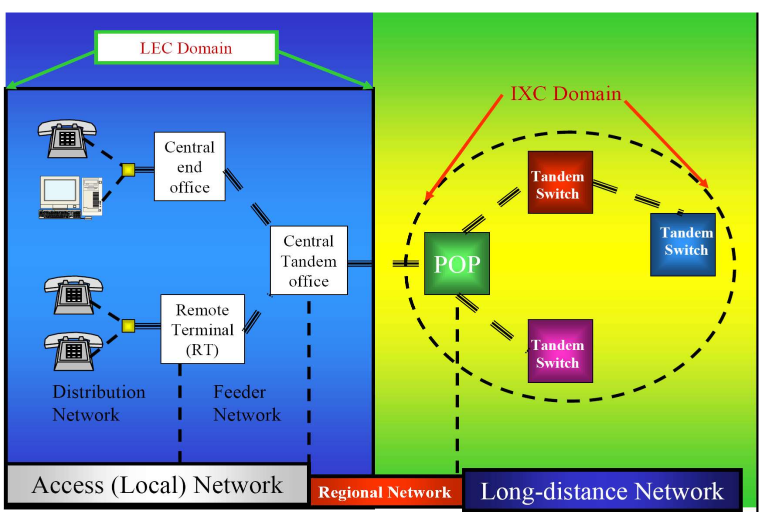
Public Switched Telephone Network (PSTN) architecture



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PSTN architecture

- Local Exchange Carriers (LECs)
  - LECs provide local telephone service, usually within the boundaries of a metropolitan area, state, or province.
  - LECs also provide short-haul, long distance service, Centrex, certain enhanced
  - services such as voice mail, and various data services.

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LATA (Local access transport areas)

- Services offered by the common carriers (telephone companies) inside a LATA are called intra-LATA services.
- The carrier that handles these services is called a local exchange carrier (LEC).
- Intra-LATA services are provided by local exchange carriers.
- Since 1996, there are two types of LECs: incumbent local exchange carriers (ILEC) and competitive local exchange carriers (CLEC)
- ILEC would provide main services and owns the local loop.
- CLEC would provide other services such as mobile telephone service, toll calls inside a LATA, …
- Communication inside a LATA is handled by end switches and tandem switches.

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Competitive Local Exchange Carrier (CLEC or Certified Local Exchange Carrier):

- A term coined for the deregulated, competitive telecommunications environment envisioned by the Telecommunications Act of 1996. While the Act is under legal challenge, many of the state regulatory authorities have moved forward.
- The CLECs compete on a selective basis for local exchange service, as well as long distance, international, Internet access, and entertainment (e.g. Cable TV and Video on Demand).
- They will build or rebuild their own local loops, wired or wireless. They also lease local loops from the ILECs at wholesale rates for resale to end-users. CLECs include cellular/ PCS providers, ISPs, IXCs, CATV providers, CAPs, LMDS operators, and power utilities.

Newton's Telecom Dictionary, 15th Edition (1999)

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PSTN architecture

- InterExchange Carriers (IXCs or IECs)
  - IXCs are responsible for long-haul, long-distance connections across LATA boundaries
  - IXC networks are connected to the LECs through a Point of Presence (POP) which typically is in the form of a tandem switch
  - A POP is a location where IXC exchange access to IXC services
  - The IXC POP is connected to the LEC access tandem switch via dedicated trunks leased from the LEC. Alternatively, the IXC may collocate network termination equipment in the LEC office, assuming that space is available and that secure physical separation can be established and maintained.
  - IXCs provide inter-LATA services

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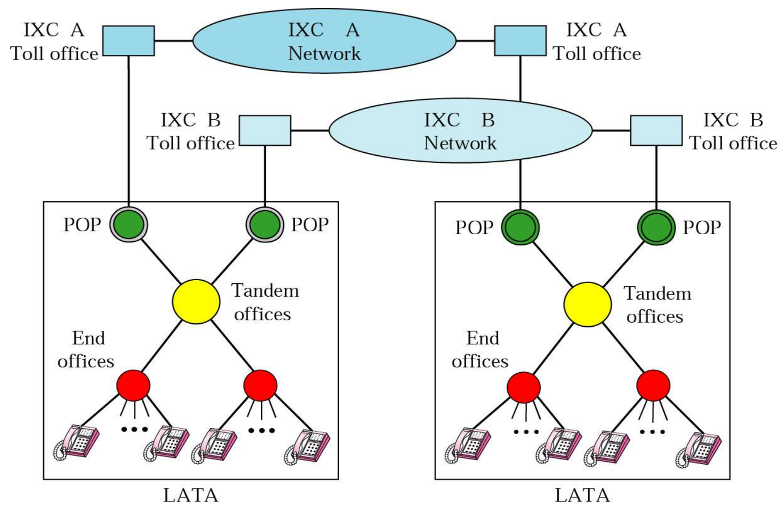
Exchange Area Network



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Interexchange carriers (IXCs)

- Interexchange carriers (IXCs) or long-distance companies handle services between LATA
- A telephone call going through an IXC is normally digitized, with the carriers using several types of networks to provide service
- Intra-LATA services can be provided by several LECs (one ILEC and possibly more than one CLEC). Point of Presence (POP) is a switching office.
- Each IXC that wants to provide inter-LATA services in a LATA must have a POP in that LATA

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Point Of Presence (POP)

- Telephone systems
  - A point of presence was a location where a long-distance carrier could terminate services and provide connections into a local telephone network.
- Internet
  - An Internet point of presence is an access point to the Internet. It is a physical location that houses servers, routers, ATM switches and digital/analog call aggregators.
  - It may be either part of the facilities of a telecommunications provider that the Internet service provider (ISP) rents or a location separate from the telecommunications provider.
  - ISPs typically have multiple POPs, sometimes numbering in the thousands.
  - POPs are also located in Internet exchange points.

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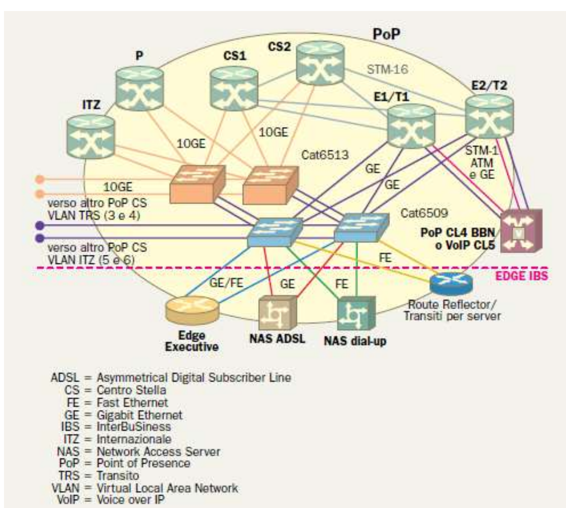
Example of Telecom Italia: Inner Core PoP



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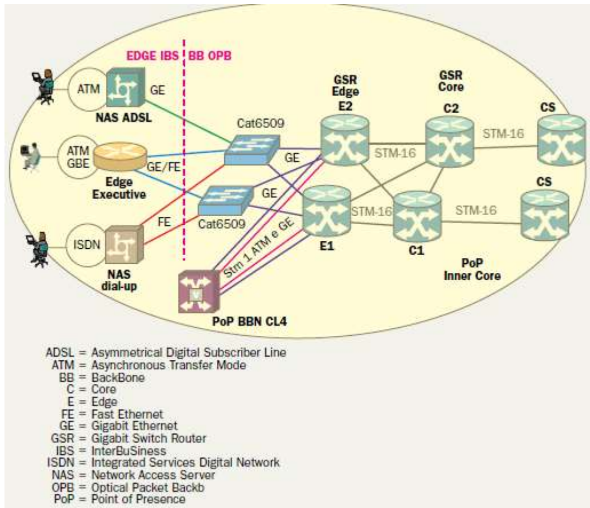
Example of Telecom Italia: Outer Core PoP



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Last-Mile Transmission Environment

- Various forms of noise: (twisting reduces noise)
  - Bridged-tap noise: bit-energy diverted to extension phone sockets
  - Crosstalk
  - Ham radio
  - AM broadcast

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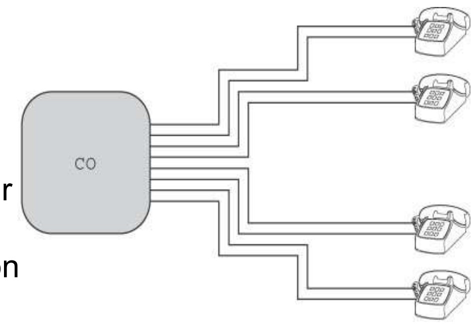
2-wire vs 4-wire: Sidetones and Echoes

- Both trans & reception circuits need two wires
  - 4 wires from every central office to home
- Alternative: Use *same* pair of wires for *both* transmission and reception
- Signal from transmission flows to receiver: **sidetone**



❑ Reverse Effect: received signal at end-system bounces back to CO (esp if delay > 20 ms): **echo**

❑ Solutions: *balance circuit* (attenuate side-tone) + *echo-cancellation circuit* (cancel echoes).

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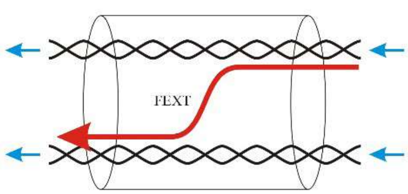
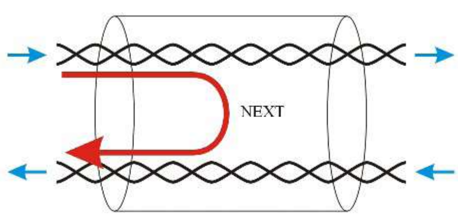
Cross-talk noise



- Far-end cross-talk (FEXT) is the cross-talk between a transmitter and a receiver placed on opposite sides of the cable



Near-end cross-talk (NEXT) is the cross-talk between a transmitter and a receiver placed on the same side of the cable

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Dialing

- Pulse
  - sends a pulse per digit
  - collected by central office (CO)
  - Interpreted by CO switching system to place call or activate special features (eg: call forwarding, prepaid-calls etc)
- Tone
  - key press (feep) sends a pair of tones = digit
  - also called Dual Tone Multifrequency (DTMF)

- CO supplies the power for ringing the bell
- Standardized interface between CO and end-system => digital handsets, cordless/cellular phones

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Telephone Pieces: Transmission Muxing

- *Trunks* between central offices carry hundreds of conversations
- Can't run thick bundles! Instead, send many calls on the same wire
  - *Multiplexing (Sharing)*
- Analog multiplexing
  - Band-limit call to 3.4 KHz and frequency shift onto higher bandwidth trunk
  - obsolete
- Digital multiplexing
  - first convert voice to *samples*
  - 1 sample = 8 bits of voice
  - 8000 samples/sec => call = 64 Kbps

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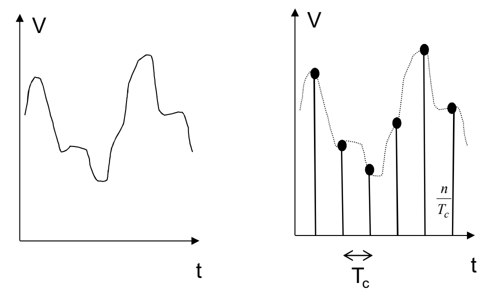
Analog/digital conversion

- A waveform is sampled at a constant rate – every Tc seconds (fc=1/Tc= sampling rate, Hz)
- – Each such sample represents the instantaneous amplitude at the instant of sampling
- – Sampling converts a continuous time signal to a discrete time signal



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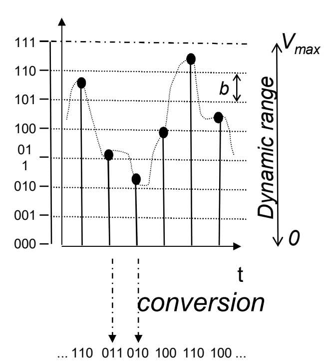
Analog/digital conversion

- The sample can now be quantized (converted) into a digital value
  - Quantization represents a continuous (analog) value with the closest discrete (digital) value



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Transmission Multiplexing

- How to choose a sample?
  - 256 *quantization levels*, logarithmically spaced
  - sample value = amplitude of nearest quantization level
  - Two choices of levels (μ law and A law)
- PCM for voice:
- fc=8Khz Tc=125μs
- Number of bit per sample n=8
- Bit rate R=64Kb/s

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Public Switched Telephone Network

- Sample voice signals at 8000 samples/s
- Quantize voice to 8 bits/sample

  Uniformly quantize to 8 bits/sample, or

  Compand by uniformly quantizing to 12 bits and map 12 bits logarithmically to 8 bits (by lookup table) to allocate more bits in quiet segments (where ear is more sensitive)
- μ = 256 in US/Japan and A = 87.6 in Europe

$$y = \frac{\log(1+\mu|x|)}{\log(1+\mu)}$$

$$y = \begin{cases} \dfrac{A|x|}{1+\log A} & if\ 0 \le |x| \le \dfrac{1}{A} \\ \dfrac{1+\log A|x|}{1+\log A} & if\ \dfrac{1}{A} \le |x| \le 1 \end{cases}$$

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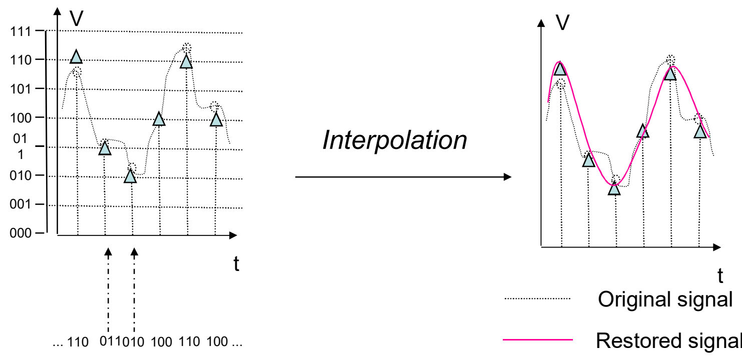
Analog/digital conversion



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Some important ITU-T speech/video coding standards

Standard no. Name	Description	Current status
G.711	Pulse code modulation (PCM) of voice frequencies (64 kbit/s)	Adopted 1984
G.722, G.725	7 kHz audio-coding within 64 kbit/s	Adopted 1988
G.726	16/24/32/46 kbit/s adaptive differential pulse code modulation (ADPCM)	Adopted 1990
G.728	16 kbit/s speech coding with excited linear prediction	Adopted 1992
G.729	8 kbit/s speech coding	Adopted 1996
H.221	Frame structure for a 64 to 1920 kbit/s channel in audiovisual teleservices	Adopted 1990
H.230	Control and indication signals for audiovisual systems	Adopted 1990
H.231, H243	Multipoint videoconferencing	Adopted 1993
H.233	Encryption / Privacy systems	Adopted 1993
H.261	Video codec for aud ovisual teleservices at p x 64 kbit/s	Adopted 1993
H.263	Video coding for low bit rate communication	Adopted 1996
MPEG1	Stored motion video stored at <2 Mbit/s	Adopted 1993
MPEG2	Stored/live motion video at 5–60 Mbit/s	Adopted 1994
MPEG4	Low bit rate (<64 kbit/s) coding of motion video	
JPEG	Still-frame graphics for multimedia	Adopted 1991

MPEG = Motion picture expert group. JPEG = Joint photograph expert group

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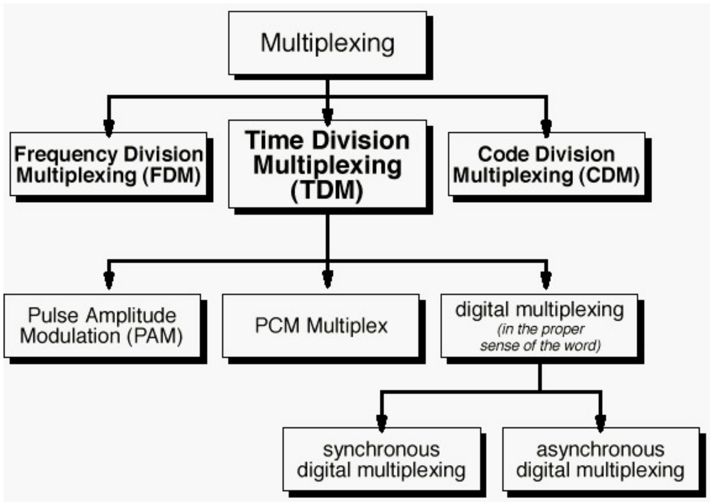
Multiplexing techniques



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Transmission Multiplexing

- Multiplexed trunks can be multiplexed further
- Need a standard!
- Called *Digital Signaling* hierarchy (DS)

Signal Level	Number of Data Channels	Total Signaling Rate (Mbps)		
		T-Carrier (North America)	E-Carrier (Europe)	J-Carrier (Japan)
0	1	0.064	0.064	0.064
1	24	1.544		1.544
	30		2.048	
1C	48	3.152		
2	96	6.312		6.312
	120		8.448	7.786
3	480		34.368	32.064
	672	44.736		
3C	1,344	91.053		
4	1,44			97.728
	1,92		139.268	
	4,032	274.176		
5	5,76	400.352		
	7,68		565.148	565.148
6	30,72		2200.00.00	

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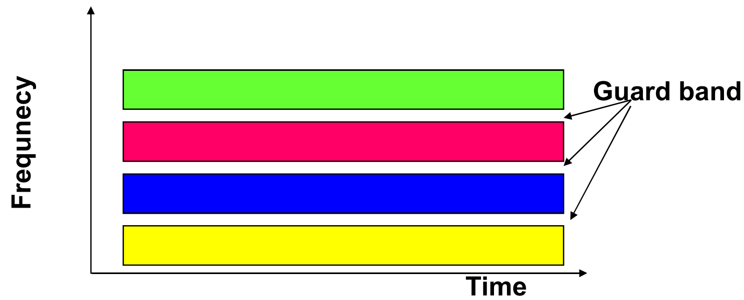
Frequency division multiplexing

- Dividing the entire frequency spectrum into smaller bands
  - A frequency band is allocated per channel for the entire transmission time
- FDM, used in 1st generation systems, wastes spectrum



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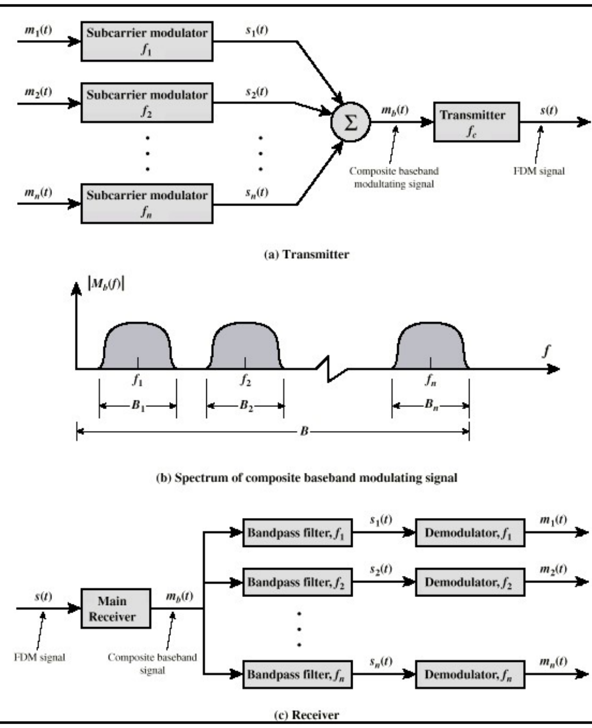

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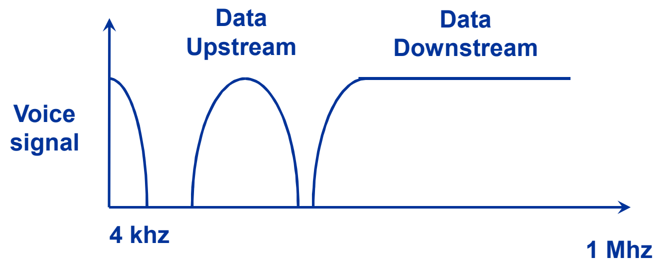
Example of FDM

- In the ADSL (Asymmetric Digital Subscriber Line) the modem divides the available bandwidth on the copper line:



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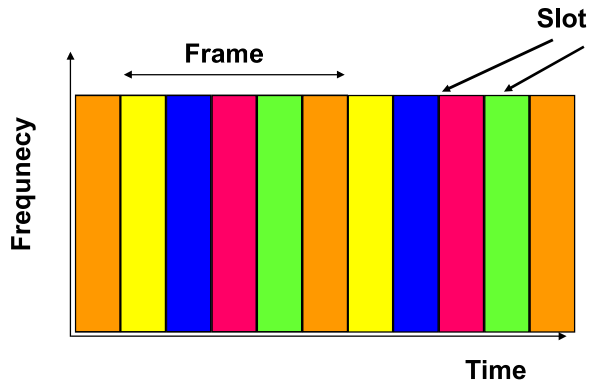
Time division multiplexing

- Entire spectrum is allocated for a channel some of the time



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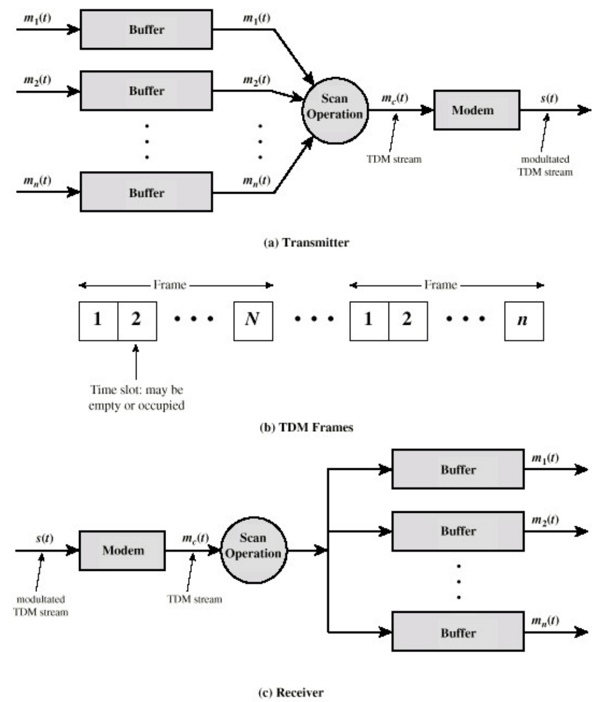

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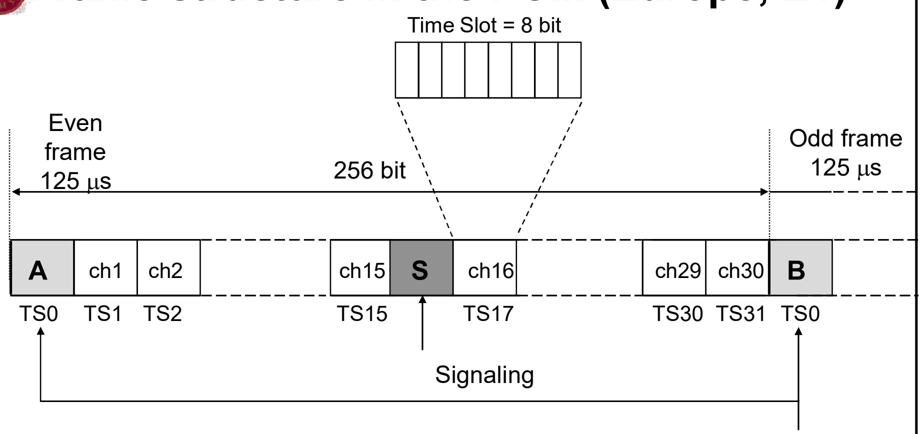
Frame structure in the PCM (Europe, E1)



- In E1
  - frame has 32 time-slots, TS 0 holds a synchronization pattern and TS 16 holds signaling information
  - An E1 frame has 32x8=256 bits and its rate is 8000x256=**2048 kb/s**

Alignment A e B
- A = X0011011
- B = X1S_1XXXXX

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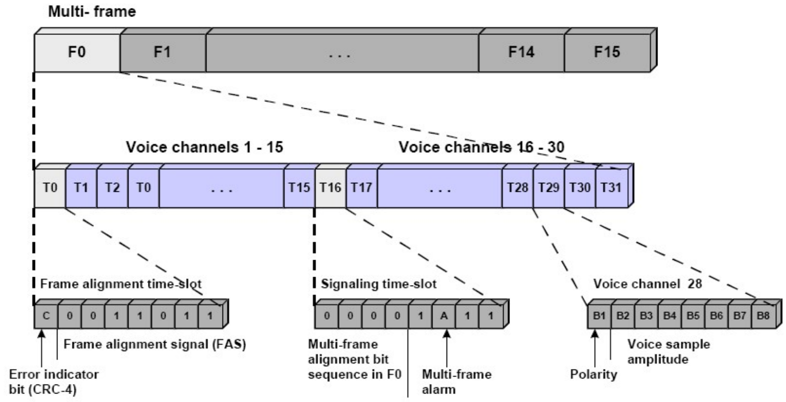
E1-frame structure (even frames)



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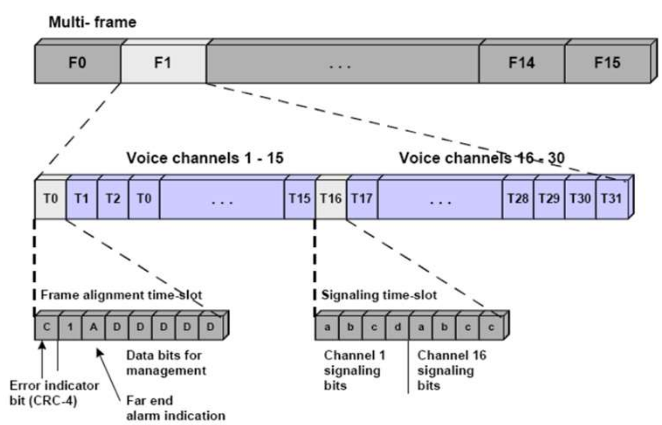
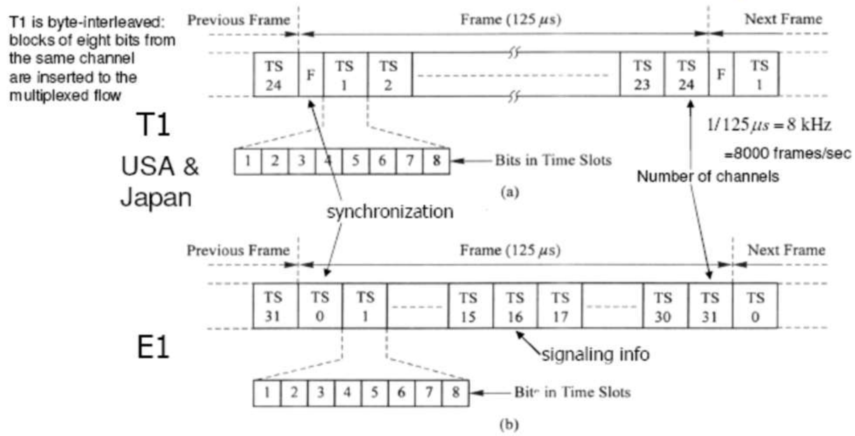
E1-frame structure (odd frames)



E1 and T1 first order frames compared



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T1

- In T1 one bit in each time slot in every sixth frame is replaced by signaling information yielding 56 kb/s only
- In T1
  - 24 time-slots and a framing (F) bit serves 24 channels
  - Frame length: 1+ 8x24=193 bits
  - Rate 193x8000 bits/second=**1544 kb/s**

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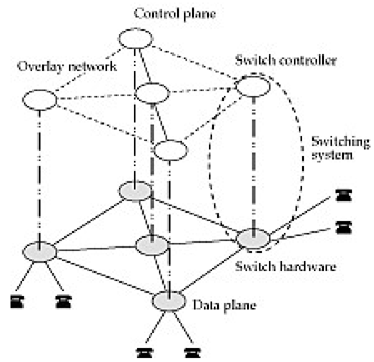
Telephone Pieces: Switching

- Problem:
  - each user can potentially call any other user
  - can't have (a billion) direct lines!
- Switches establish temporary *circuits*
- Switching systems come in two parts: *switch* and *switch controller*



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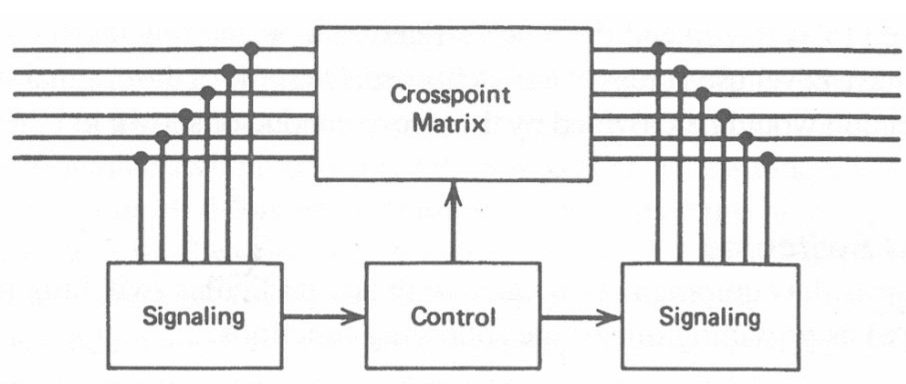
Switching System Components



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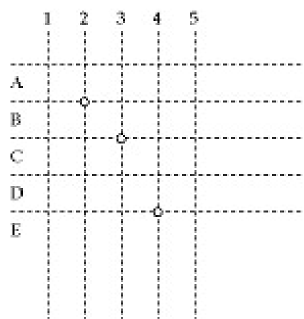
Switch: What does it do?

- Transferts data from an input to an output
  - many ports (up to 200,000 simultaneous calls)
  - need high speeds
- Some ways to switch:
  - *1. space division switching: eg: crossbar*
  - if inputs (or crosspoints) are multiplexed, need a *schedule*



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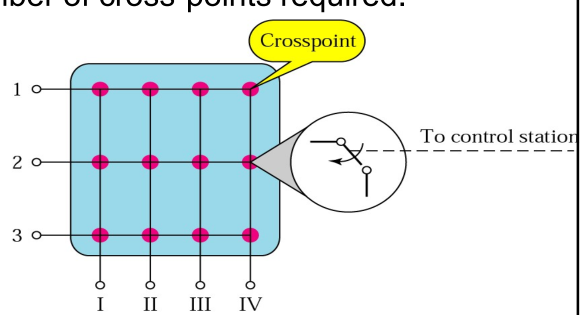
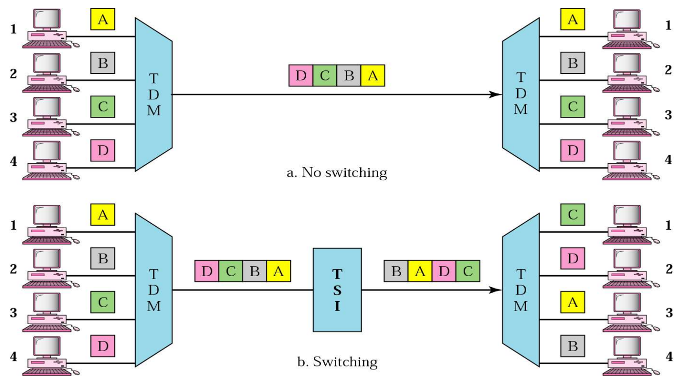
Space-Division Switch

- Paths in the circuit are separated from each other spatially.
- Crossbar switch connects n inputs to m outputs in a grid, using electronic micro-switches (transistors) at each cross-point.
- Limitation is the number of cross-points required.
- Crossbar Switch



Time-Division Switch

- Time-division switching uses time-division multiplexing to achieve switching
- Time-slot interchange (TSI) changes the order of the slots based on the desired connection



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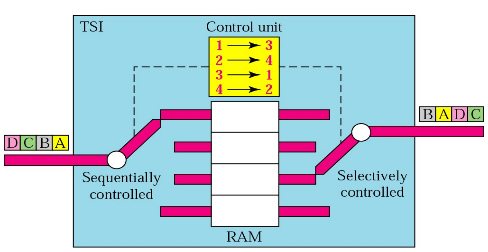
Time-slot interchange

- TSI consists of random access memory (RAM) with several memory locations. The size of each location is the same as the size of a single time slot.
- The number of locations is the same as the number of inputs.
- The RAM fills up with incoming data from time slots in the order received. Slots are then sent out in an order based on the decisions of a control unit.



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Telephone pieces: Signaling

- A switching system has a switch and a switch controller
- Switch controller is in the *control* plane
  - does not touch voice samples
- Manages the network
  - call routing (collect *dialstring* and forward call)
  - alarms (ring bell at receiver)
  - billing
  - directory lookup (for 800/888 calls)

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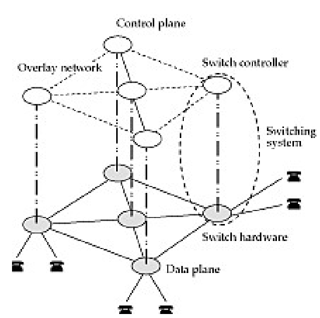
Signaling

- Switch controllers are special purpose computers
- Linked by their own internal computer network
  - *Common Channel Interoffice Signaling (CCIS) network*
- Earlier design used *in-band* tones, but was hacked
  - Also was very rigid
- Messages on CCIS conform to *Signaling System 7 (SS7)*



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Channel Associated Signaling (CAS)

- Initially the Time slot 16 of the E1 was dedicated to transport CAS
- When CAS is used, ITU recommendation G.732 describes a "MultiFrame" format for the E1 signal
- The multi-frame is constututed by 16 frames (2 ms)
- Frame 0: MultiFrame Alignment Signal
  - When Timeslot 16 of the E1 frame is used for Channel Associated Signaling purposes, Frame 0 contains information that is used by the receiver to identify the incoming frame. Specifically, this pattern in Timeslot 0, Frame 0 is called the MultiFrame Alignment Signal (MFAS).
- Timeslot 16 of Frames 1-15 is used to convey the state signaling bits associated to the 30 channels

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Channel Associated Signaling (CAS)

- For each channel, there is a frame where half of its TS16, is dedicated for that channel signaling:
  - Frame 0 is used for alarm indication and spare bit
  - Frame 1 is used for channels 1 and 16 (4 bits each)
  - Frame 2 is used for channels 2 and 17 (4 bits each)
  - ...
  - Frame 15 is used for channels 15 and 30 (4 bits each)
- When the bits aren’t used for signaling 2nd and 4th bits should be 1 and the 3rd should be 0
- The bits can be used for signaling of 2 states (1 bit), 4 states (2 bits)
  - signaling channel rate 2 bit/2 ms = 1 kbit/s
  - signaling channel rate 1 bit/2 ms = 0.5 kbit/s

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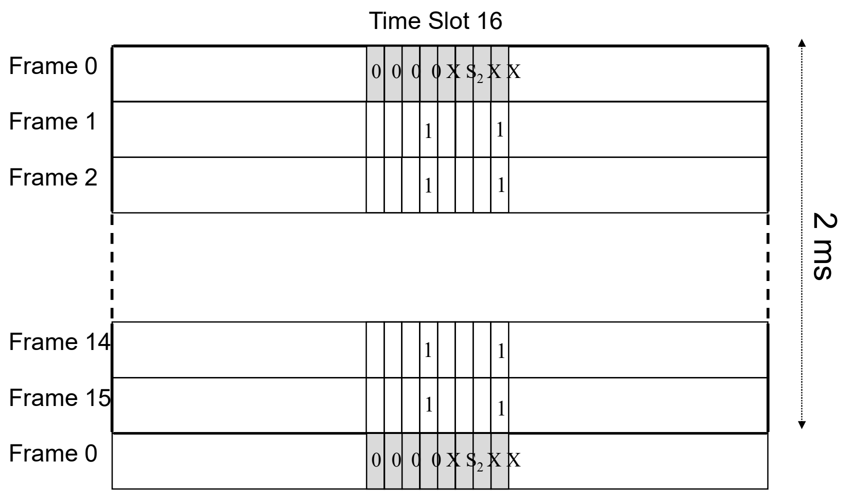
Signaling multi-frame



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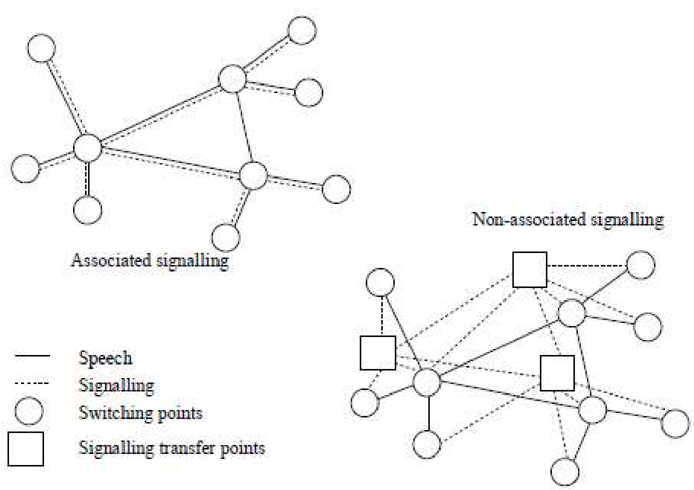
Common Channel Signalling



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Common Channel Signalling System No. 7 (SS7)

- Is a data communications network standard
- SS7 is intended to be used as a control and management network for telecommunication networks
- SS7 provides call management, data base query, routing, flow and congestion control functionality
- For telecommunication networks SS7 is specifically designed to support the functions of an Integrated Services Digital Network

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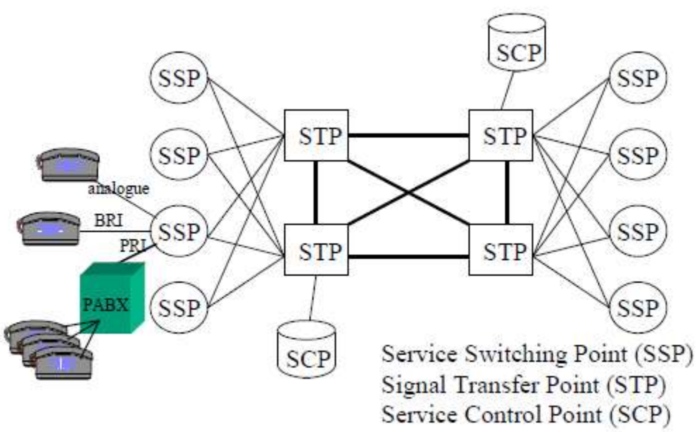
SS7 network Model



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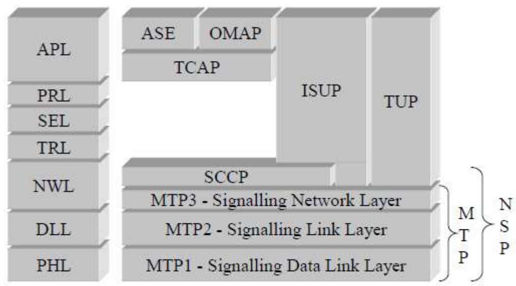
SS7 Protocol architecture

- MTP - Message Transfer Part
- SCCP - Signalling Connection Control part
- NSP - Network Service Part
- ISUP - ISDN User Part
- TUP - Telephone User Part
- TCAP - Transaction Capabilities Application Part
- ASE - Application Service E
- OMAP - Operations and Ma Application Part



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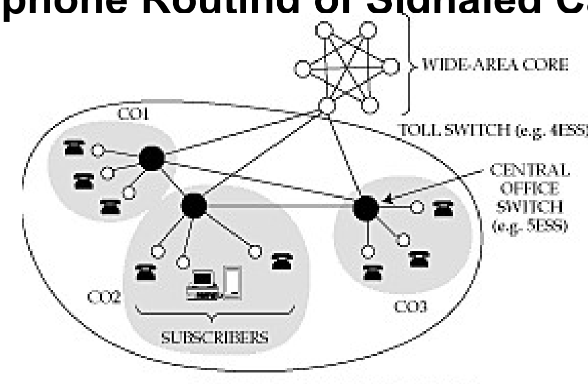
Telephone Routing of Signaled Calls



- Circuit-setup (I.e. the signaling call) is what is routed.
- Voice then follows route, and claims reserved resources.
- 3-level hierarchy, with a fully-connected core
- AT&T: 135 core switches with nearly 5 million circuits
- LECs may connect to multiple cores

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Telephony Routing algorithm

- If endpoints are within same CO, directly connect
- If call is between COs in same LEC, use one-hop path between COs
- Otherwise send call to one of the cores
- Only major decision is at toll switch
  - one-hop or two-hop path to the destination toll switch.
- Essence of telephony routing problem:
  - which two-hop path to use if one-hop path is full (almost a static routing problem…)

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Features of telephone routing

- Resource reservation aspects:
  - Resource reservation is coupled with path reservation
    - » Connections need resources (same 64kbps)
    - » Signaling to reserve resources and the path
  - Stable load
    - » Network built for voice only.
    - » Can predict pairwise load throughout the day
    - » Can choose optimal routes in advance
- Technology and economic aspects:
  - Extremely reliable switches
    - » Why? End-systems (phones) dumb because computation was non-existent in early 1900s.
    - » Downtime is less than a few minutes per year => topology does not change dynamically

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Features of telephone routing

    - » Source can learn topology and compute route
    - » Can assume that a chosen route is available as the signaling proceeds through the network
    - » Component reliability drove system reliability and hence acceptance of service by customers
  - – Simplified topology:
    - » Very highly connected network
    - » Hierarchy + full mesh at each level: simple routing
    - » High cost to achieve this degree of connectivity
- Organizational aspects:
  - – Single organization controls entire core
  - – Afford the scale economics to build expensive network
  - – Collect global statistics and implement global changes

- => Source-based, signaled, simple alternate-path routing

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