TELECOMMUNICATIONS NETWORKS

University Pierre and Marie Curie (Paris 6)
Master Informatique – Spécialité Réseaux

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Program

- Introduction
- ATM
- Ethernet
- MPLS
- Wireless networks
- Mobile networks
- Virtualization – Software Defined Networking (SDN)
- Future directions

Bibliography

- Guy Pujolle, « Les Réseaux », Eyrolles.
- Computer Networking, James Kurose and Keith Ross
- Data and Computer Communications, William Stallings
- Connection-oriented networks – SONET/SDH, ATM, MPLS, and Optical Networks, Harry G. Perros, Wiley 2005
- Wireless Communications, Andreas F. Molisch, Wiley
- Slides : http://www-phare.lip6.fr/~trnguyen/teaching/2016-2017/rtel

INTRODUCTION

Outline

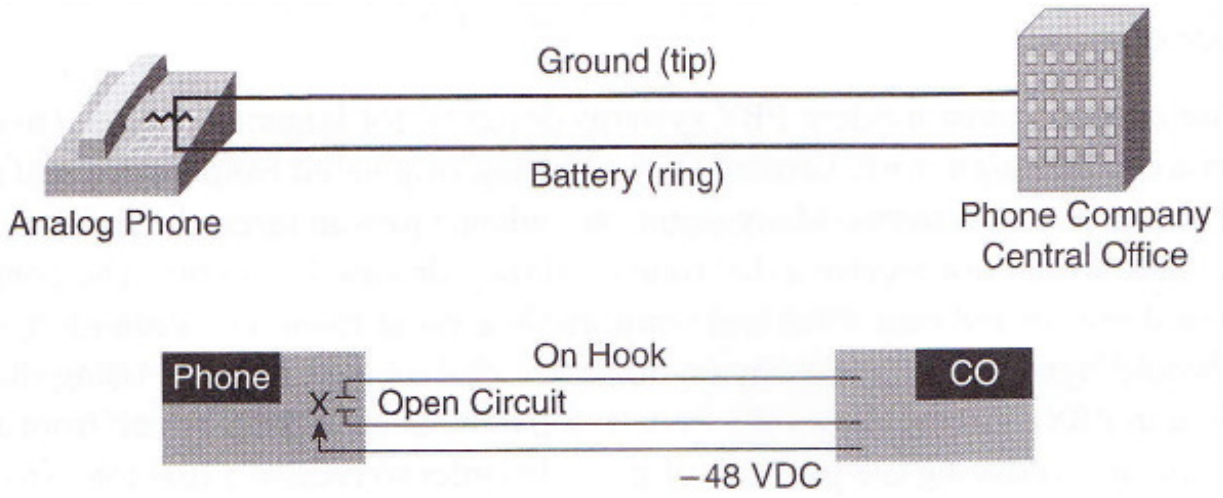
- **History**
  - Telecommunication networks
  - Computer networks
  - Broadcast networks
  - Convergence
- Basic concepts
  - PAN, LAN, MAN, WAN
  - Core and access networks
  - Frame and packet
- Transfer techniques
  - Multiplexing
  - Routing
  - Switching
  - Hybrid

History – 3 network families

- Telecommunication networks (voice services)
  - Telephone networks
  - Cellular networks
- Computer networks (data services)
  - Local area networks
  - Internet
- Audiovisual networks (radio and television services)
  - Television networks
  - Radio broadcasting networks

Telephone networks

- Public Switched Telephone Network (PSTN)
  - Analog circuit



Limitations of analog connections

- Voice quality over long distance
  - Signal quality is degraded along with the distance traveled
  - Repeaters regenerate both voice and noise
- Problem of multiplexing several calls over the same line
  - Each wire is dedicated to only one call

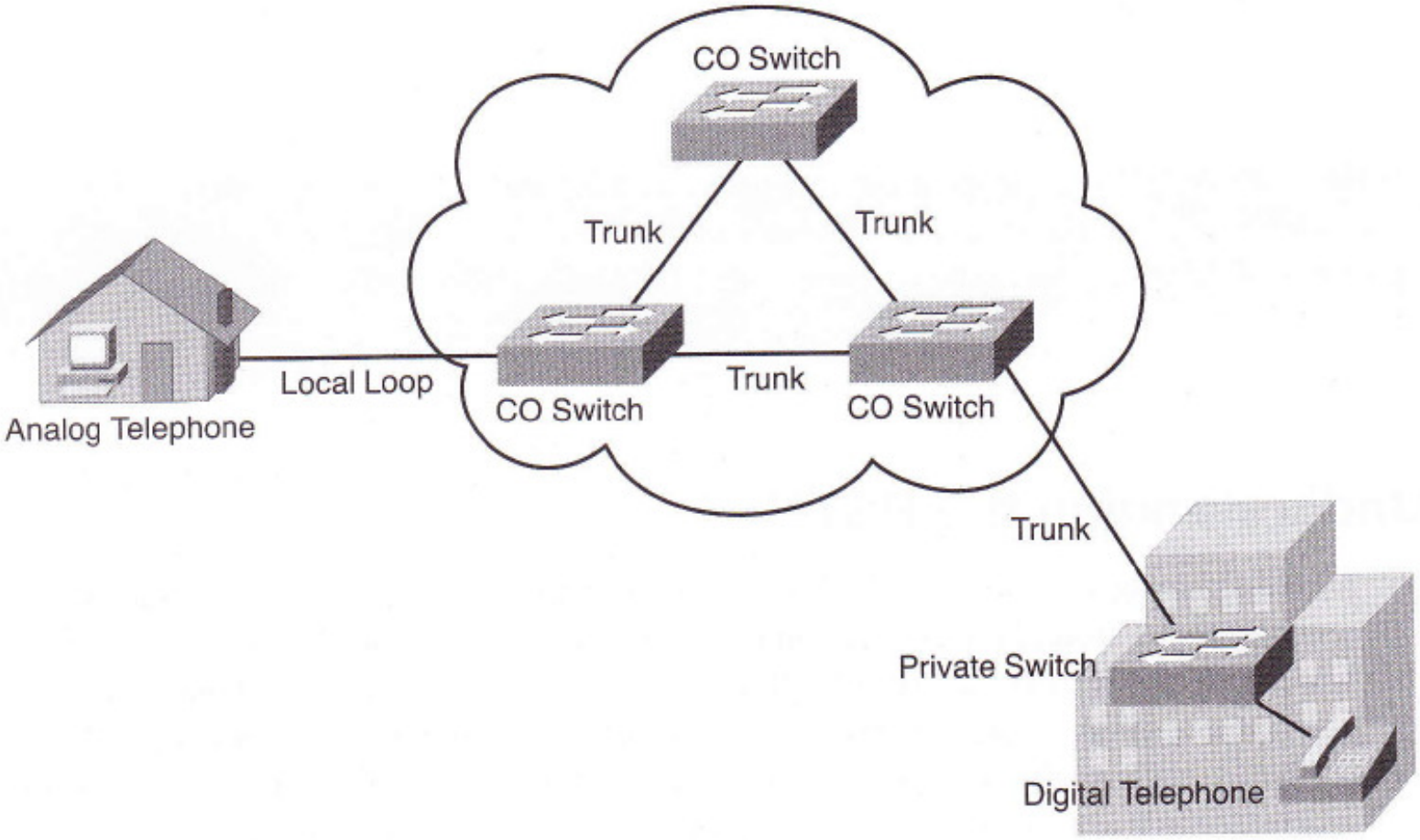
Digital connections

- Digital connections use digital signals instead of analog signals to convey voice
- Digital signal is more resistant to noises
- It is possible to share a single line between simultaneous calls using time-division multiplexing

Analog-Digital conversion

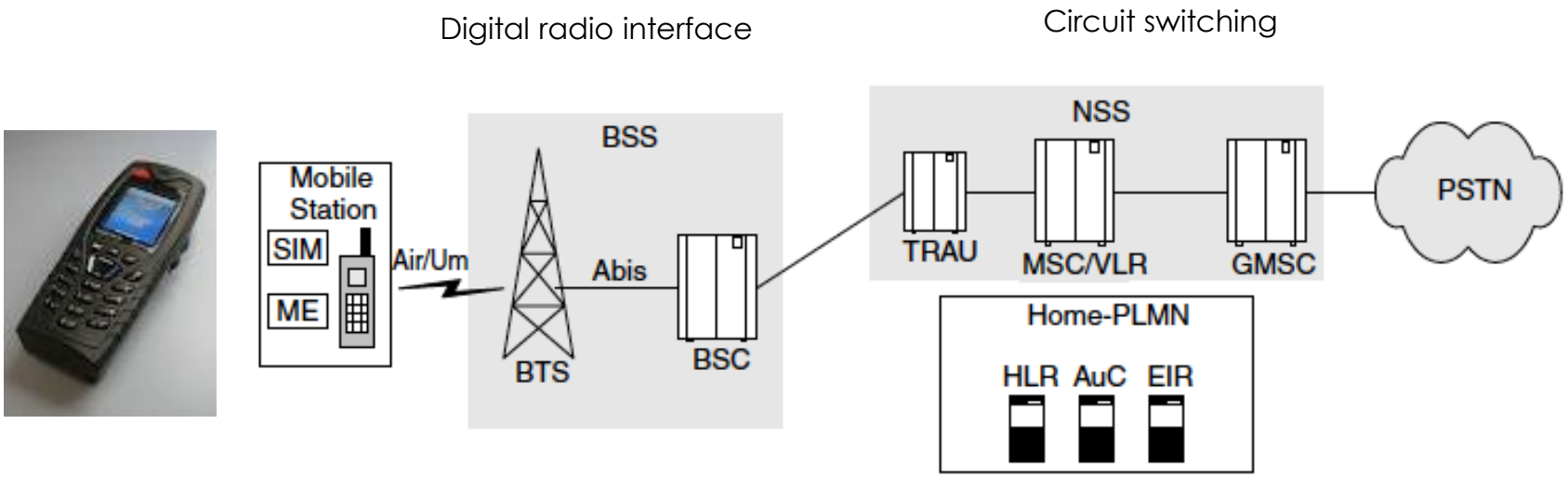
- Sampling
- Quantization
- Encoding
- Compression (optional)

PSTN architecture



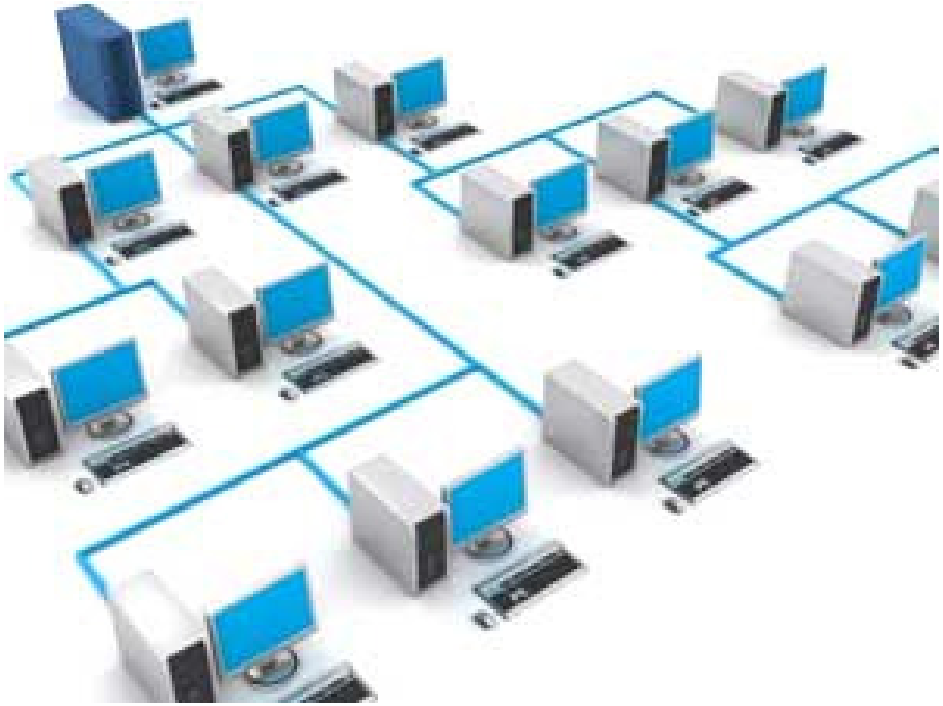
Cellular networks

- GSM

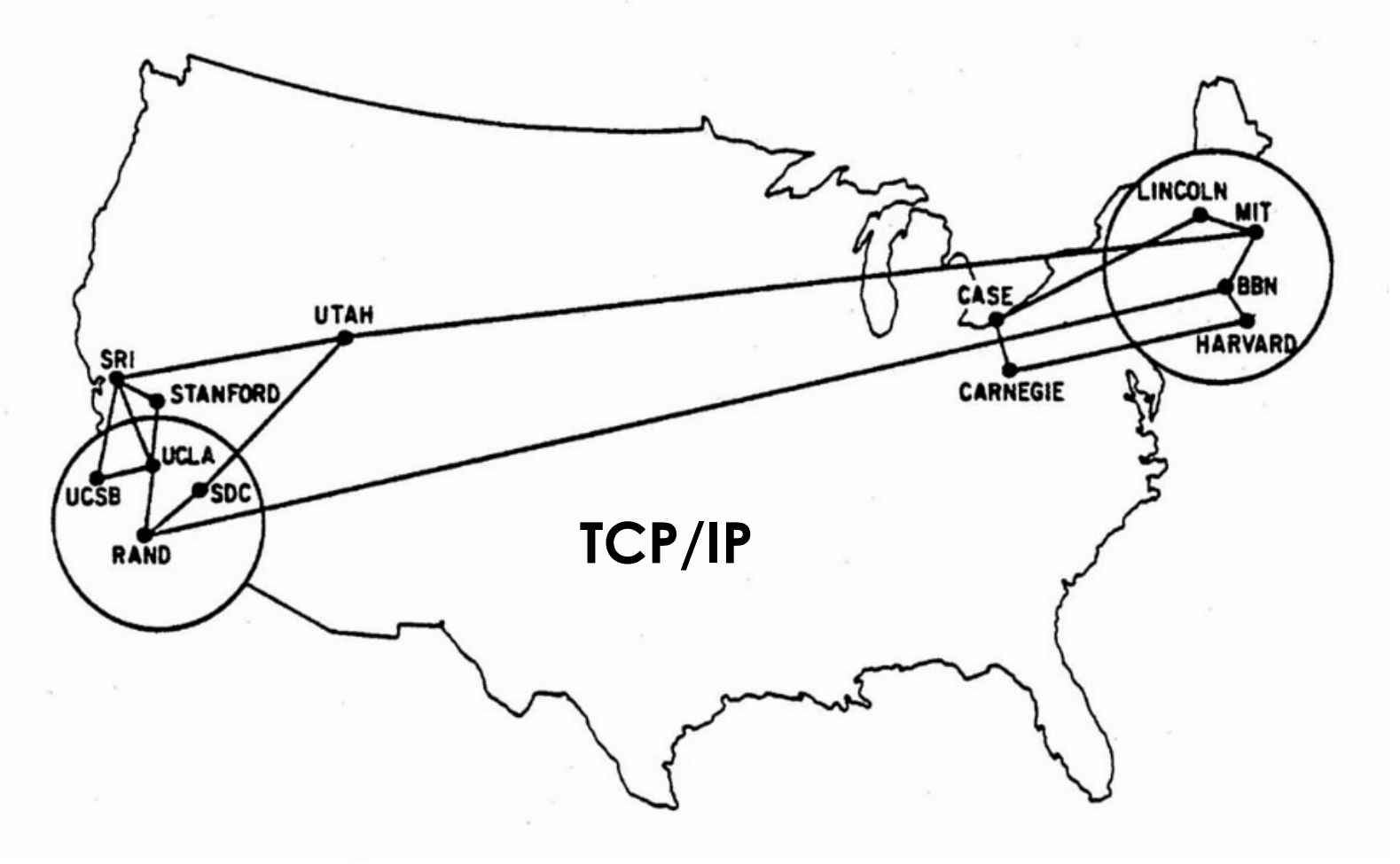


Computer networks

- LAN

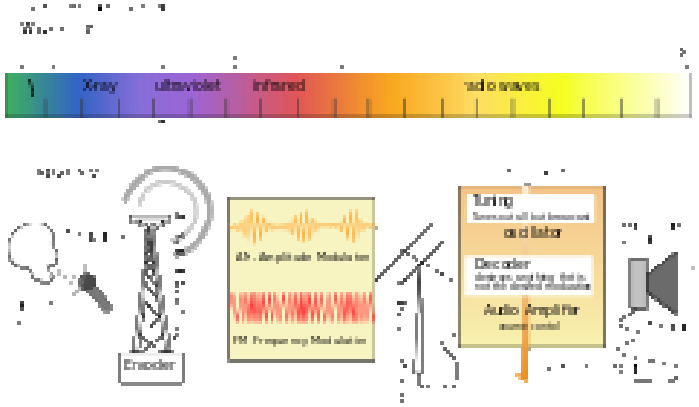


Internet – The ARPANET



Television and radio networks

UHF/VHF



AM/FM

Convergence (1)

- Services have been added into each type of network
  - Voice over IP, Video streaming, television services are available on computers
  - Residential access (ADSL, FTTH) provides Internet access and television services in addition to the voice service
  - Mobile networks offer Internet access, television and radio services
- Users have access to all services independently of the type of network used
- A convergence to all IP-based networks has been witnessed

Convergence (2)

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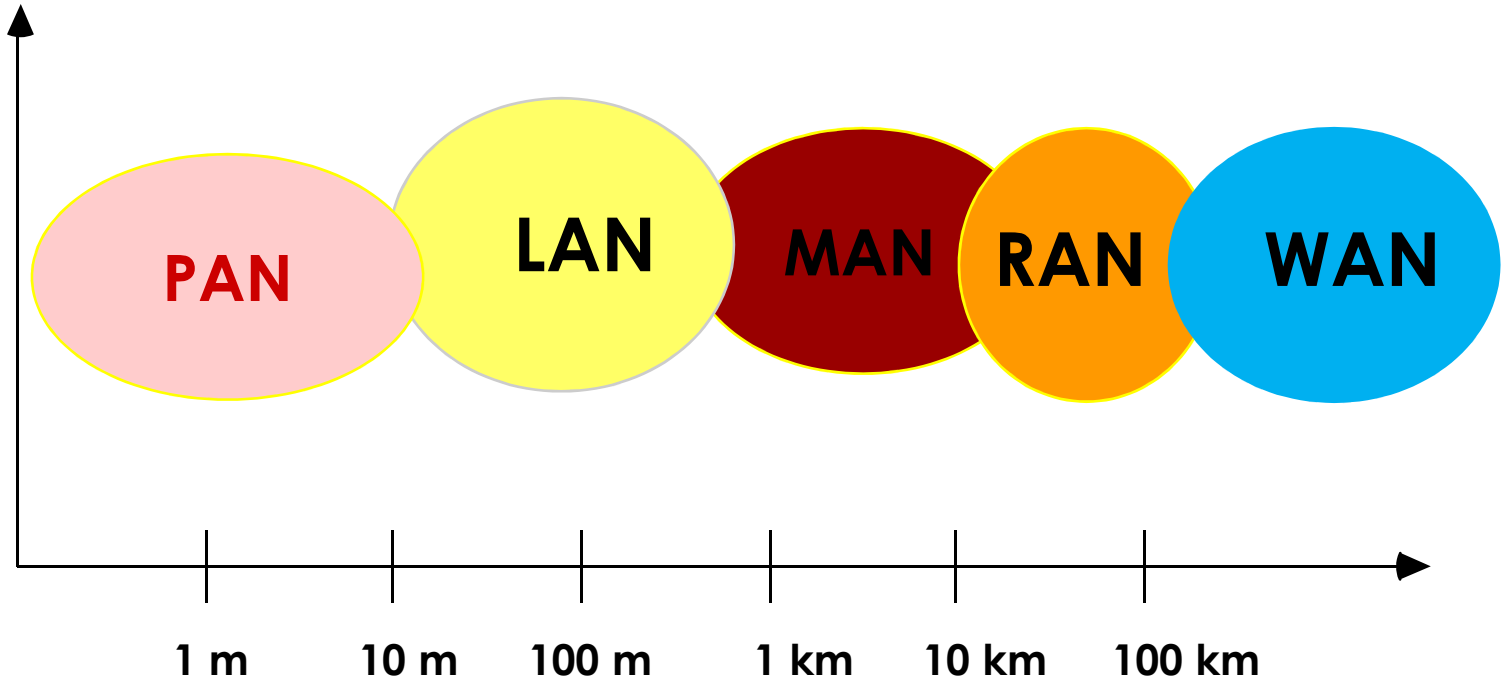
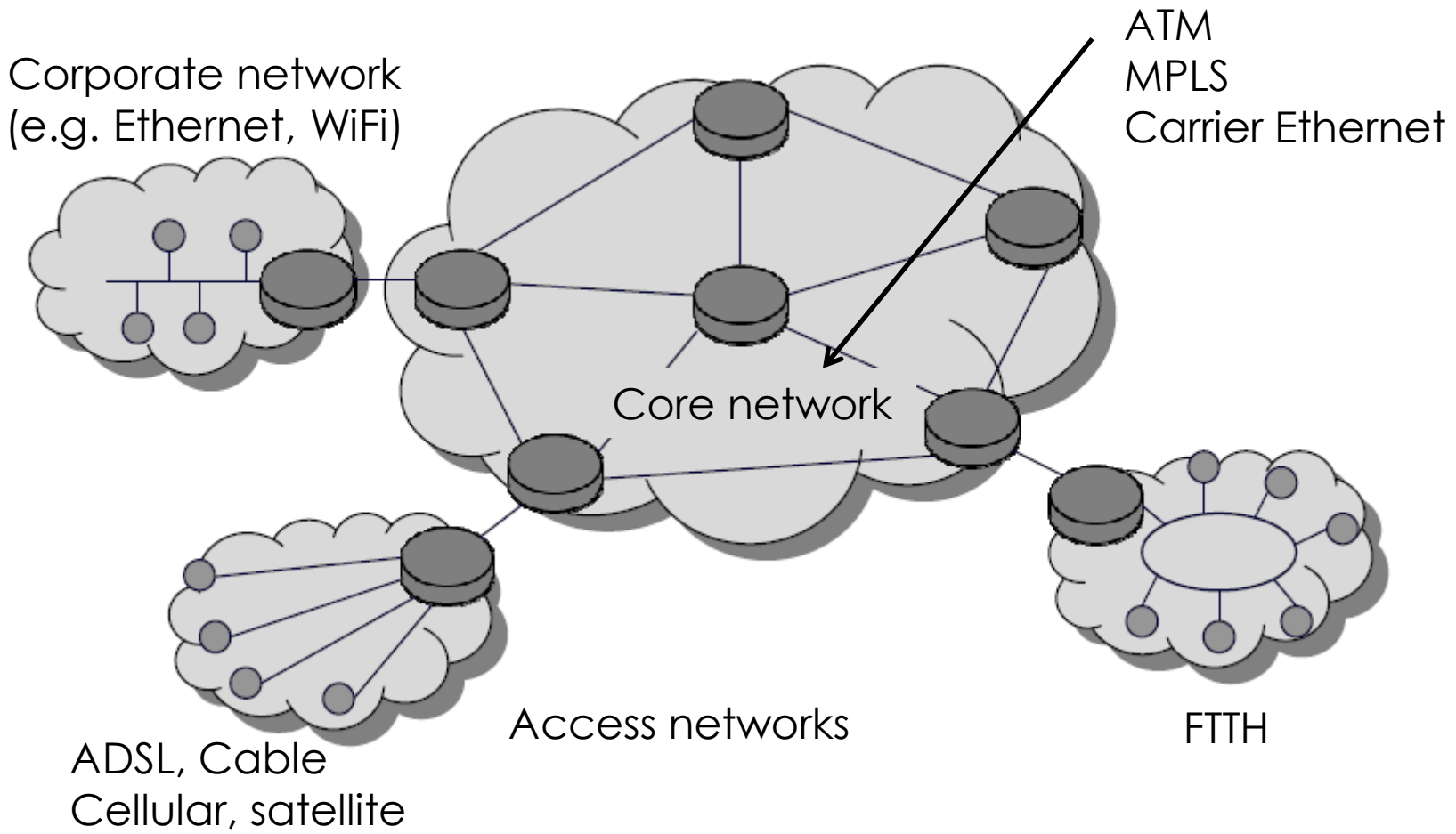
- **Basic concepts**
  - PAN, LAN, MAN, WAN
  - Core and access networks
  - Frame and packet
- Transfer techniques
  - Multiplexing
  - Routing
  - Switching
  - Hybrid

Network classification



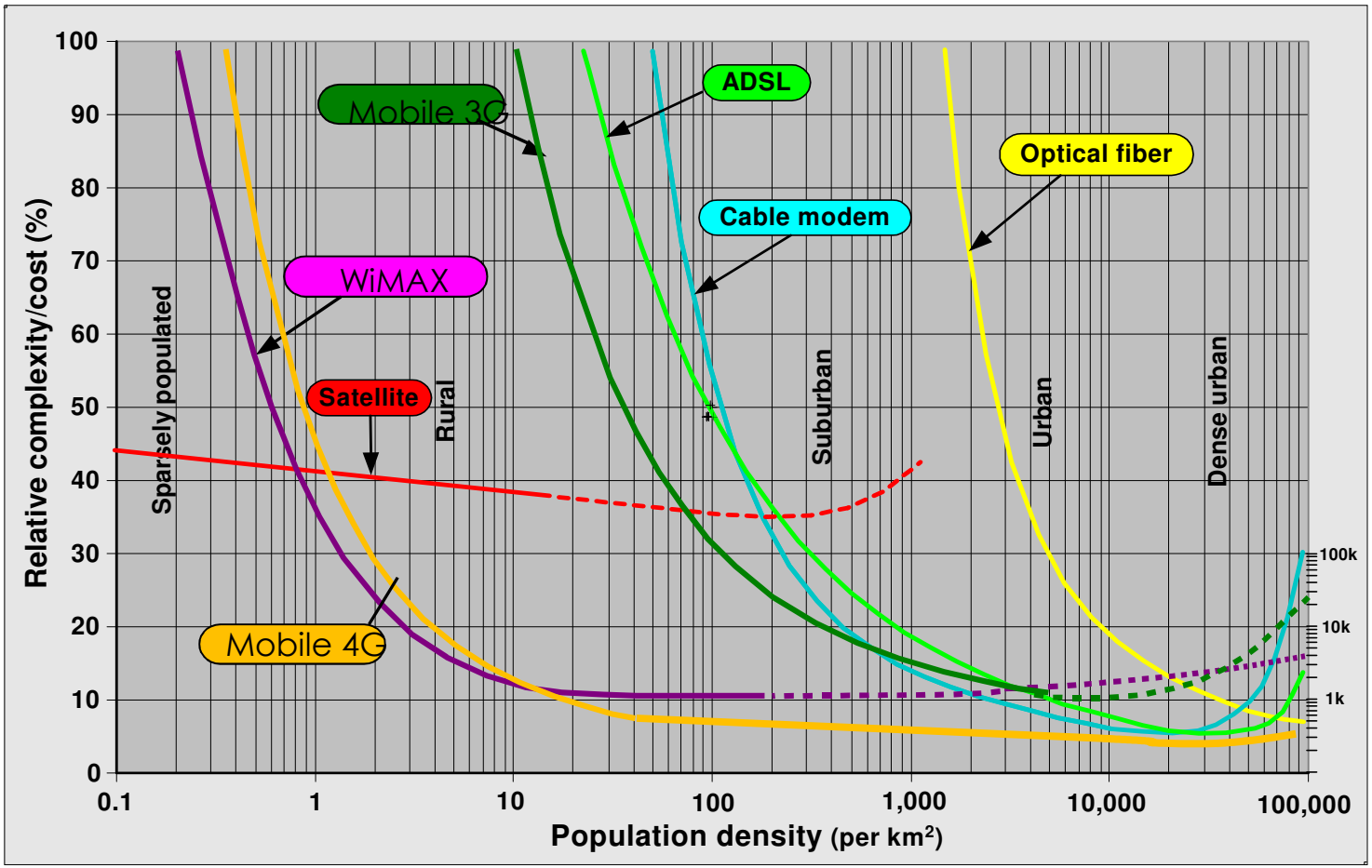
Core and access networks



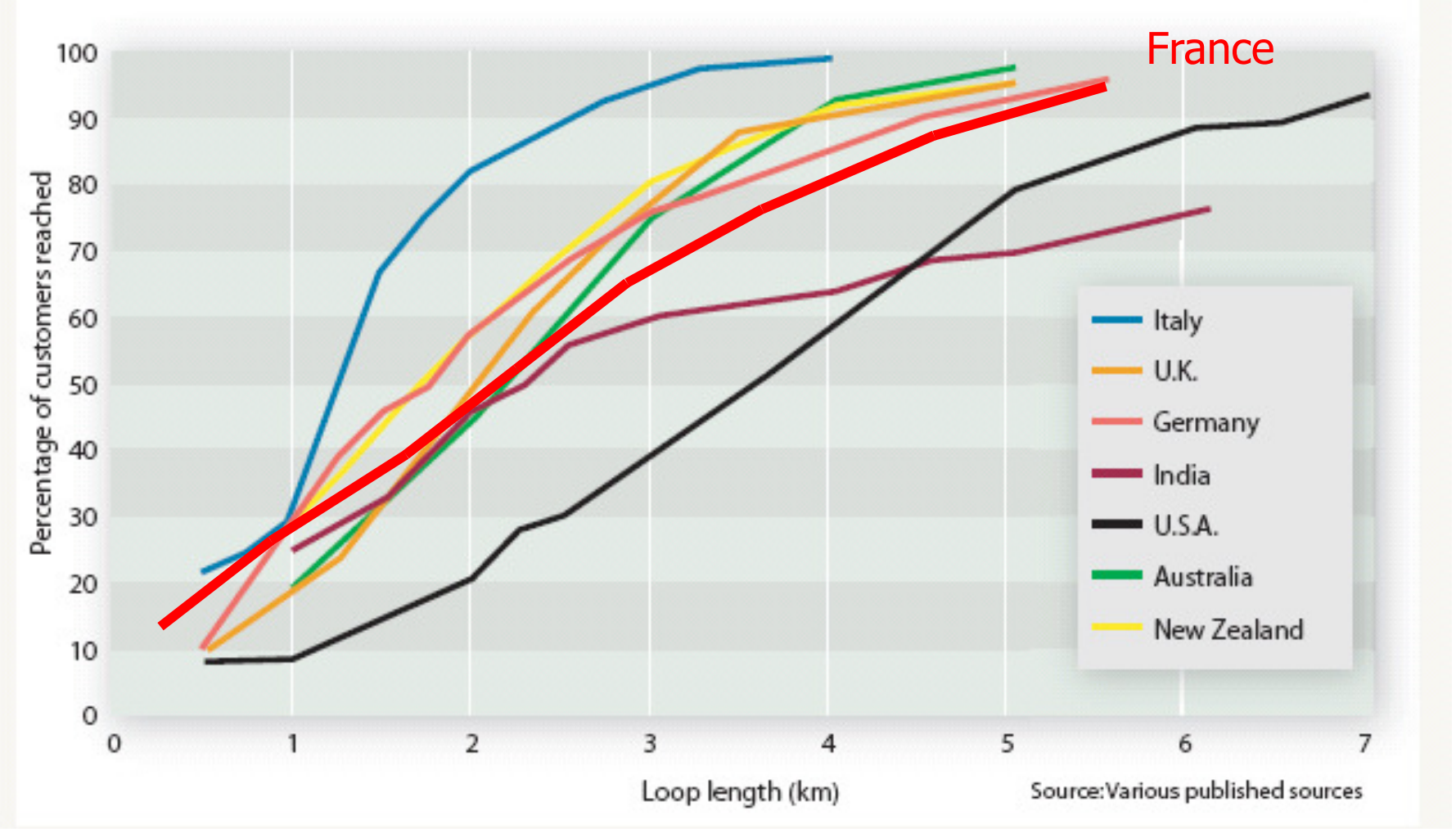
Access Networks Evolution

- A large number of recent technologies:
  - xDSL and unbundling of the local loop
  - CATV, HFC (Hybrid Fiber Coax)
  - FTTx, PON
  - Power Line Communication (PLC)
- WLL (Wireless Local Loop)
  - 802.11 (WiFi)
  - 802.16 (Wimax)
  - Satellites (LEO/MEO/GEO)
  - 3rd Generation Mobile Systems (UMTS)
  - LTE, femtocells

The Local Loop solutions

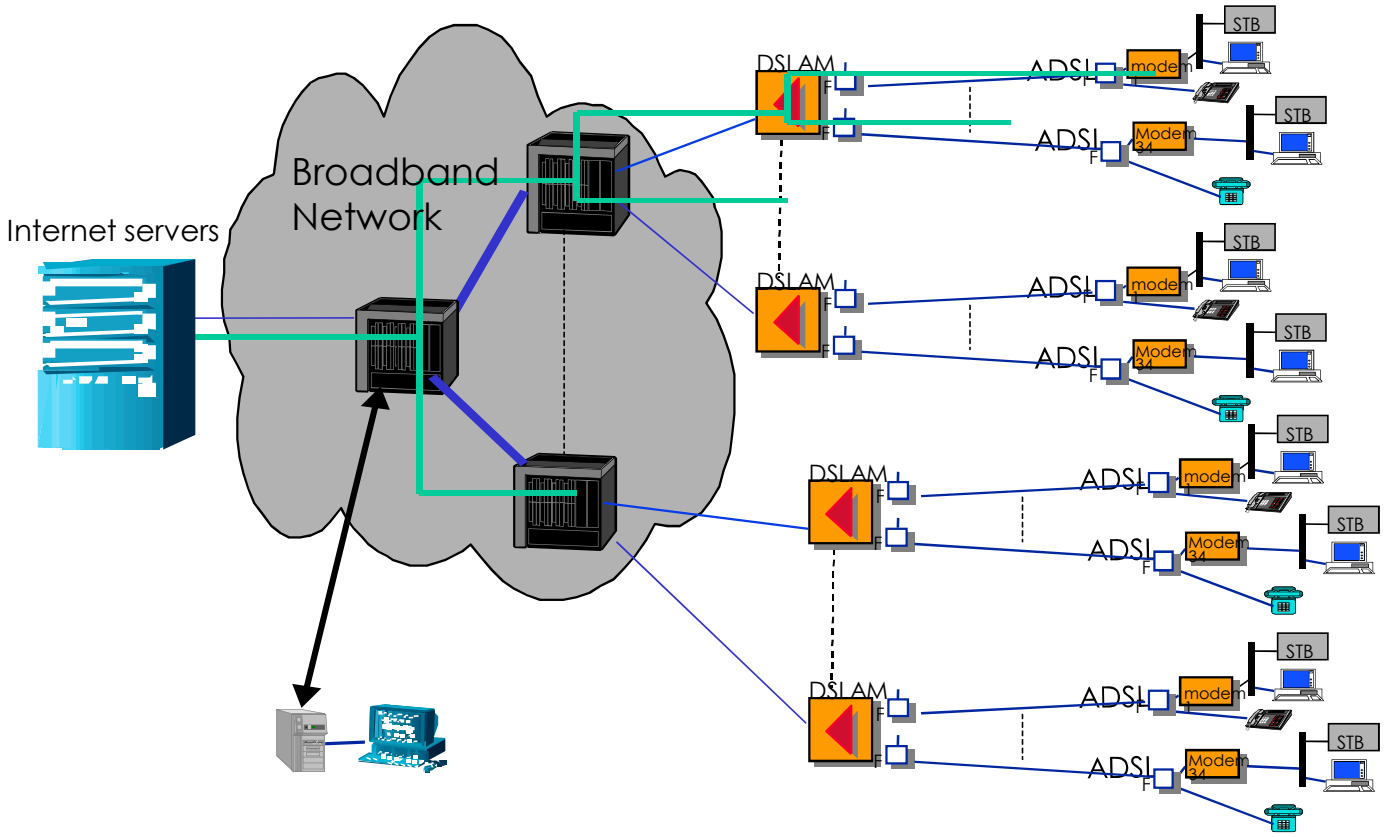


Length of the wired Local Loop



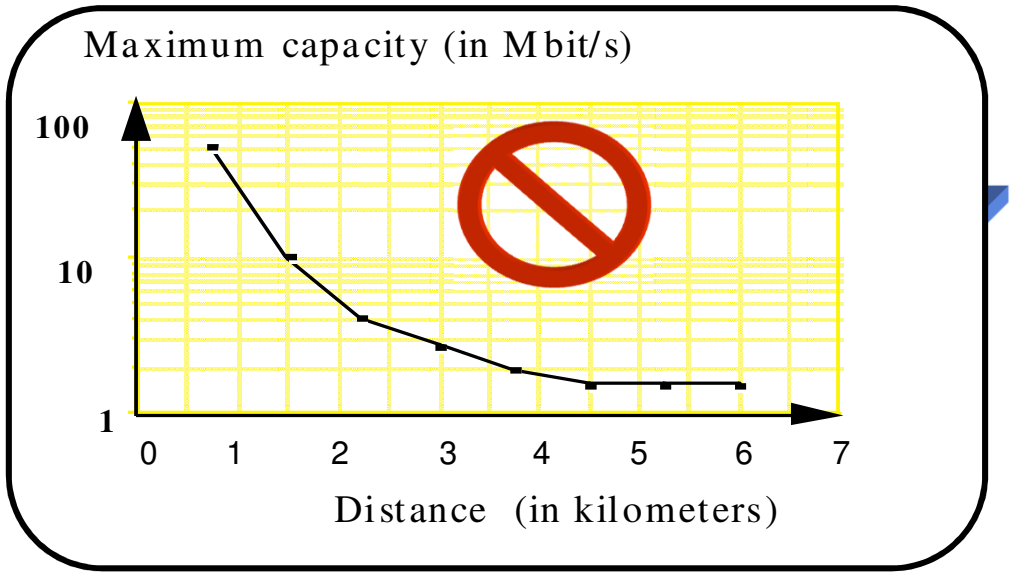
Communication medium (wire)

Legacy wired DSL access infrastructure

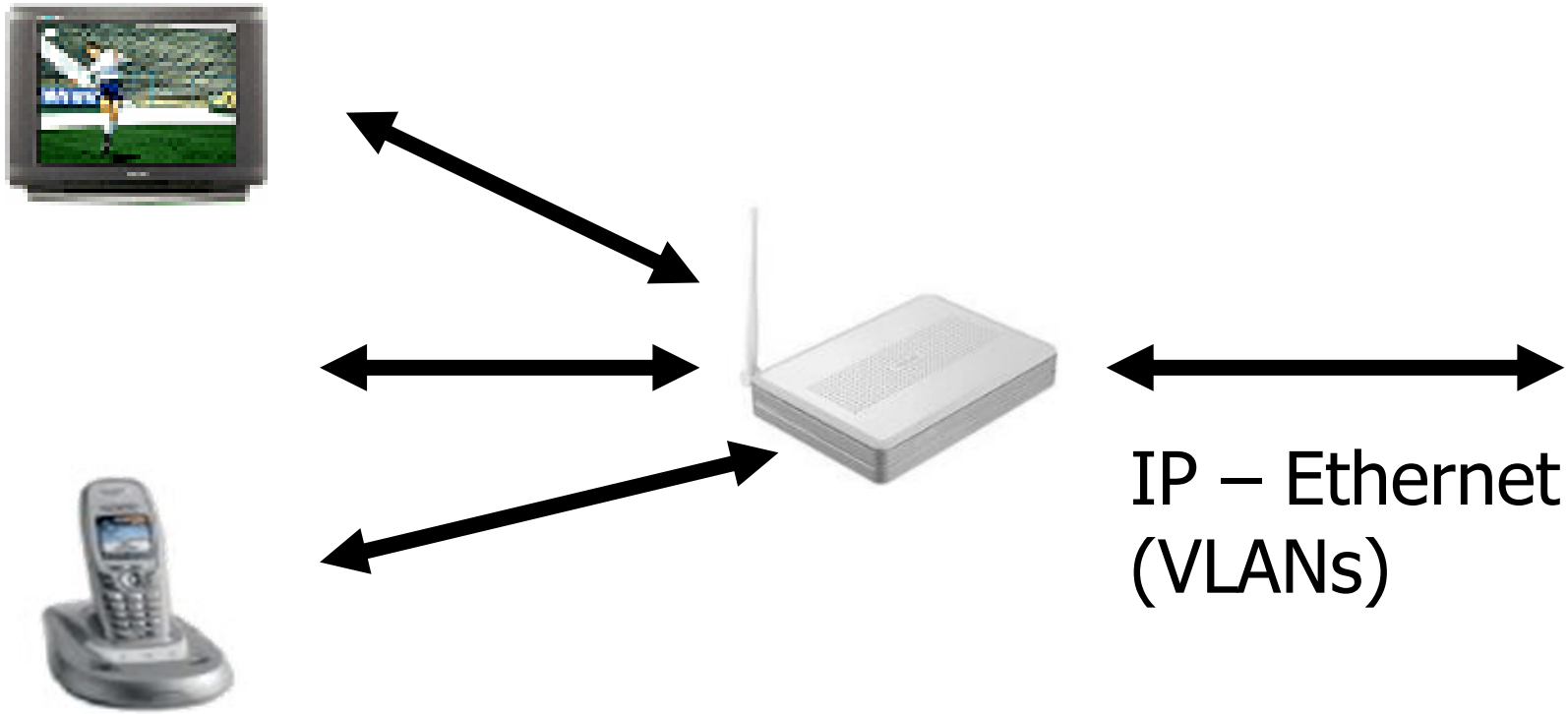


ADSL: bandwidth-distance constraints

- ADSL 2
  - Max 10 Mbps downstream
  - ~ 1 Mbps upstream
- ADSL 2+
  - Max 25 Mbps downstream



Triple play



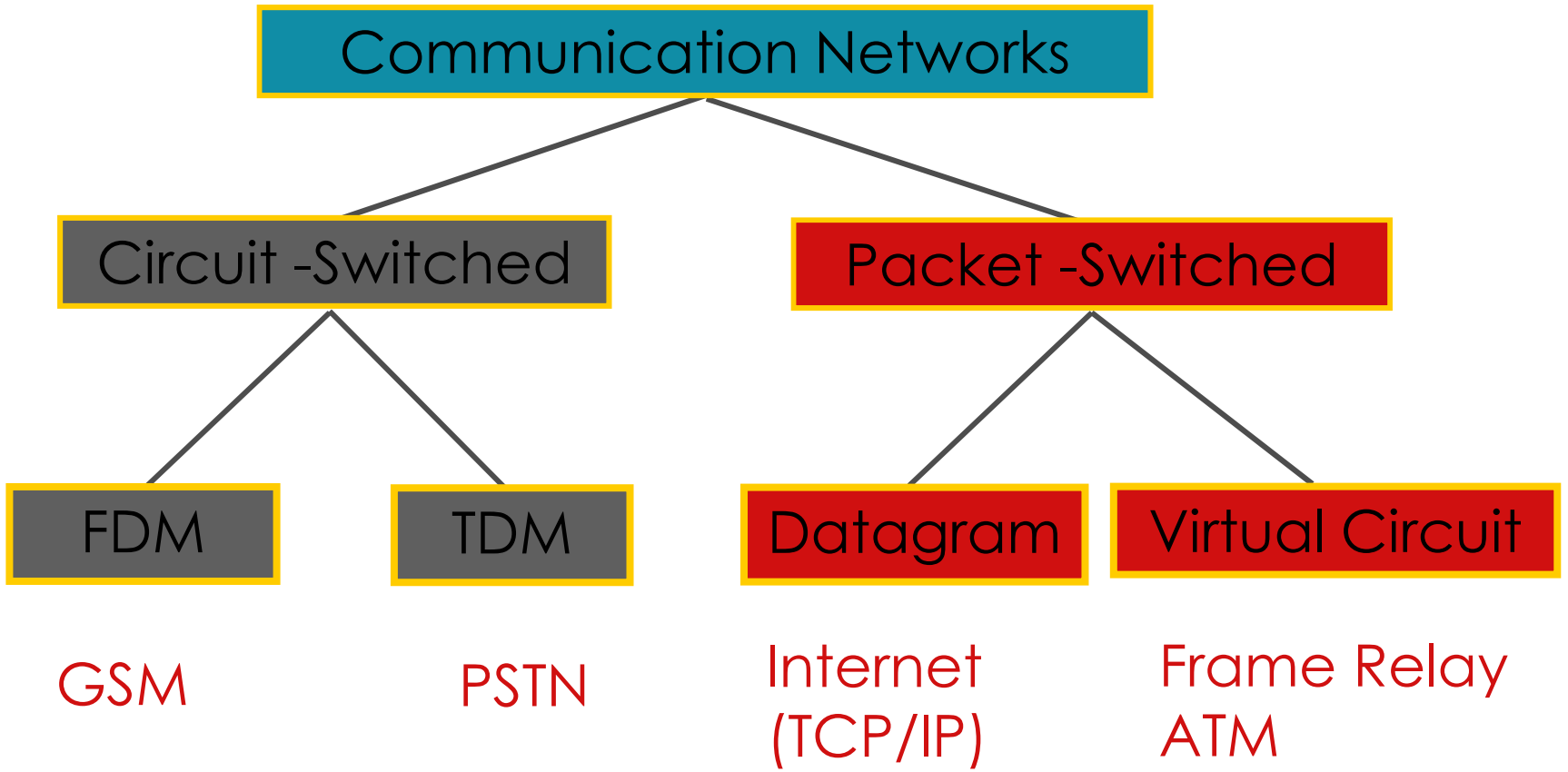
Internet Box : xDSL modem + Codecs + Telephony/TV flows packing

Priorities : Telephony > TV > Data

Core networks

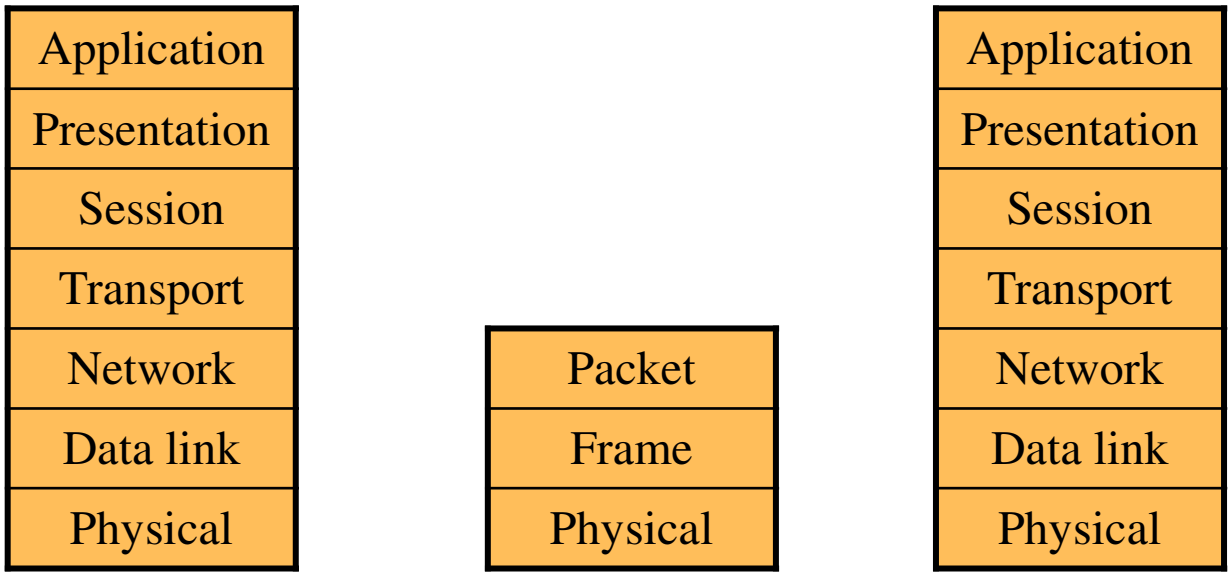
- Implemented using one of these technologies
  - Circuit switching (e.g. telephone network)
    - Dedicated communications path between two stations through the nodes of the network
    - A path is a connected sequence of physical links between nodes
    - On each link, a logical channel is dedicated to the connection
    - Data transmitted as rapidly as possible
  - Packet switching
    - No dedicated resources for a connection
    - Data sent in a sequence of packets
    - In each node, the entire packet is received, stored briefly and then transmitted (store-and-forward mechanism)

Transfer technique taxonomy



Frame and packet

- A frame is a packet with elements allowing to determine the beginning and the end of the packet within series of bits or blocs of bytes
- Frame can be sent directly to the medium
- Packet need to be encapsulated within a frame



Outline

- History
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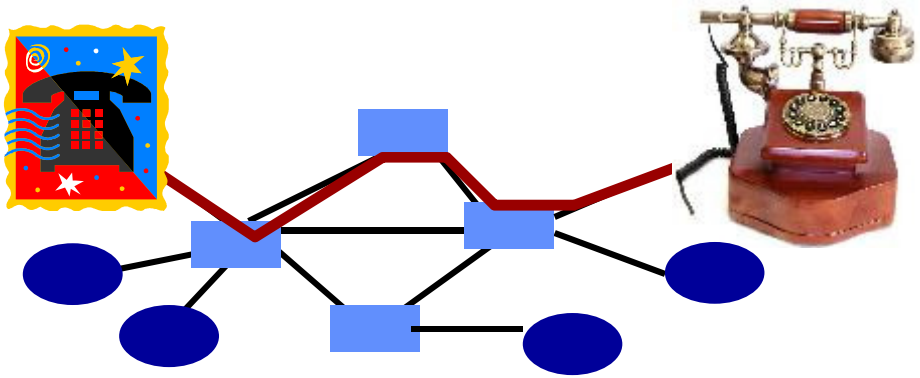
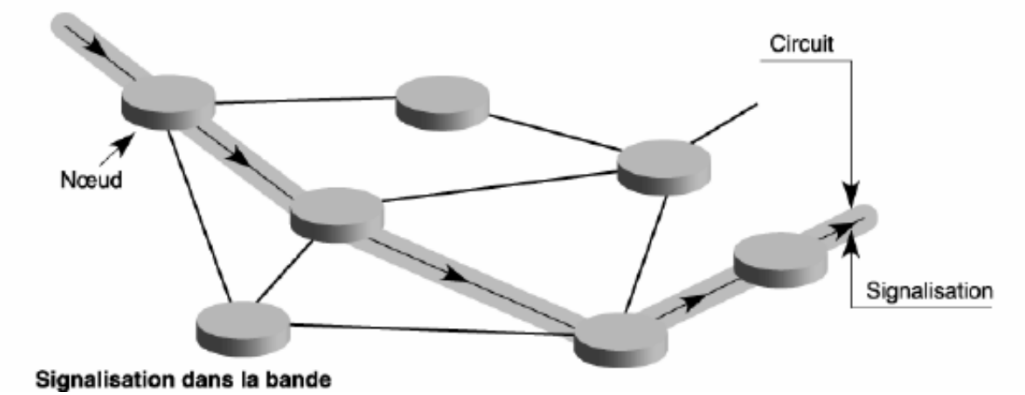
- **Transfer techniques**
  - Multiplexing
  - Routing
  - Switching
  - Hybrid

Circuit switching

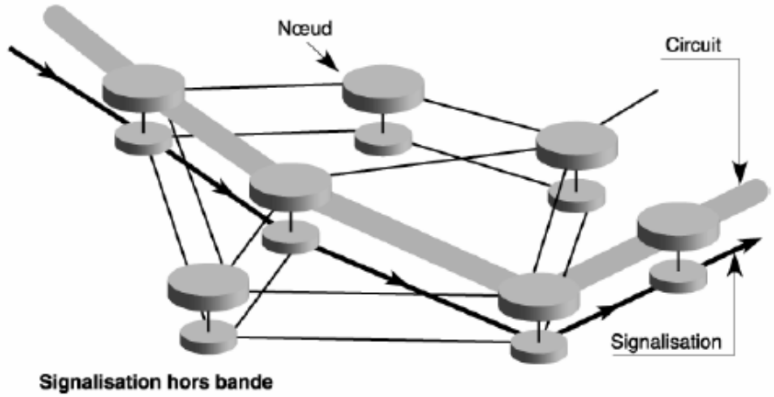
- Source establishes connection to destination
  - Node along the path store connection info
  - Nodes may reserve resources for the connection
- Signaling
  - Signaling in-band: Set-up messages for circuit establishment along the path use the same circuit under construction for communication.
  - Signaling out-band: Set-up messages use a dedicated path different from the circuit under construction.
- Source sends data over the connection
  - No destination address, since nodes know path
- Teardown: source tears down connection when done

Circuit switching



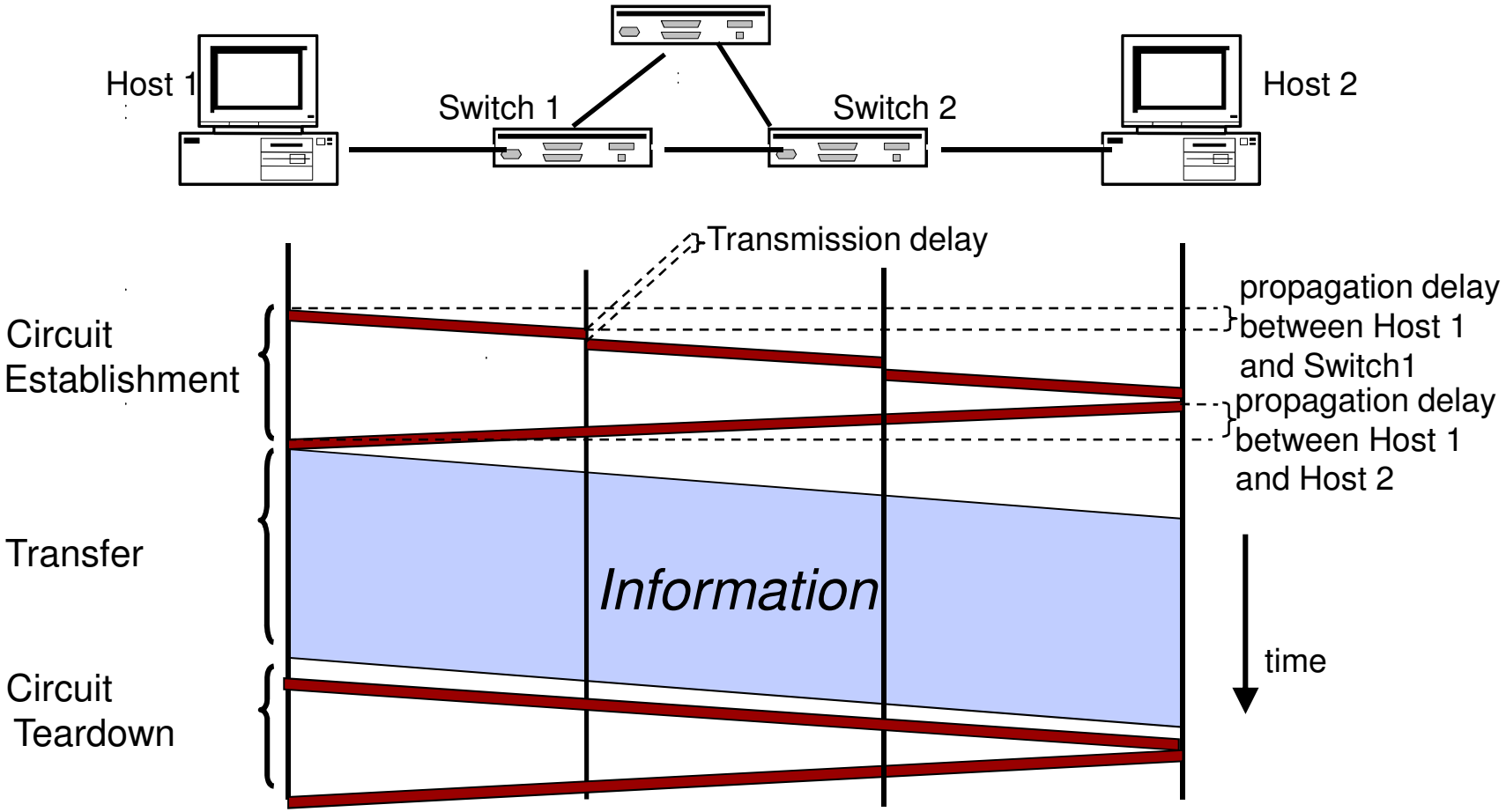


Signalisation dans la bande



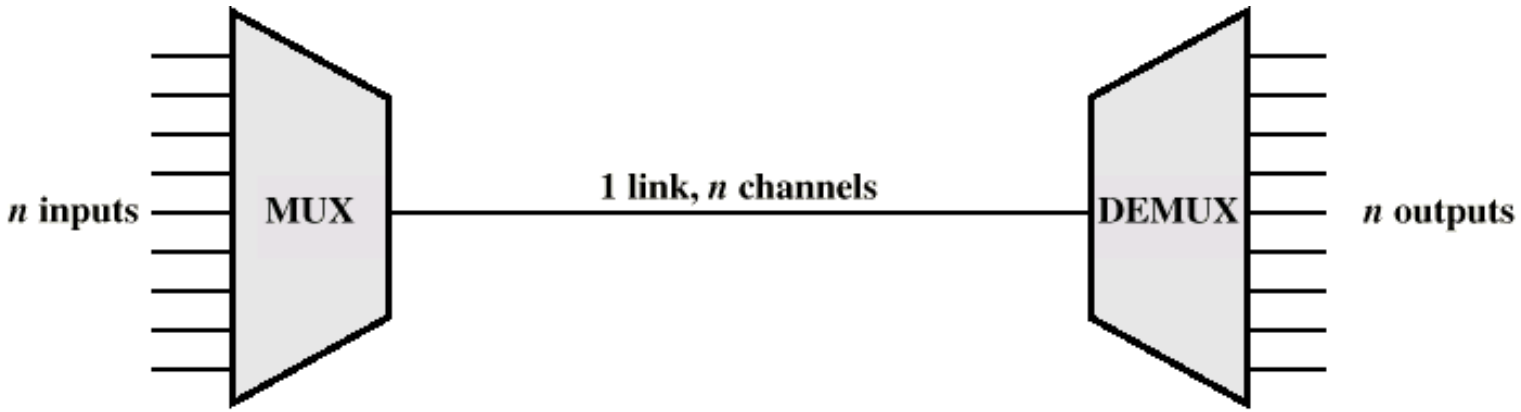
Signalisation hors bande

Data transmission in circuit switching

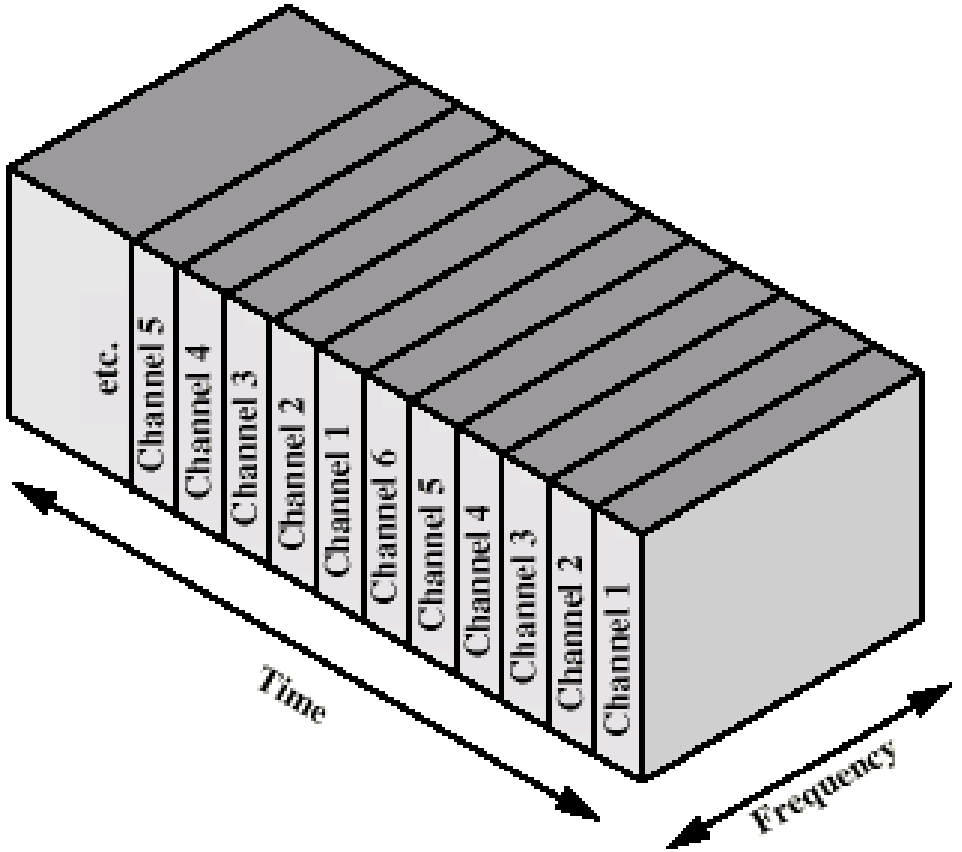


Multiplexing

- To make efficient use of high-speed telecommunications lines, some form of multiplexing is used
- Multiplexing allows several transmission sources to share the same transmission media
- Trunks on long-haul networks are high-capacity fiber, coaxial, or microwave links
- Common forms of multiplexing are Frequency Division Multiplexing (FDM), Time Division Multiplexing (TDM).



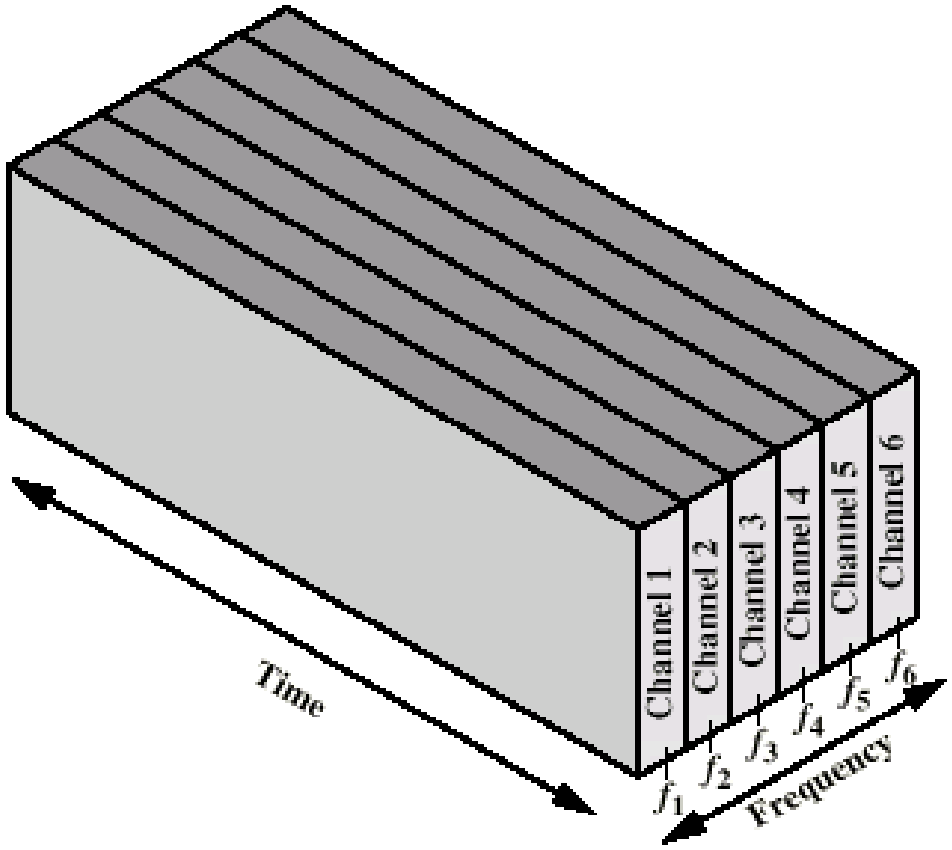
Time Division Multiplexing (TDM)



Time Division Multiplexing (TDM)

- Used with digital signals or analog signals carrying digital data
- Data rate of medium exceeds data rate of digital signal to be transmitted
- Multiple digital signals interleaved in time
- May be at bit level or blocks of Bytes (typically 1 Byte)
- The sequence of slots dedicated to one source is called a channel
- TDM is called synchronous because time slots are preassigned to sources and fixed. The time slots for each source are transmitted whether or not the source has data to send.
- Time slots allocated even if no data
- Time slots do not have to be evenly distributed amongst sources

Frequency Division Multiplexing (FDM)



Frequency Division Multiplexing (FDM)

- Can be used for analog signals. Useful bandwidth of medium exceeds required bandwidth of channel
- Each signal is modulated to a different carrier frequency (move each signal to the required frequency band)
- Carrier frequencies separated so signals do not overlap (guard bands)
- Composite signal transmitted across the medium is analog. However, input signals can be analog/digital.
- If digital input, the input signals must be passed though modems to be converted to analog.
- e.g. broadcast radio
- Channel allocated even if no data

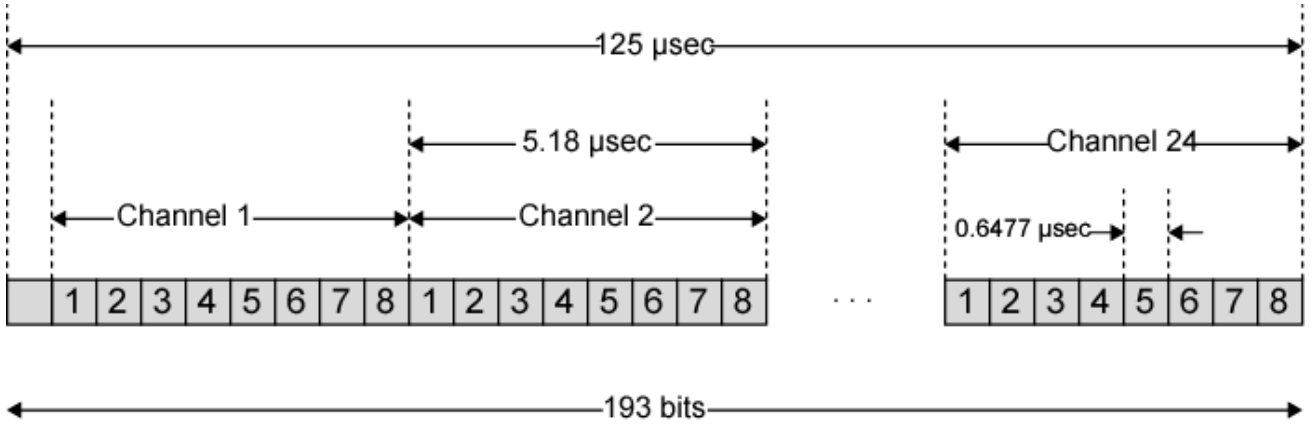
Digital Carrier Systems

- Hierarchy of TDM
  - USA/Canada/Japan use one system, ITU-T (Europe) use a similar (but different) system
- US system based on DS-1 format
  - Multiplexes 24 channels
  - Each frame has 8 bits per channel plus one framing bit: 193 bits per frame
- For voice, each channel contains one word of digitized data (PCM, 8000 samples per sec)
  - A total data rate of 8000*193=1.544Mbps
  - Five out of six frames have 8 bit PCM samples
  - Sixth frame is 7 bit PCM word plus signaling bit
  - Signaling bits form stream for each channel containing control and routing info

Digital Carrier Systems

- Same format for digital data
  - 23 channels of data
    - 7 bits per frame plus indicator bit for data or systems control
  - 24th channel is sync
- DS-1 can carry mixed voice and data signals
- 24 channels used
- No sync byte
- Can also interleave DS-1 channels
  - DS-2 is four DS-1 giving 6.312Mbps

DS1 frame format



Notes:

1. The first bit is a framing bit, used for synchronization.
2. Voice channels:
   8-bit PCM used on five of six frames.
   7-bit PCM used on every sixth frame; bit 8 of each channel is a signaling bit.
3. Data channels:
   Channel 24 is used for signaling only in some schemes.
   Bits 1-7 used for 56 kbps service
   Bits 2-7 used for 9.6, 4.8, and 2.4 kbps service.

TDM applications

- Digital Service lines: DS-n
  - Implemented as telephone lines: T-n

Service	Phone line	Data rate	# of voice channels
(DS-0)	standard phone line	64 Kb/s	1
DS-1	T-1	1.544 Mb/s	24
DS-2	T-2	6.312 Mb/s	96
DS-3	T-3	44.736 Mb/s	672
DS-4	T-4	274.176 Mb/s	4032

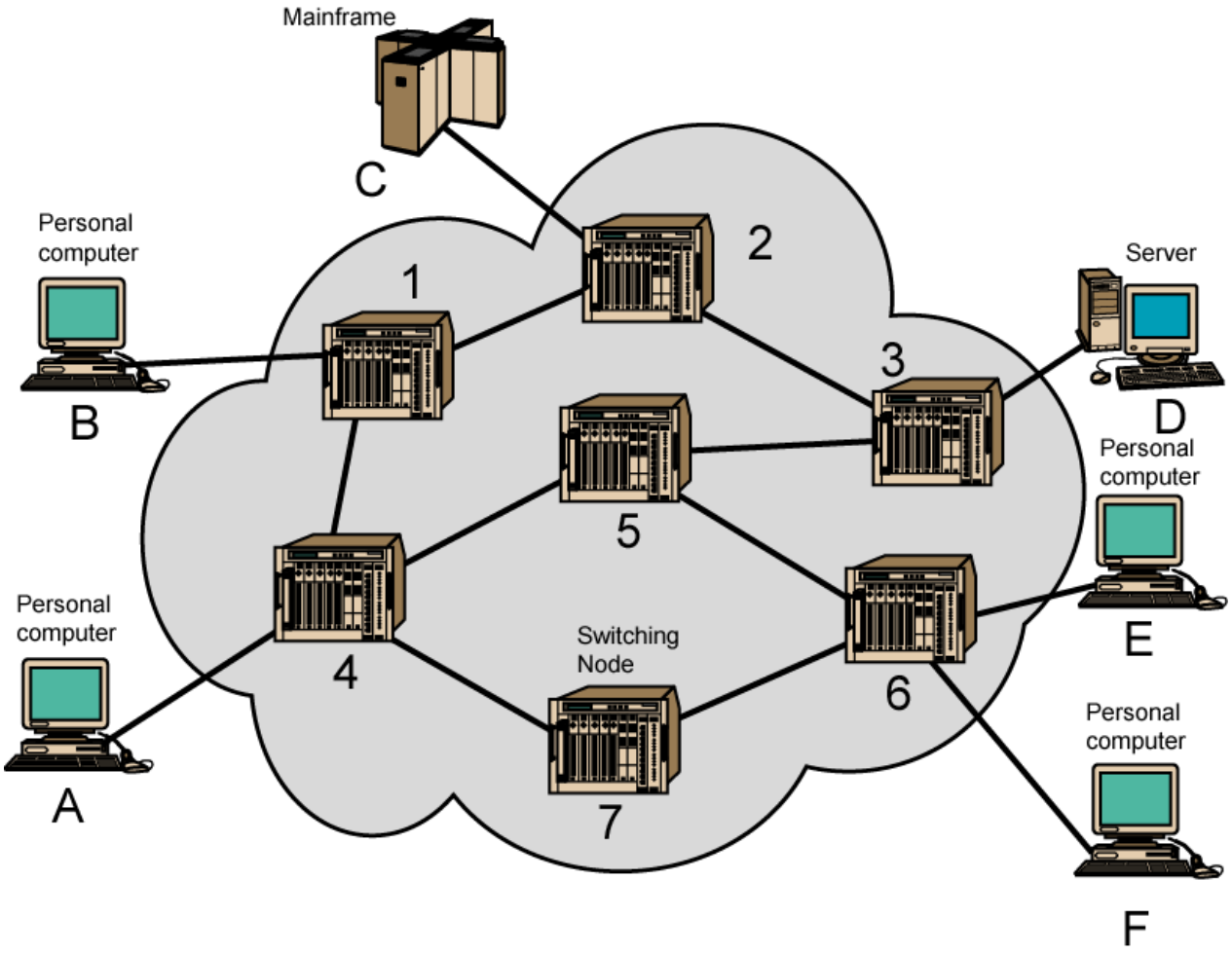
Strength of circuit switching

- Guaranteed bandwidth
  - Predictable communication performance
  - Not "best-effort" delivery
- Simple abstraction
  - Reliable communication channel between hosts
  - No worries about lost or out-of-order packets
- Simple forwarding
  - Forwarding based on time slot or frequency
  - No need to inspect a packet header
- Low per-packet overhead
  - Forwarding based on time slot or frequency
  - No byte consumed for packet header purpose

Drawback of circuit switching

- Wasted bandwidth
  - Bursty traffic leads to idle connection during silent period
  - Unable to achieve gains from statistical multiplexing
- Blocked connections
  - Connection refused when resources are not sufficient
  - Unable to offer "okay" service to everybody
- Connection set-up delay
  - No communication until the connection is set up
  - Unable to avoid extra latency for small data transfers
- Network state
  - Network nodes must store per-connection information
  - Unable to avoid per-connection storage and state

Packet switching



Why packet switching ?

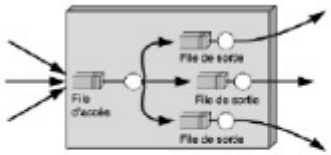
- Circuit switching designed for voice
  - Resources dedicated to a particular call
  - Much of the time a data connection is idle
  - Data rate is fixed
    - Both ends must operate at the same rate
- Solution: packet switching

Packet switching principles

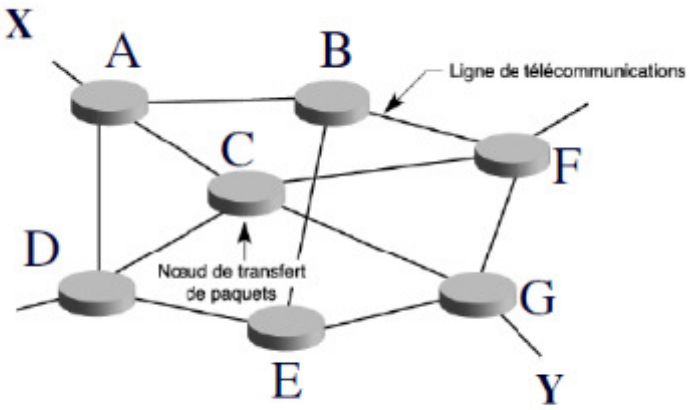
- Data traffic divided into packets
  - Data transmitted in small packets (typically 1000 octets)
  - Longer messages split into series of packets
  - Each packet contains a portion of user data plus some control info
- Control info
  - Routing (addressing) info
- Packets travel separately through network
  - Packet forwarding based on the header
    - Use a reference or label in the header: trace a "Virtual Circuit" using signaling messages (e.g., ATM),
    - Use the full destination IP address for forwarding (no signaling) => routing with IP datagram (e.g., Internet)
  - Network nodes may store packets temporarily: Store and forward
- Destination reconstructs the message

Routing

- Each node has a unique
- Destination address is carried in the IP header
- At each node, a routing table is used to determine the output interface towards the destination

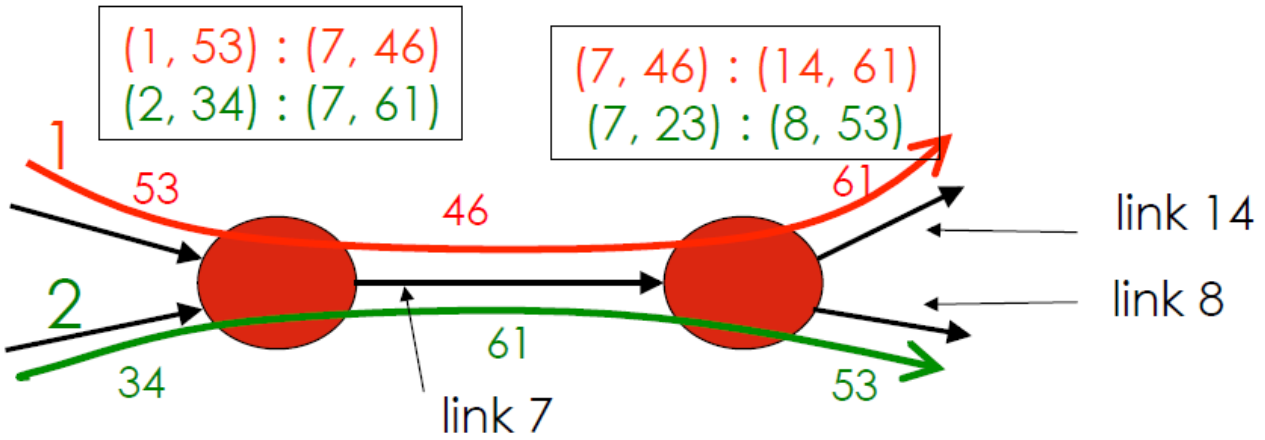


Destination	Interface de sortie
Y	C
F	B
E	D
…	…



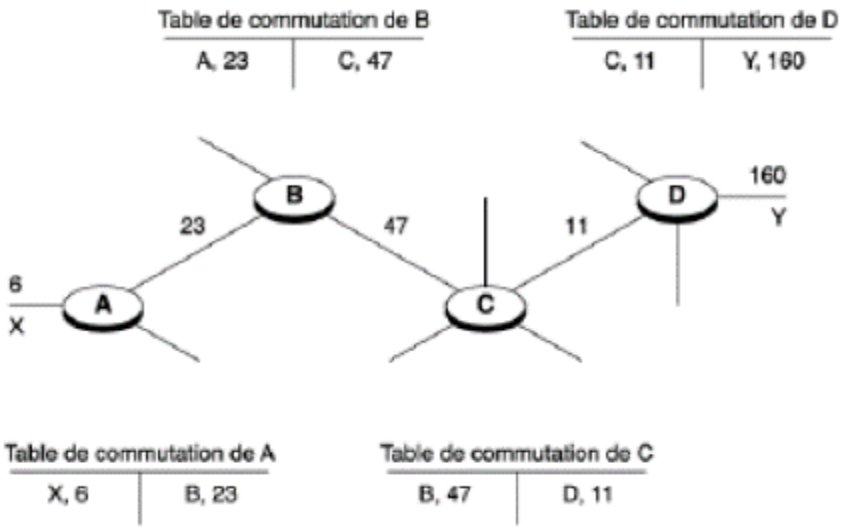
Switching

- Each node has a unique address
- A virtual circuit need to be established before sending packets to users.
- Packets did not contain the destination address, but a label or reference (VC ID), which has a local signification (only along the link between two neighboring nodes)
- At each node (called switch), a switching table is used to indicate the output interface as well as the out label according to the incoming label and interface (label swapping).



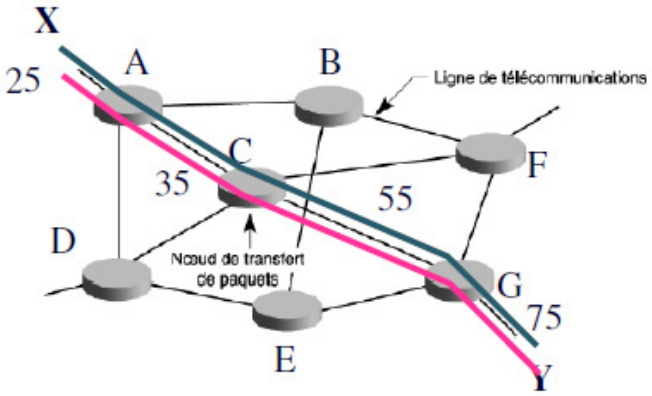
Virtual Circuit

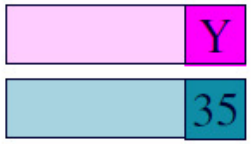
- A VC is a preplanned route established before any packets sent
- VC is a succession of VC ID along a path
- Packets of a same connection use the same path (the Virtual Circuit)
- No out of order packets
- The circuit is called virtual since links are not dedicated

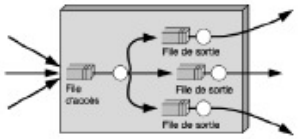


Signaling

Destination	Interface de sortie
Y	2
B	3
C	4
…	…







Interface d'entrée	Référence d'entrée	Interface de sortie	Référence de sortie
D	40	F	42
F	30	A	33
…	…	…	…

VC establishment

- Signaling
  - Creating the entries in the forwarding tables
  - Reserving resources for the virtual circuit, if needed
- Two main approaches to signaling
  - Network administrator configures each node
  - Source sends set-up message along the path
- Set-up latency
  - Time for the set-up message to traverse the path
  - … and return back to the source
- Routing
  - End-to-end path is selected during circuit set-up

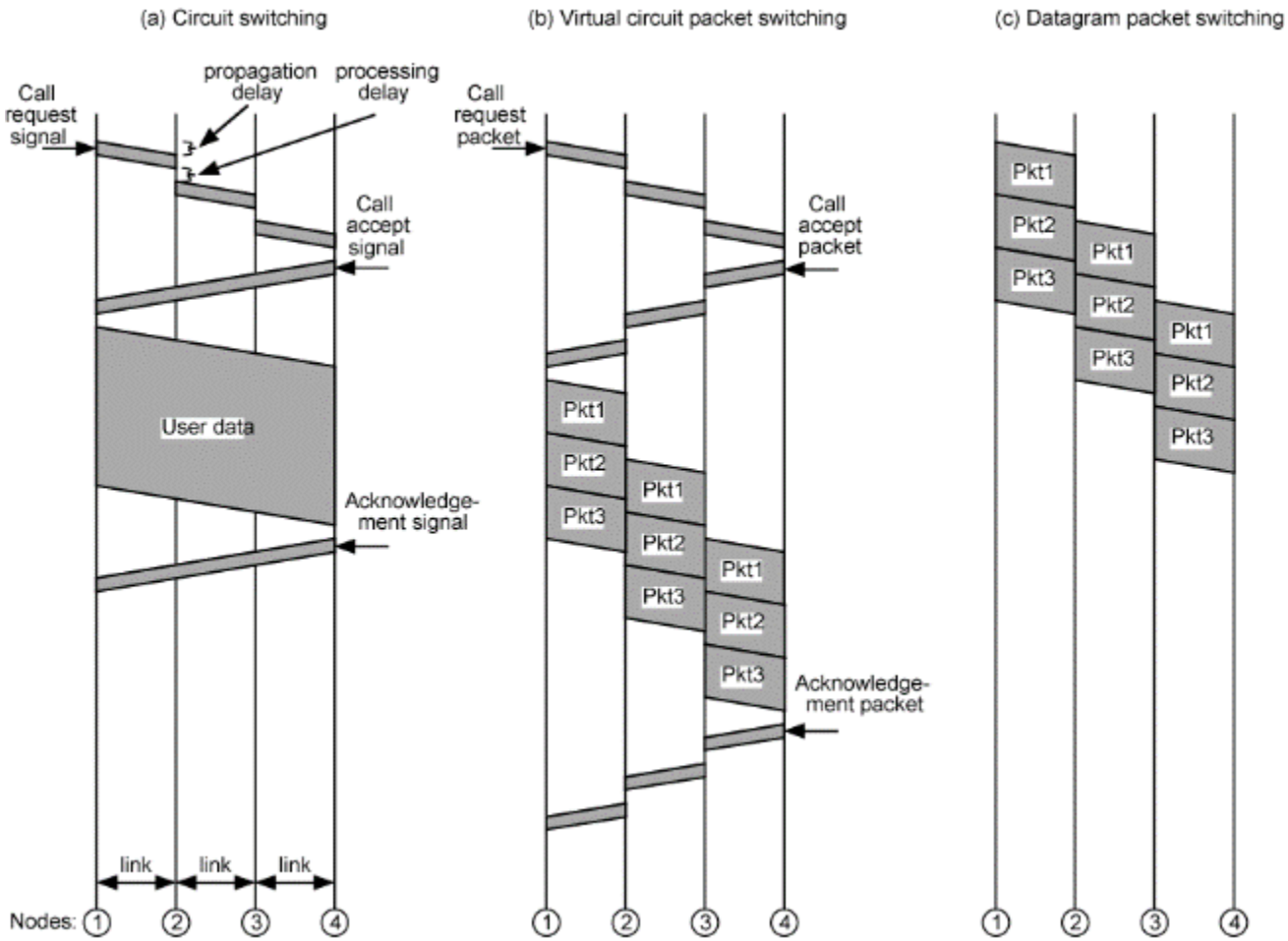
Similarity between VC and Datagram

- Data divided in to packets
  - Sender divides the data into packets
  - Packet has address (e.g., IP address or VC ID)
- Store-and-forward transmission
  - Multiple packets may arrive at once
  - Need buffer space for temporary storage
- Multiplexing on a link
  - No reservations: statistical multiplexing
    - Packets are interleaved without a fixed pattern
  - Reservations: resources for group of packets
    - Guarantees to get a certain number of "slots"

Difference between VC and Datagram

- Forwarding look-up
  - Virtual circuits: fixed-length connection id
  - IP datagrams: destination IP address
- Initiating data transmission
  - Virtual circuits: must signal along the path
  - IP datagrams: just start sending packets
- Router state
  - Virtual circuits: routers know about connections
  - IP datagrams: no state, easier failure recovery
- Quality of service
  - Virtual circuits: resources and scheduling per VC
  - IP datagrams: difficult to provide QoS

Transfer delay



Hybrid architecture

- Nodes are switching and routers at the same time