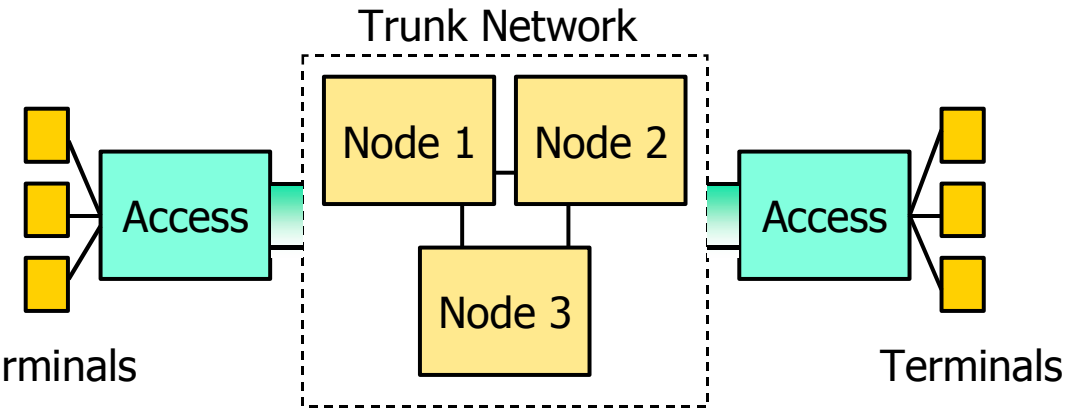
Public Switched Telephone Network (PSTN)

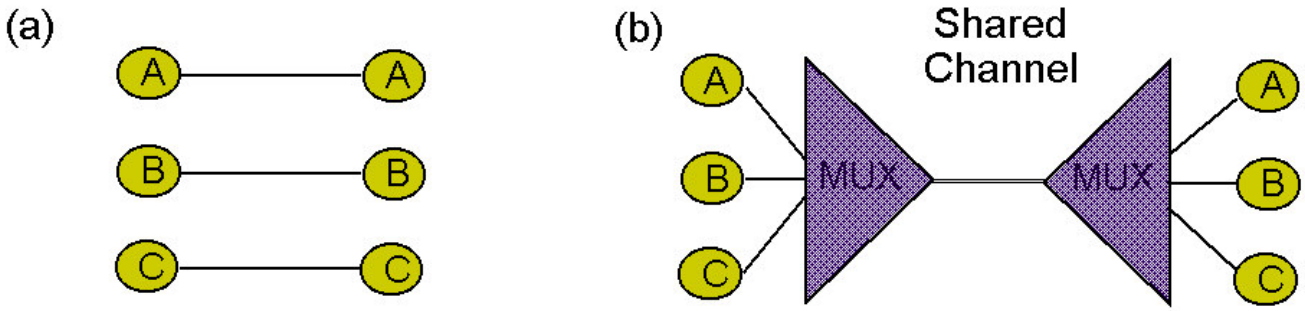
Topics in PSTN



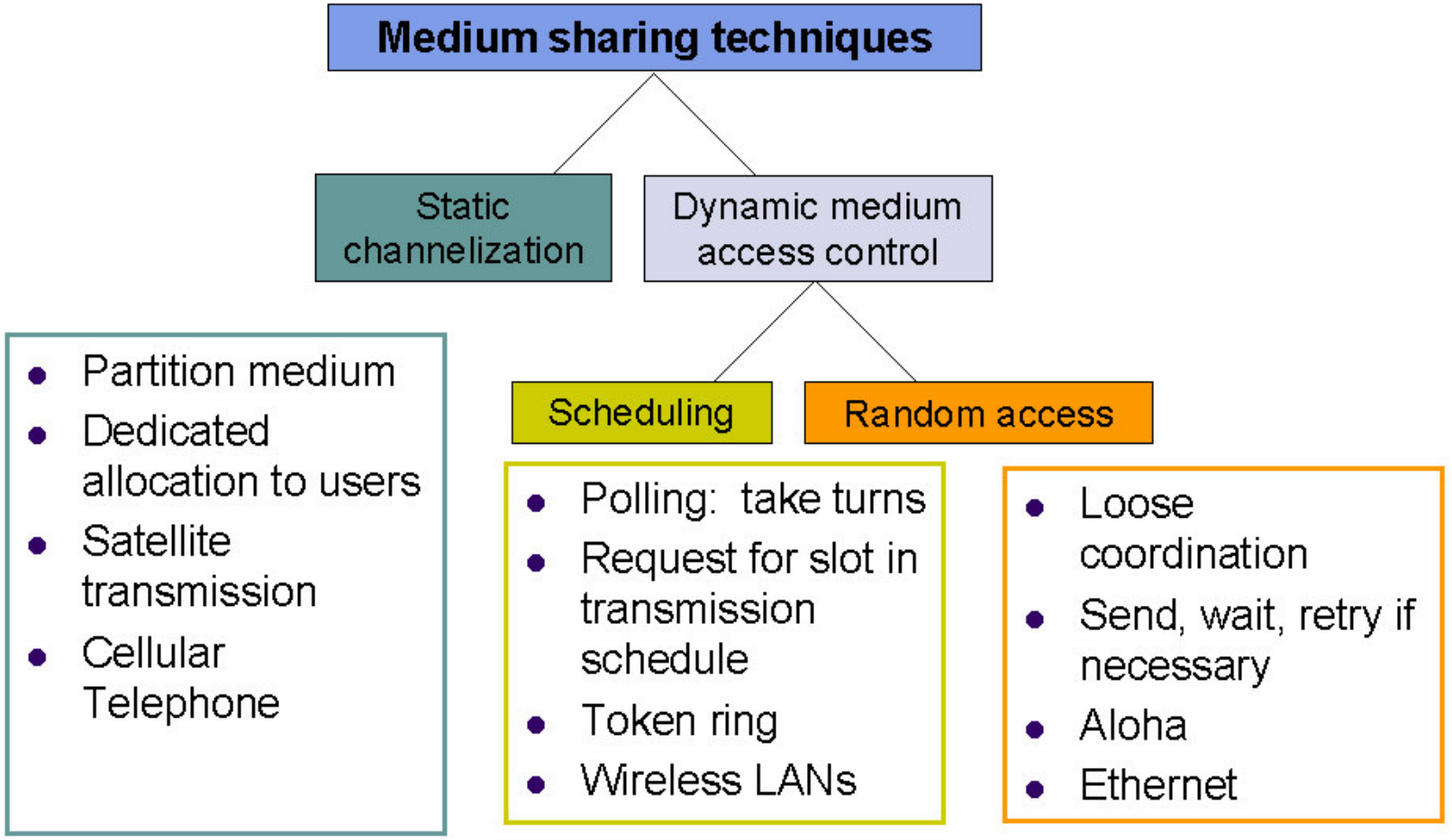
- Medium sharing
  - FDMA/TDMA/CDMA/CSMA
  - Circuit/packet switching - connection-oriented and connectionless switching -
- Digital hierarchies
- Exchanges
  - technologies: development, modern local exchange
  - interfaces: ISDN and line interface circuit (LIC)
  - signaling
  - services
  - operation and maintenance (O&M)
- Terminals in access network: phones, modems, faxes

Medium sharing (multiplexing, channelization)

- Multiplexing involves the sharing of a transmission channel (resource) by several connections or information flows
  - Channel = 1 wire, 1 optical fiber, or 1 frequency band
- Significant economies of scale can be achieved by combining many signals into one
  - Fewer wires/pole; fiber replaces thousands of cables
- Implicit or explicit information is required to demultiplex the information flows.



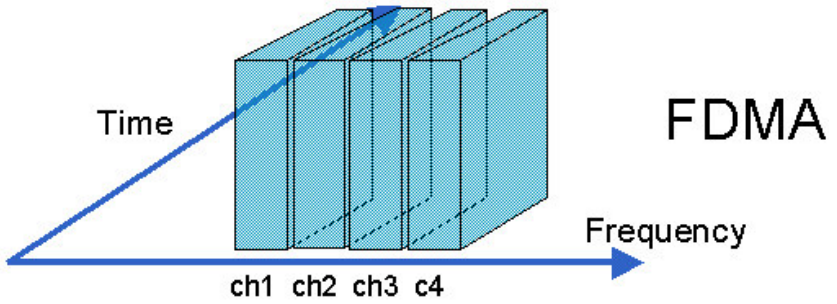
Medium sharing techniques

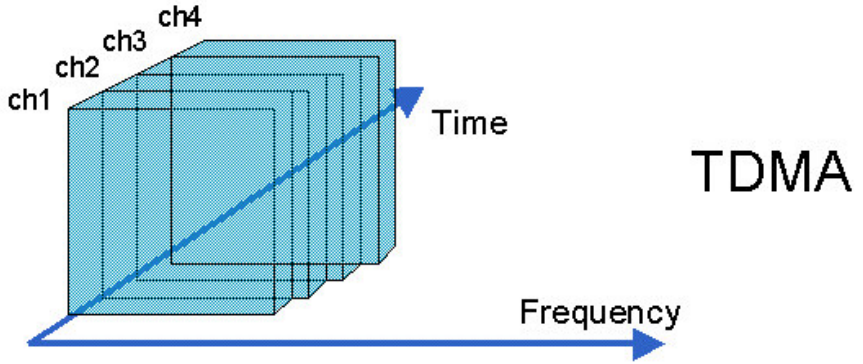


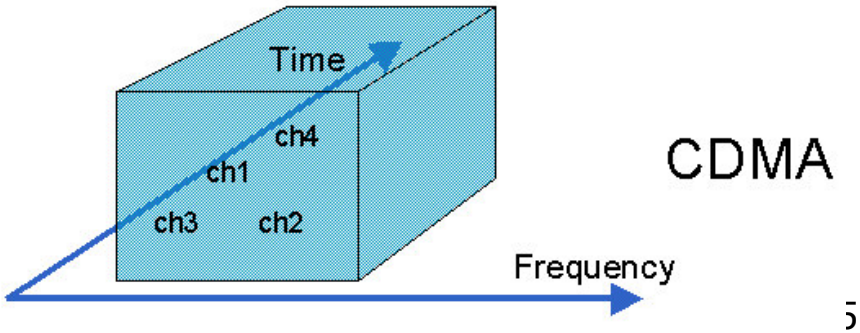
Ref: A. Leon-Garcia: Communication Networks 2th ed slide set

Basic channelization techniques

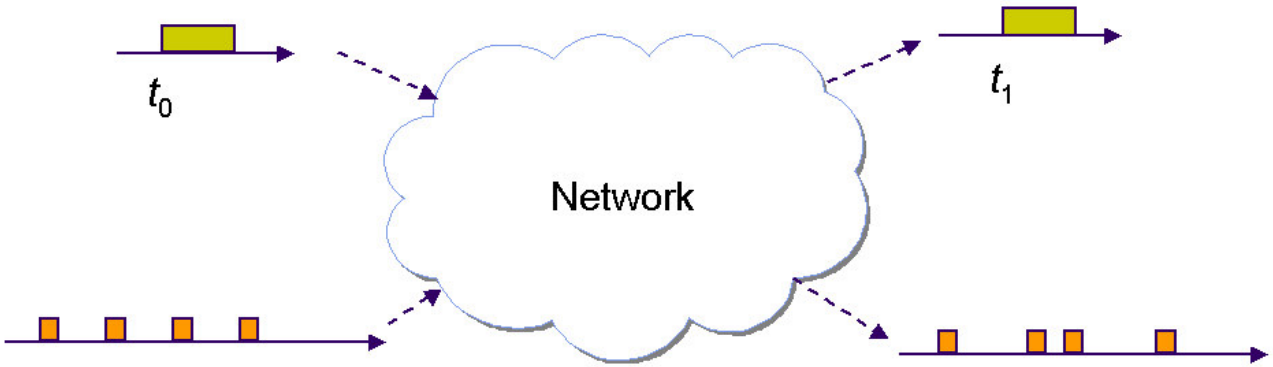
- **FDMA**:
  - Oldest, first in PSTN
  - Used in GSM uplink/downlink channel separation
  - ADSL uplink/downlink & in OFDM
- **TDMA**:
  - ISDN-exchanges, GSM calls
  - Other applications: DECT
- **CDMA**:
  - Supports statistical multiplexing
  - Suits well to wireless cellular channel (channel adaptation)







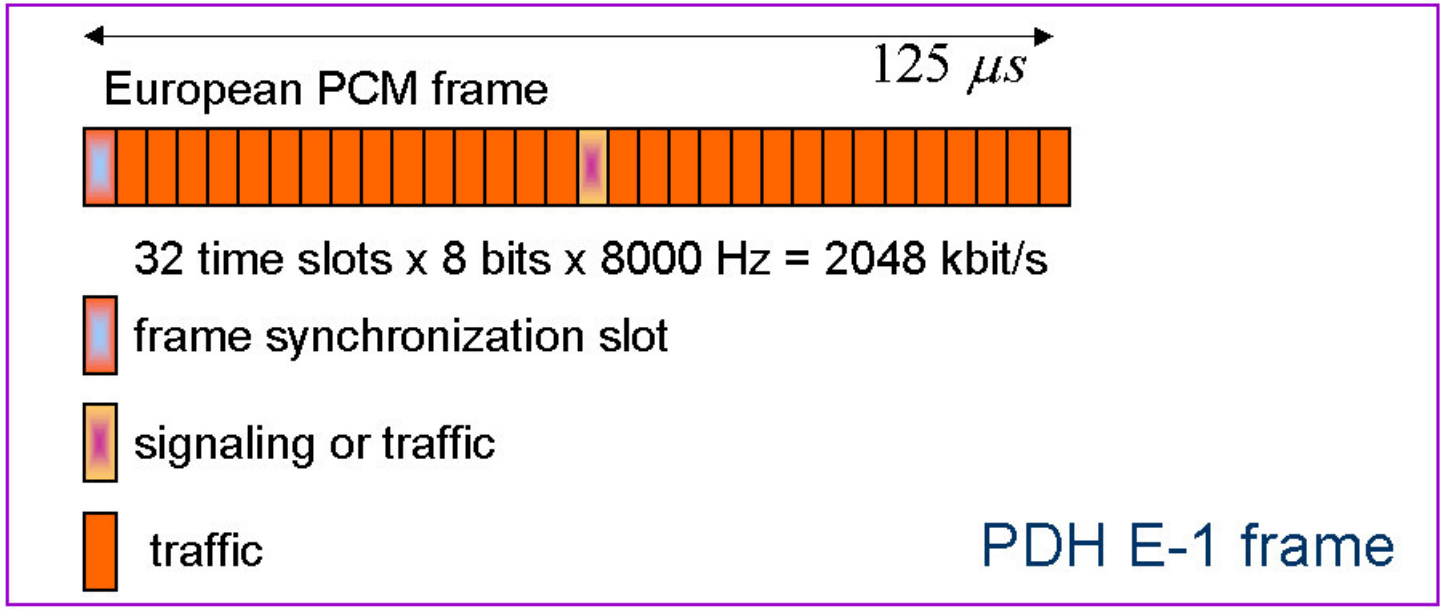
Dynamic medium access (CSMA / CDMA)



- Transfer of information as payload in data packets
- Packets undergo random delays & possible loss
- Different applications impose differing requirements on the transfer of information
- Typical Medium Access Control (MAC) schemes: Aloha and CSMA

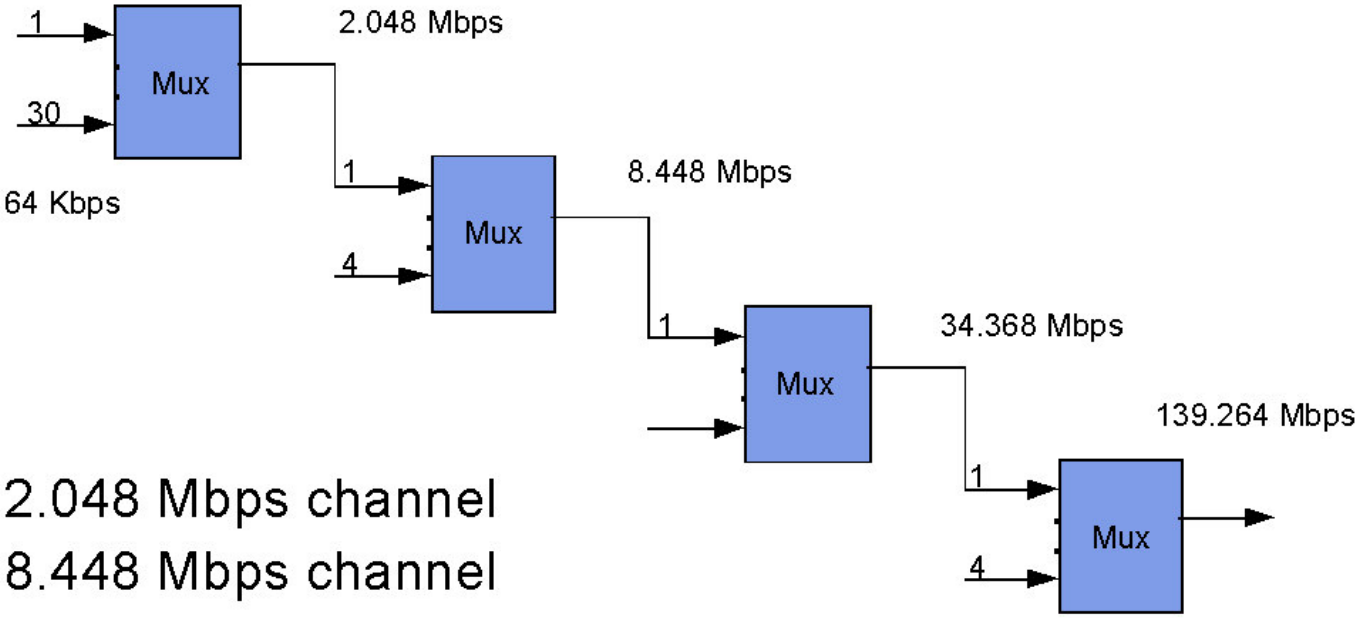
Digital hierarchies

- In digital multiplexing several messages are transmitted via same physical channel. For multiplexing 64 kbit/s channels in digital exchanges following three methods are available:
  - **PDH** (plesiochronous digital hierarchy) (the dominant method today, E1 & T1) ('50-'60, G.702)
  - **SONET** (synchronous optical network) ('85)
  - **SDH** (synchronous digital hierarchy) (CCITT '88)



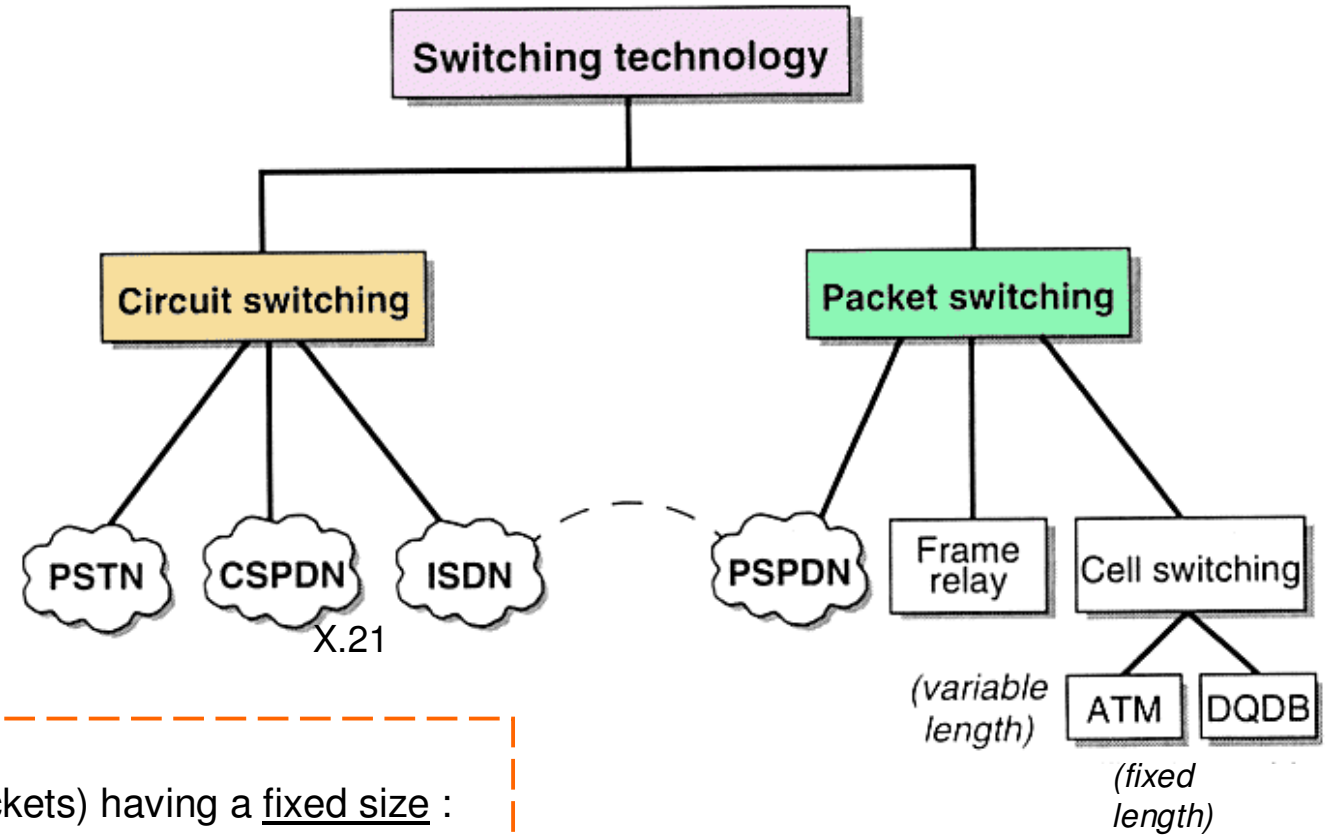
European PDH digital hierarchy

- CCITT digital hierarchy based on 30 PCM channels



- E1, 2.048 Mbps channel
- E2, 8.448 Mbps channel
- E3, 34.368 Mbps channel
- E4, 139.264 Mbps channel

Switching in public networks



Cell switching

- works with cells (packets) having a fixed size : offers bounded delay guarantees (QoS compatible, long packets won't stuck cells)

CSPDN: Circuit switched public data net*
PSPDN: Packet switched public data net**
DQDB: Distributed queue dual bus

** Used by European Telecom's that use X.21 in circuit switched nets*
***Used by British Telecom's Packet-switched Service (PSS), Data Pac (Canada) ...*

Circuit switching - TDM

Circuit switching

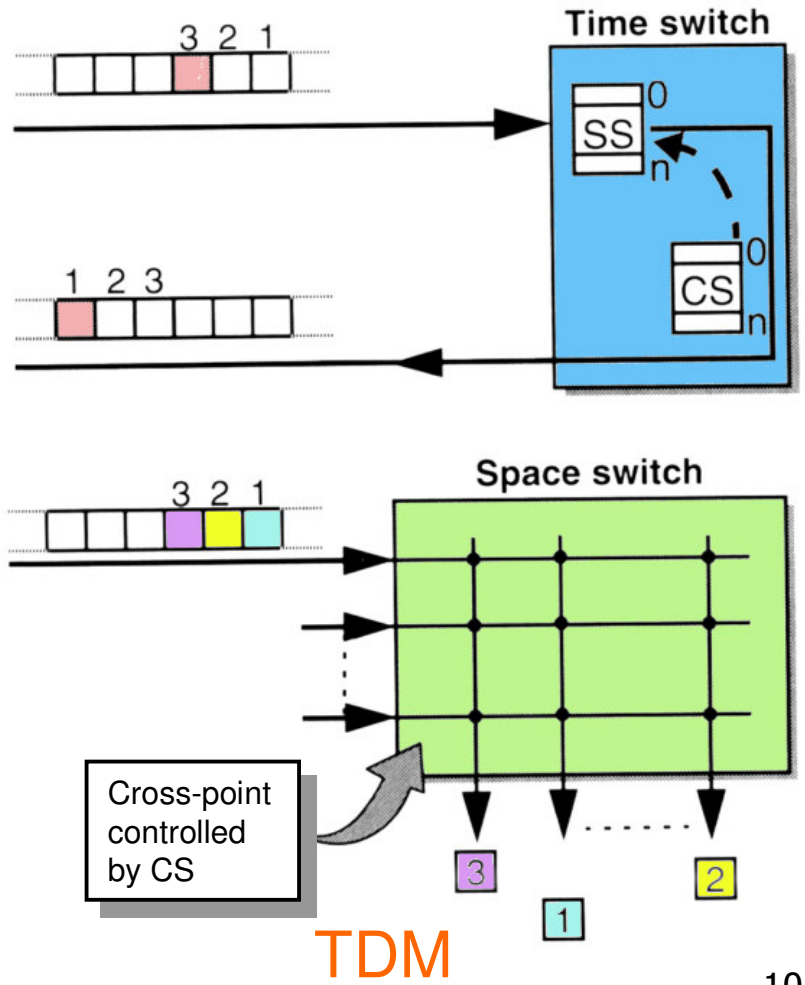
- dedicated path
- constant delay/bandwidth
- voice/data
- paid by time
- examples: PSTN, GSM?

Time switch

- Makes switching between time slots
- In the figure incoming slot 3 is switched to outgoing slot 3 for one voice direction
- Each coming timeslot stored in Speech Store (SS)
- Control store (CS) determines the order the slot are read from SS
- The info in CS is determined during setup phase of the call

Space switch

- makes switching between PCM lines
- *works with* electronic gates controlled by CS

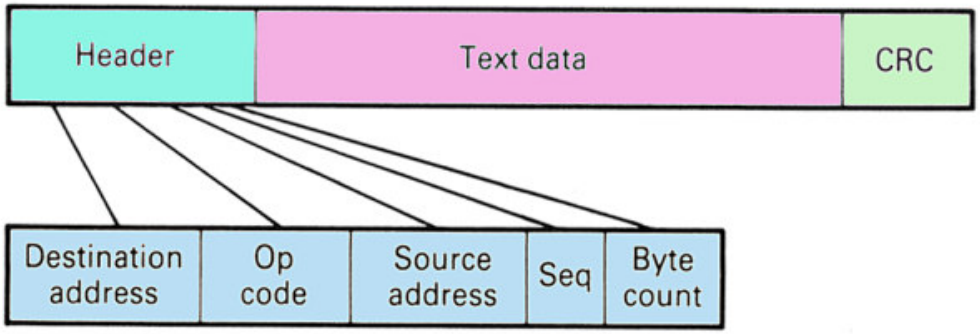


TDM

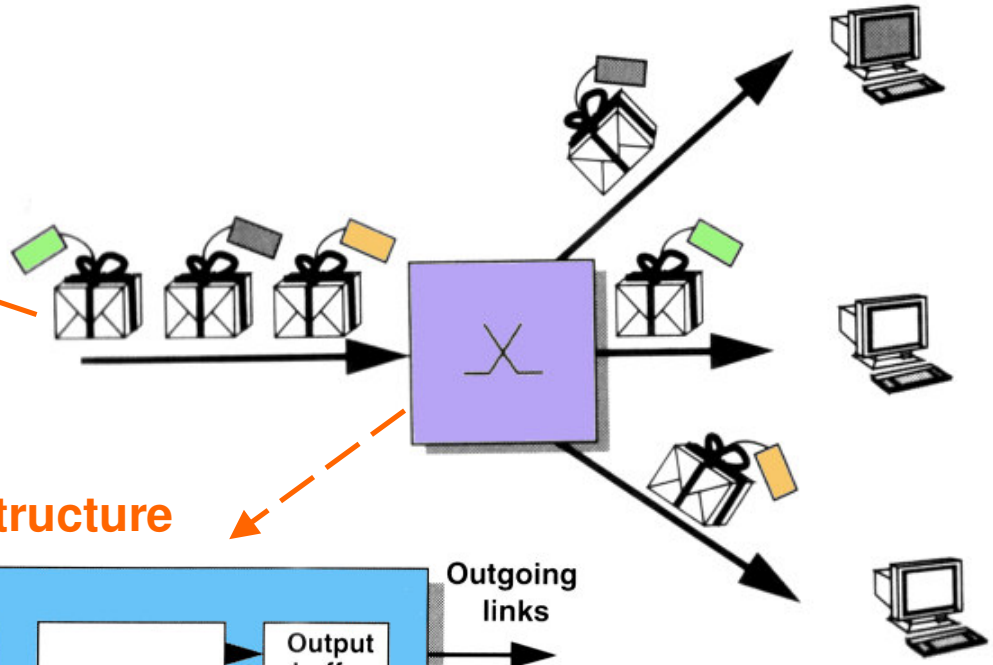
Circuit switching - summary

- End-to-end dedicated circuits between clients
  - Client can be a person or equipment (router or switch)
- Circuit can take different forms
  - Dedicated path for the transfer of electrical current
  - Dedicated time slots for transfer of voice samples
  - Dedicated frames for transfer of super frames
  - Dedicated wavelengths for transfer of optical signals
- Circuit switching networks require:
  - Multiplexing & switching of circuits
  - Signaling & control for establishing circuits

Packet switching



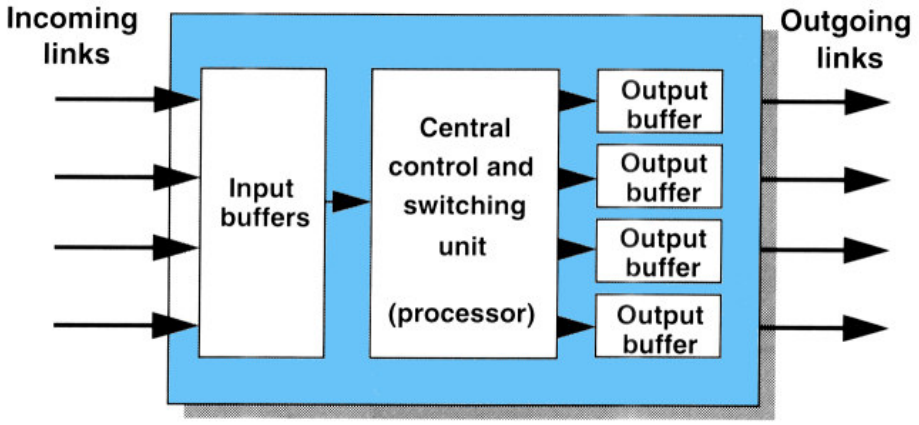
example



Packet structure

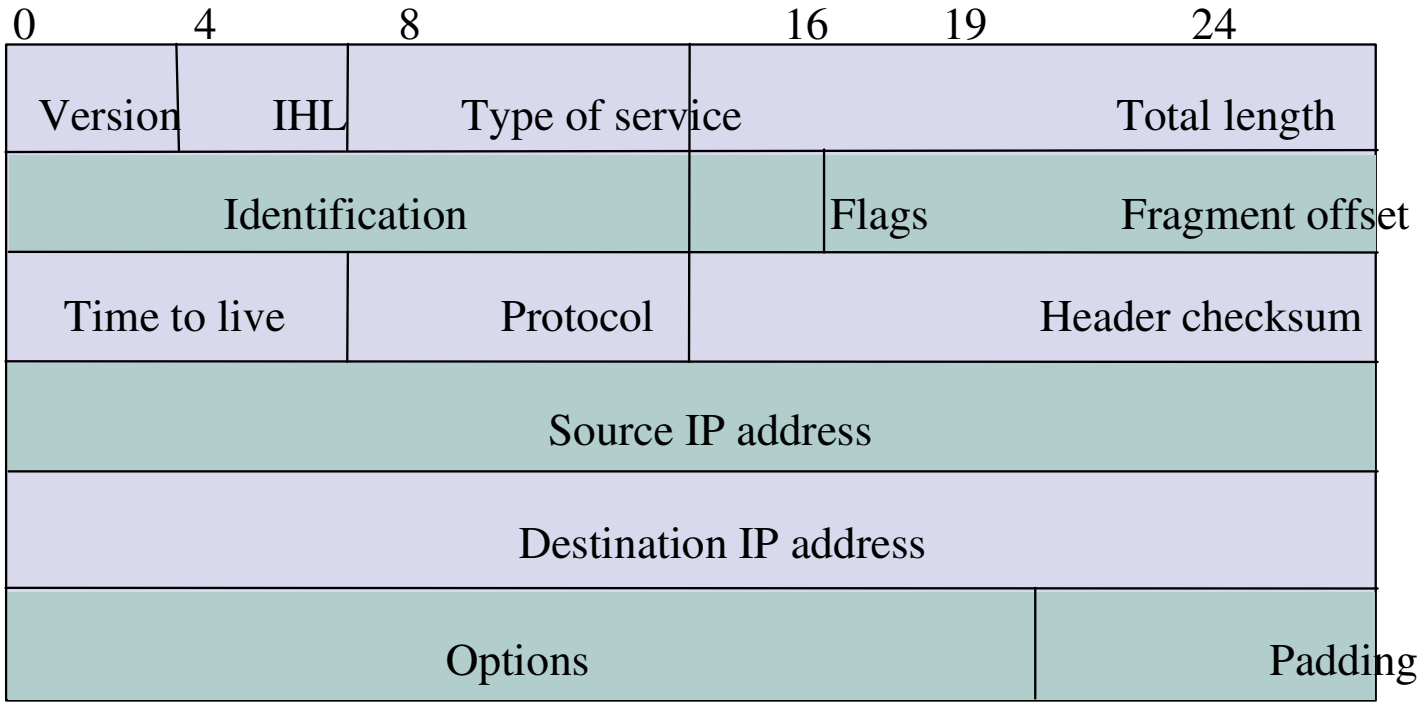
Seq: sequence number
Op code: message/control identifier
CRC: Cyclic Redundancy Code

Node structure



Note:
- source address required for retransmission in ARQ
- byte count could be also an end flag

Example: IP packets in Internet

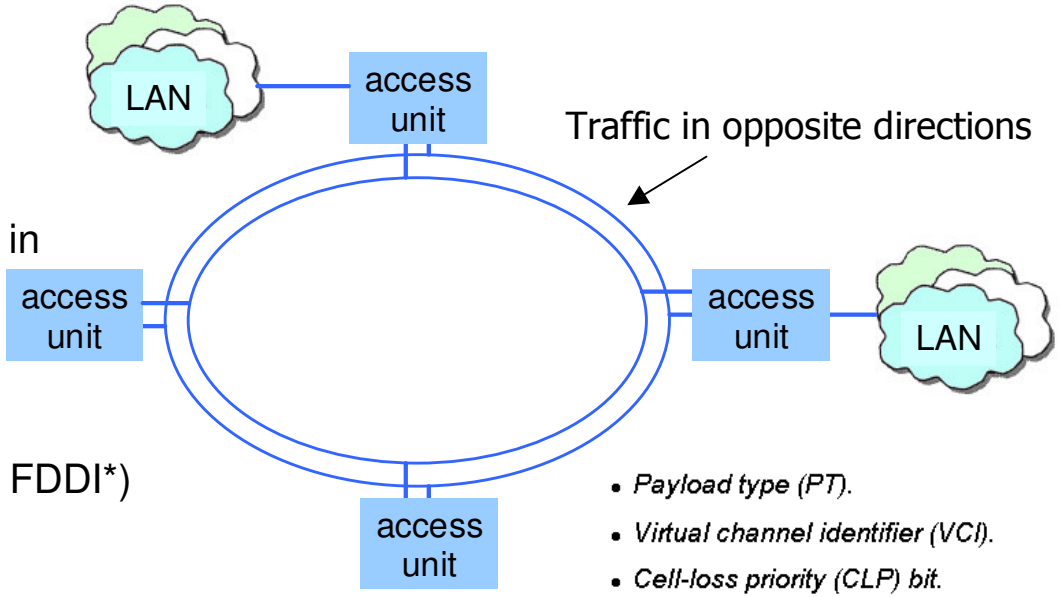


- IPv4 packet header (to be further discussed in Internet lecture)

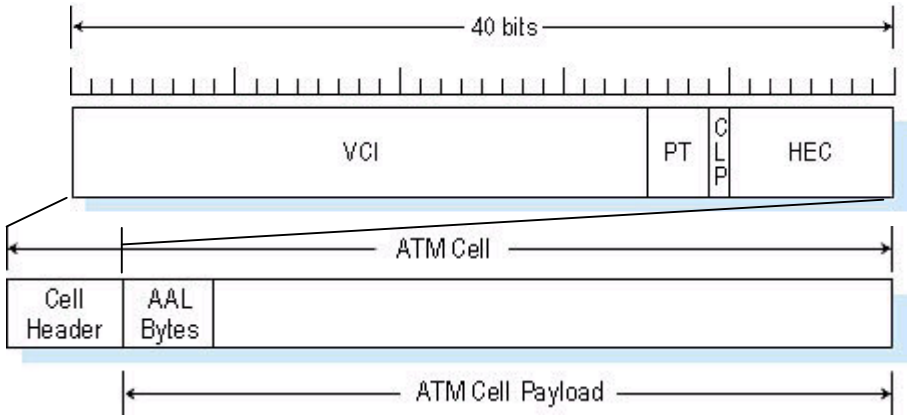
Example of cell switching: Distributed queue dual buss (DQDB, 802.6)

Function
- **transport units** have a constant length
- **access units** access known subscribers in access unit's subnets and route packets for them
- **access protocol** applies token ring

Properties
- decentralized (distributed switching as in FDDI*)
- for ATM compatible MANs (metropolitan area networks)
- rates: up to 155 Mbps
- geographical limit up to 200 km



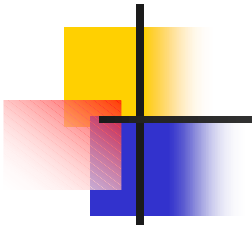
- *Payload type (PT).*
- *Virtual channel identifier (VCI).*
- *Cell-loss priority (CLP) bit.*
- *Header error checksum* (HEC) *byte.*



Transport Unit (same as in ATM)

** FDDI: Fiber Distributed Data Interface*
for description, see the supplementary material of this lecture

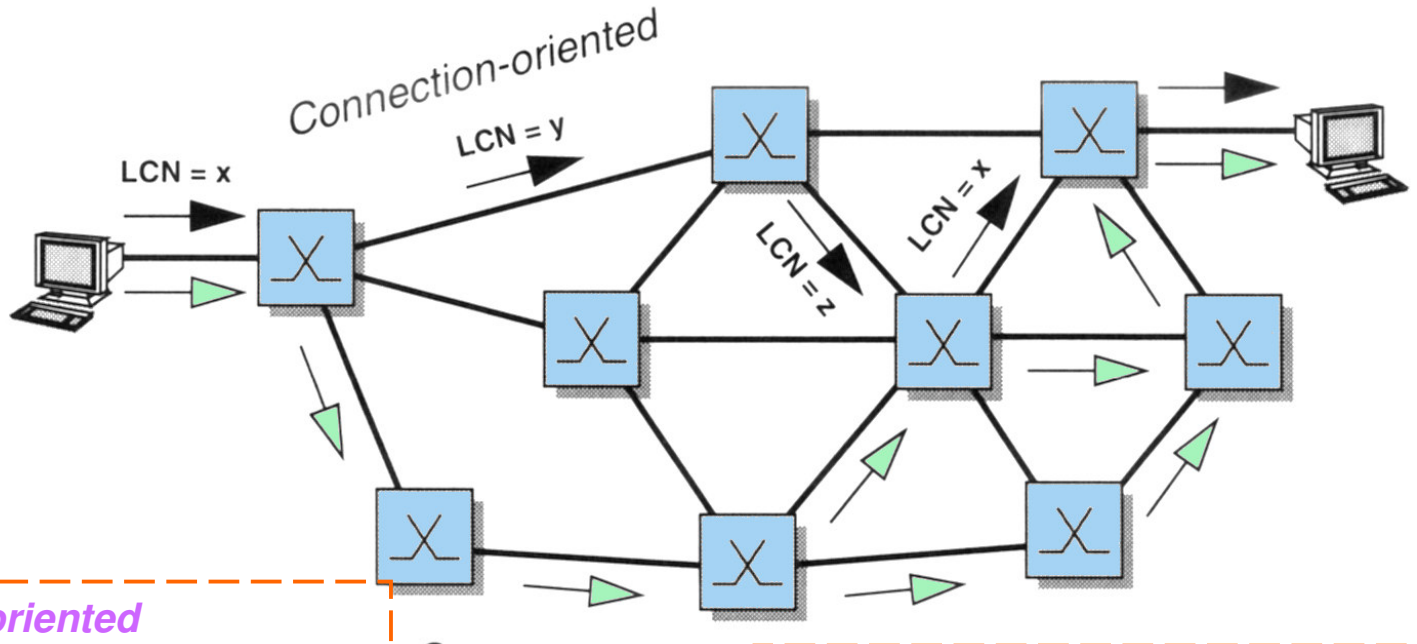
AAL 1: For constant-bit-rate (CBR) services and circuit emulation.
AAL 2: For variable-bit-rate (VBR) services.
AAL 5: For data (for example, IP datagrams)



Packet switching - summary

- General characteristics
  - can use packets of **varying length**
  - packet is assigned an **address** and the necessary **control** information
  - packets are placed in **frames**
- Each sent frame stored in a buffer (**store & forward**) in a receiving node and its information is checked before re-sending -> **delays** but **errorless transmission** possible
- In summary: packet handing by nodes consists of
  - checking the **packet format**
  - checking for **errors** (link level - OSI 2)
  - **waiting** for available outgoing path capacity
- Nodes have routing tables (network level - OSI 3)

Connection-oriented and connectionless switching



Connection oriented

- Applies same route
- QoS well defined

- Phases
  - Connection setup
  - Data transmission
  - Release
- Packets received in same order
- Example: ATM, frame relay, PCM

Connectionless

- Use of different routes for each packet possible
- Each packet has address fields
- QoS not guaranteed

- Packets may come in different order
- Example: IP (Internet Protocol), TCP takes care of cleaning the mess

Transfer modes & connections summarized

Transfer modes

Circuit switching

PSTN
ISDN
PCM

- developed for voice
- nowadays also for data
- well-specified delays
- echo problems

Packet switching

- developed for data
- nowadays also for voice
- statistical multiplexing
- traditionally variable delays

IP, Frame-relay
ATM

Connection types

ATM

Connection oriented

- hand-shaking
- strict error requirements
- for fast data transfer

Frame-relay
X.25

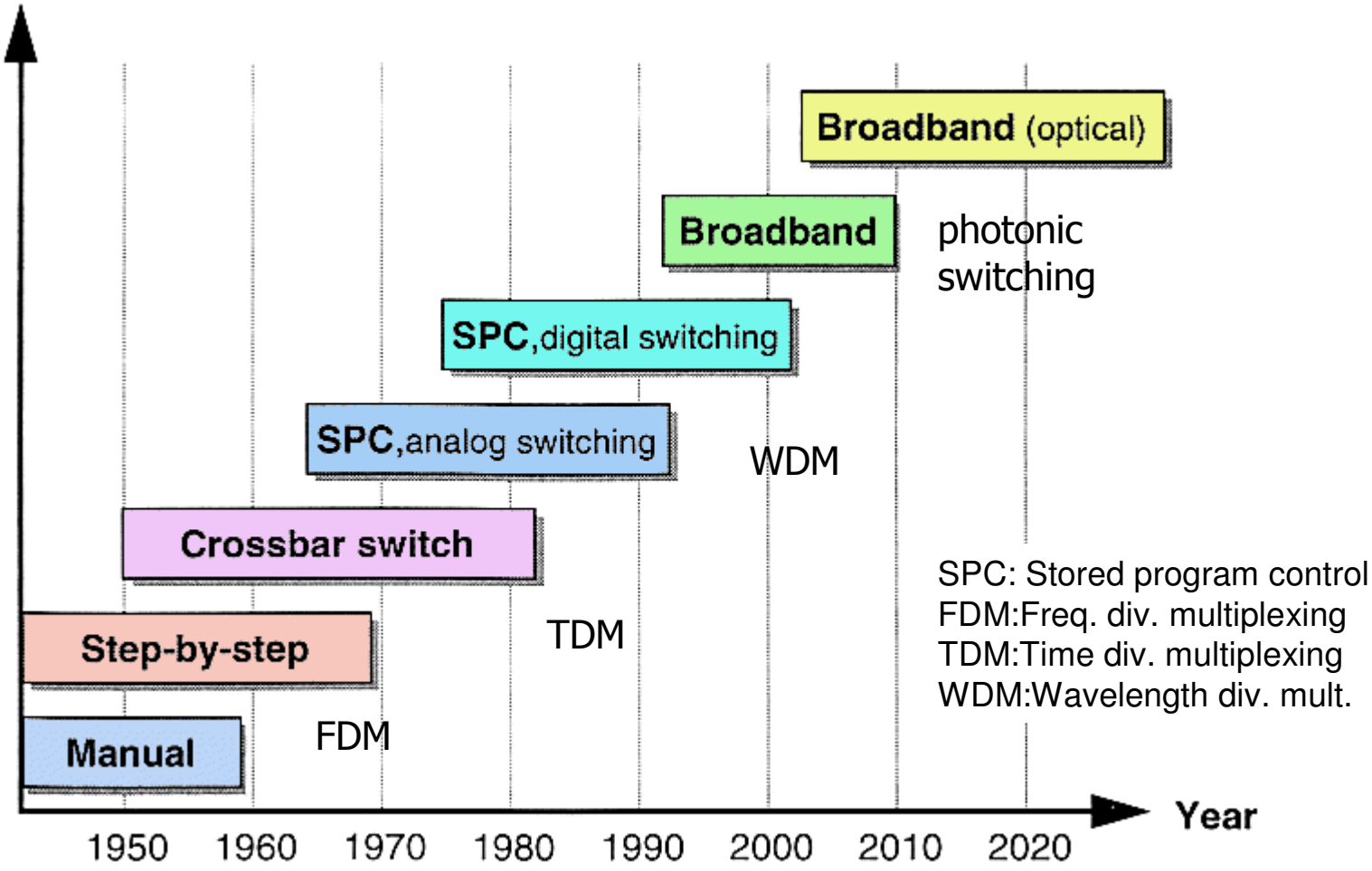
Connectionless

- especially for broadcasting/ streaming
- modest error rates often accepted
- for fast data in good channels

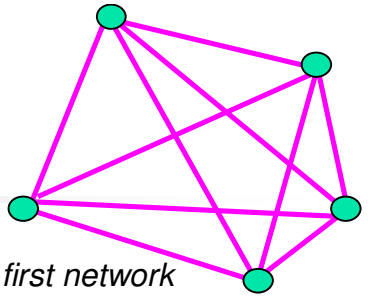
X.25, IP, UDP*

*User Datagram Protocol

Development of exchanges

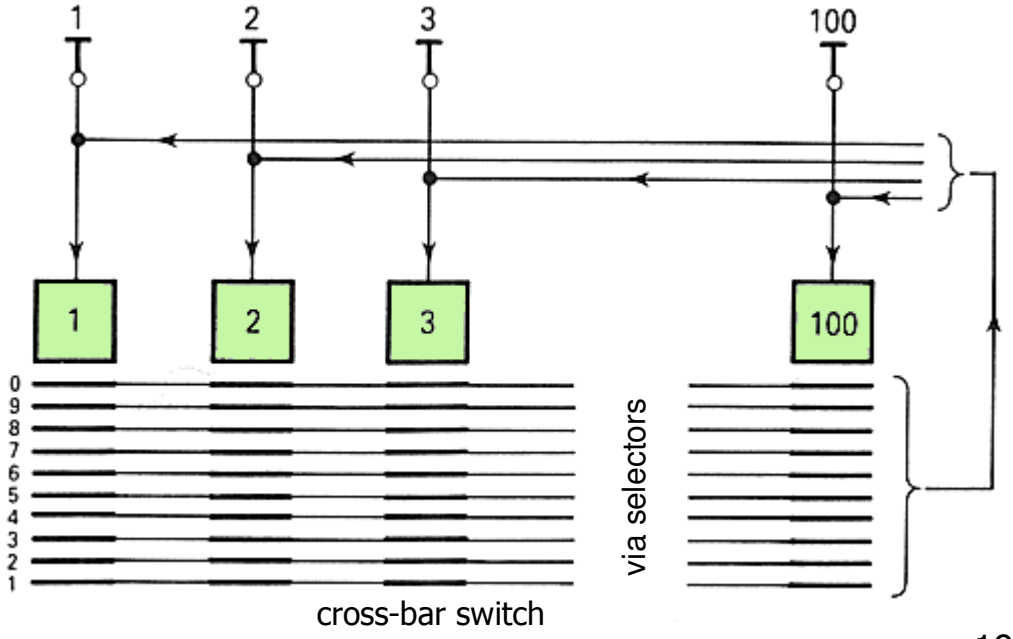


Early exchanges



Topology of the first network using Strowger switch

- 1876 A. G. Bell telephone patent
- 1878 The first exchange constructed in La Porte, the US
  - could connect any two of the 21 subscribers
  - manual switching
- 1891 first automatic exchange: Strowger Switch by Almon B. Strowger: an undertaker in Kansas City
- A 100 line Strowger switch:
  - each user has its own selector
  - no concentrators
  - expensive

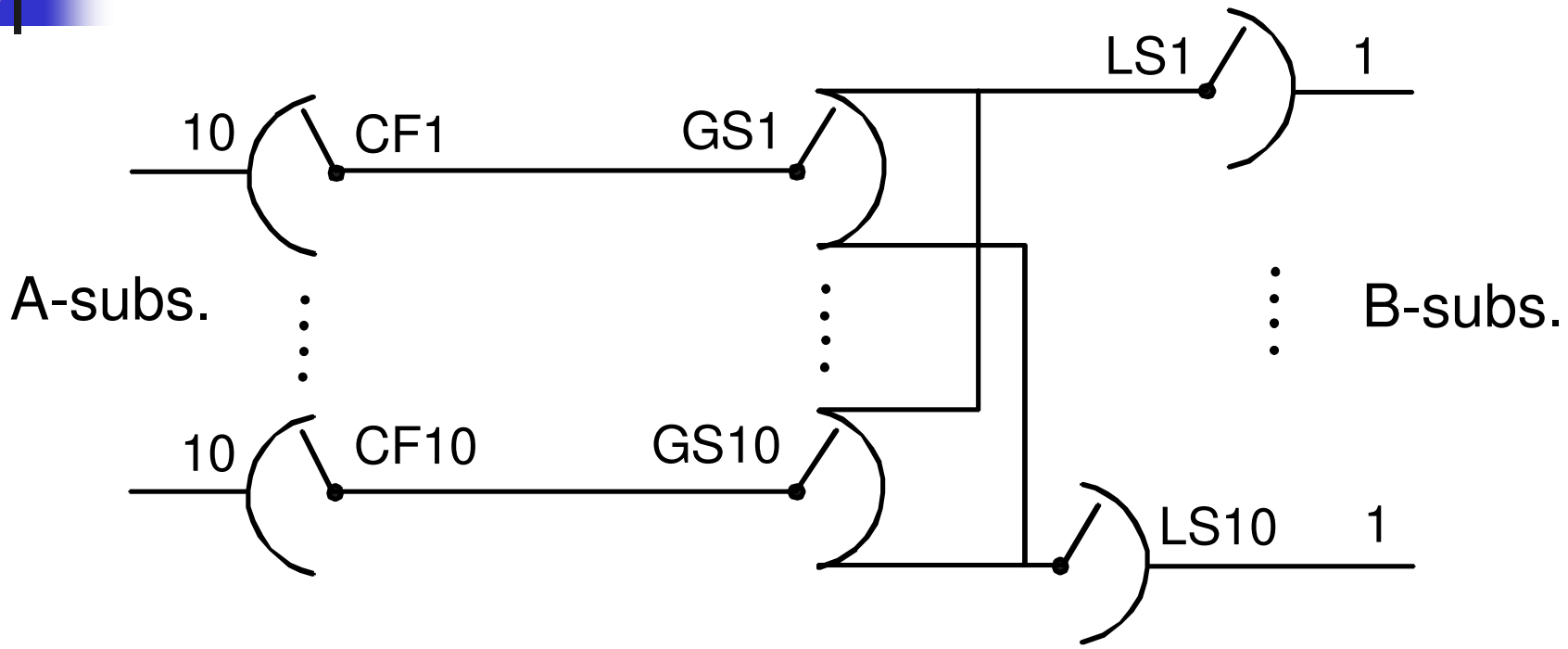


cross-bar switch

See further info also at: http://www.seg.co.uk/telecomm/

An early analog PBX: 100 subscriber exchange

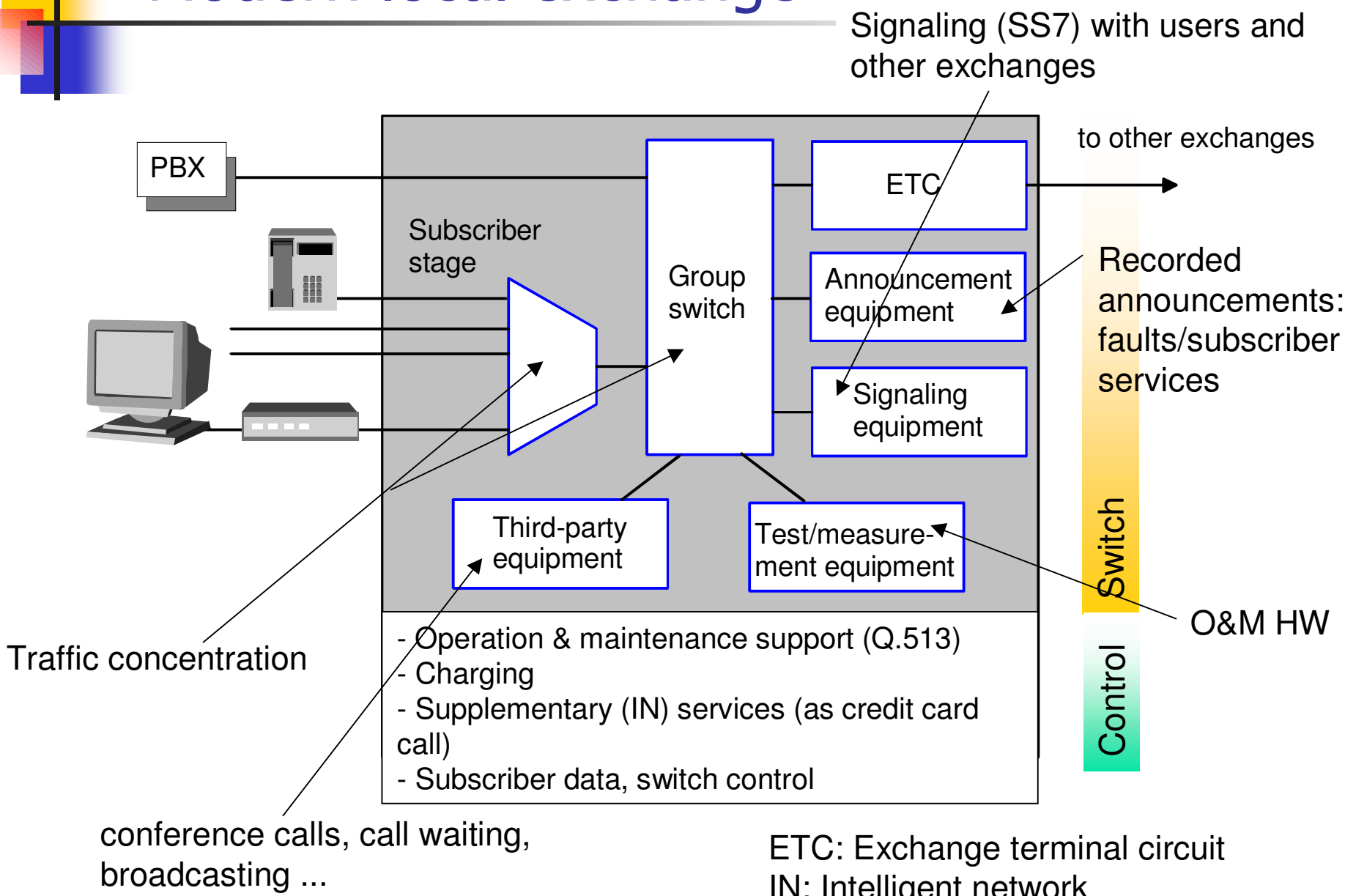
(Step-by- step: Subscriber controlled call set-up)



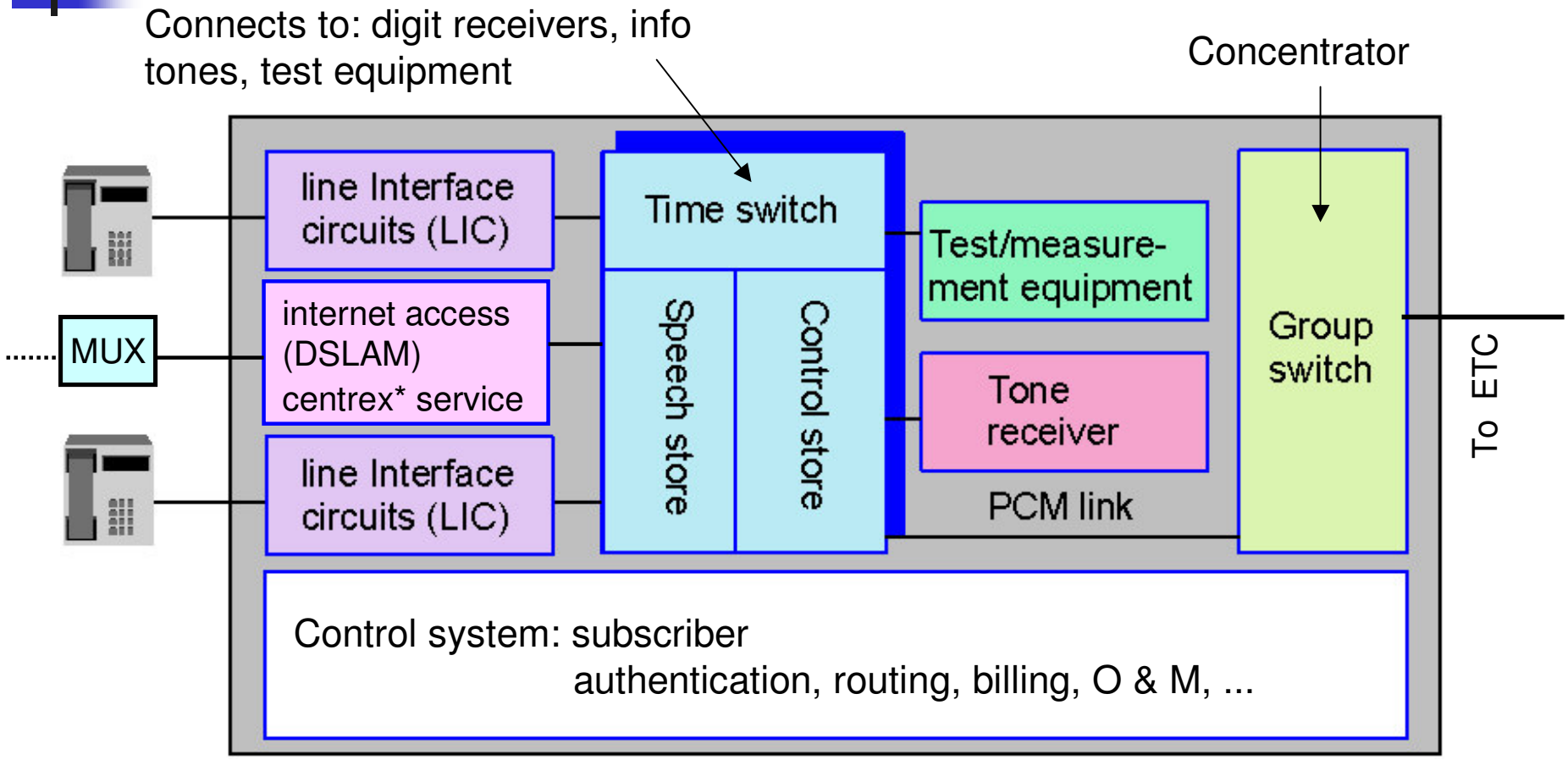
MAIN PARTS:
- Call finders (CF)
- Group selectors (GS)
- Line selectors (LS)

Call setup:
1. A-sub. picks up handset (CF detects)
   - exchange sends line available -tone
2. A-sub. sends pulses (GS, LS activated)
   - exchange sends ringing tone

Modern local exchange



Subscriber stage



ETC: Exchange terminal circuit
Speech store: shift registers storing bits for time switching
Control store: gates guiding speech store switches
* leased PBX function from local exchange

Exchange control functions

- **Maintenance** functions
  - supervision of subscriber lines and trunk circuits
- **Operational** functions
  - ***administrative*** data as
    - subscriber database
    - routing database
  - ***statistical*** data as
    - from where and whom subscribers call
    - holding times for different equipment types
    - utilization of IN services
- **User services**

Sample of Intelligent network (IN) services

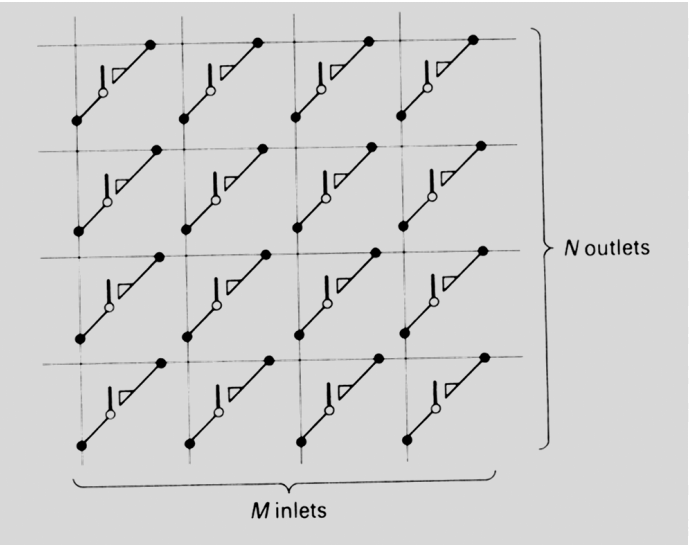
• Pre-Paid	• Calling Card
• Free Phone/Toll-free (NDB 800)	• Single Number Service
• Virtual Private Network	• Number Portability
• Personal Number	• IN based call centers
• Premium Rate	• Call Screening Capabilities

Exchange user services (examples)

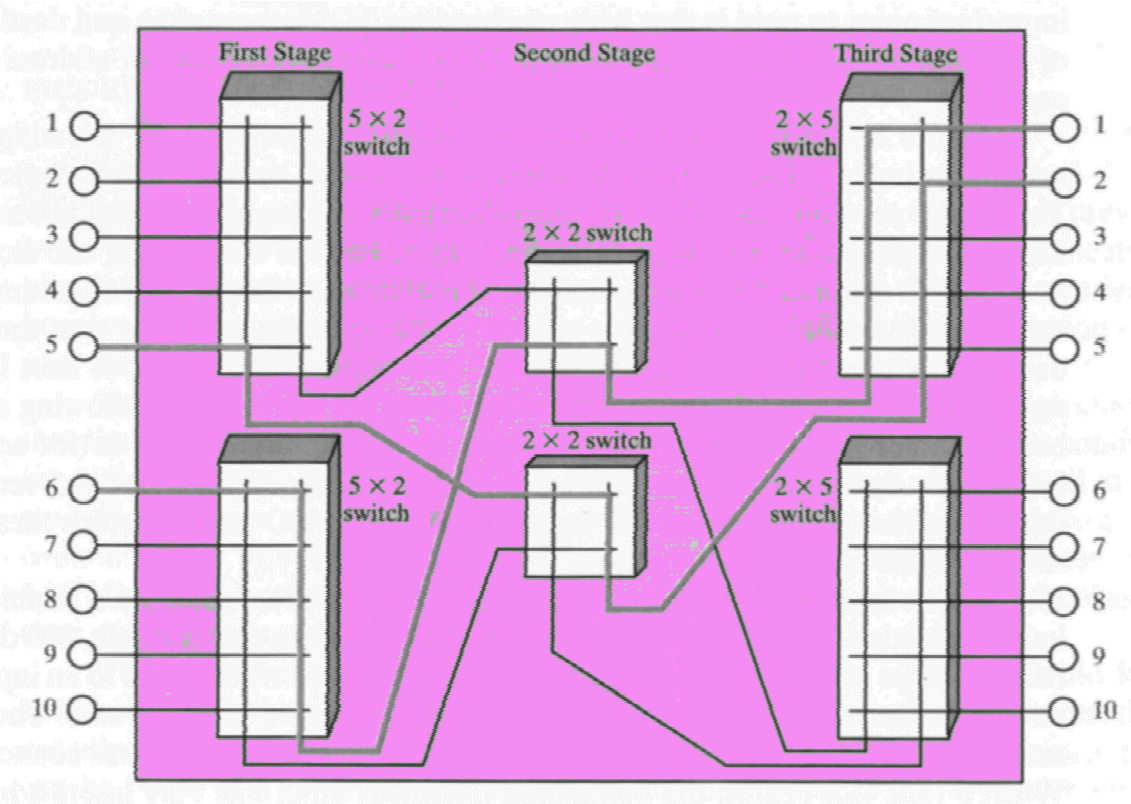
- **Absent-subscriber** services as the answering machine
- **Call booking**: connection at the desired time
- **Person-to-person call**: ensures that call goes to a right person
- **Serial call**: setting up several calls
- **Telephone conferencing**: several persons participate to call in real-time (compare: tele-conferencing)
- **Directory inquiries**: also speech recognition, recorded messages

(many of these nowadays available in terminals)

The space-switch (used as a cross-switch and concentrator)

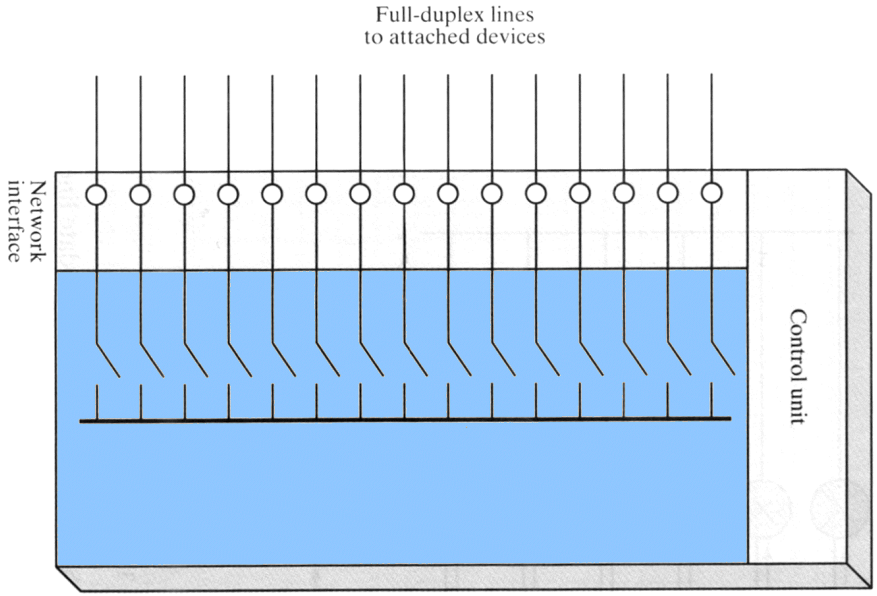


Cross-bar switch
(space division matrix)



- Number of cross-connections reduced compared if a simple space division matrix of NxM (input x output) would be used
- Usually performs concentration: Blocking possible
- Same signal can be routed via different paths: increased reliability
- application: connects physically separate PCM-lines

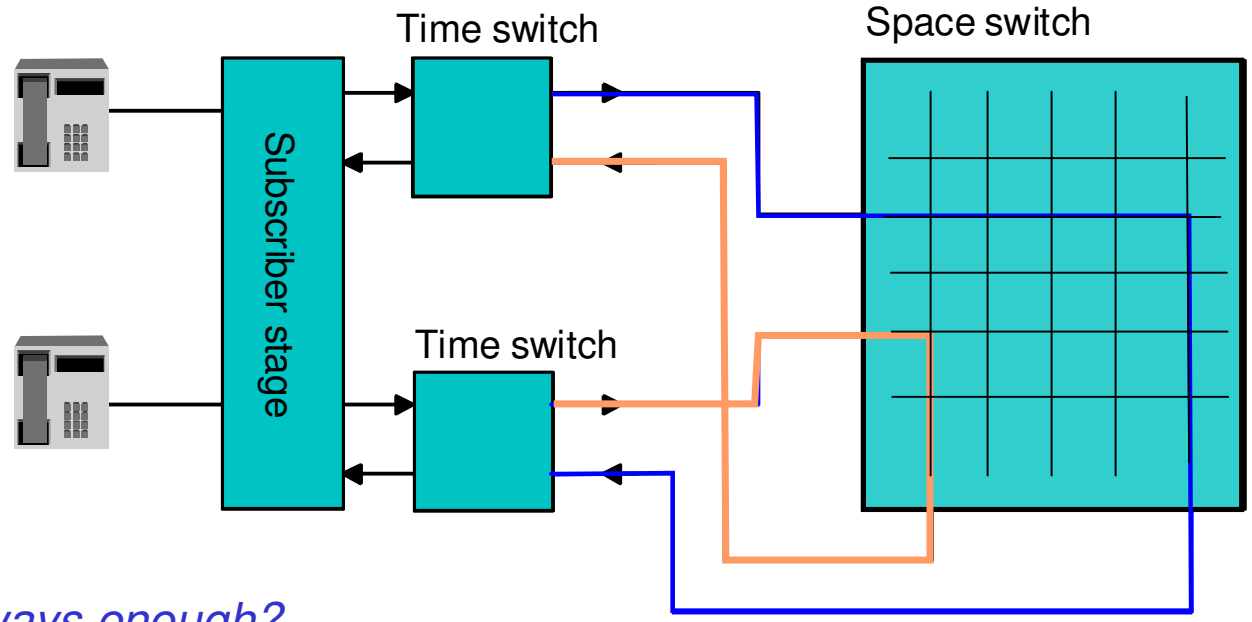
The time-switch



- One of the time slots of any **full-duplex** lines is connected to some other line (at a time)
- Thus two switches / time slot connect a line
- For 100 full-duplex lines at 19.6 kbps a 1.92 Mbps bus is thus required for no blocking
- If no fixed assignment of input lines to time slot but on demand allocation -> blocking switch that reduces number of switches and switch clock frequency. For instance 200 lines of 19.6 kbps with bus of 1.92 Mbps
  -> about half of the devices can connect at any time, eg concentration is 2:1

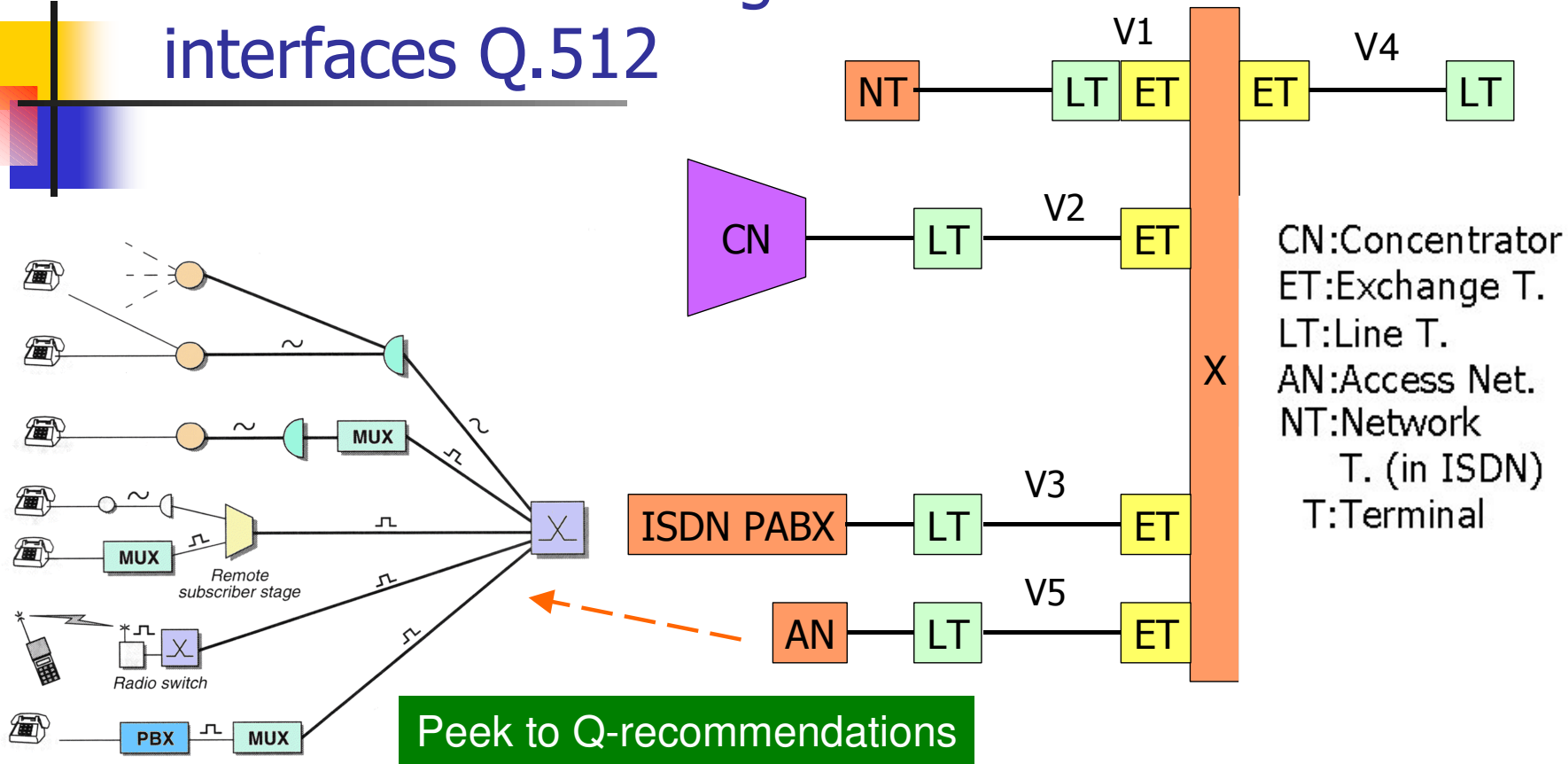
The time-space-time (TST) switch

- Works in local exchange and subscriber stage
- Performs PCM concentration, usually 10:1 … 3:1
- Connects subscribers also to information tones and test equipment
- Time switch contains one bus for incoming and outgoing calls (full-duplex)



Question: Why time or space switch is not always enough?

PSTN ISDN exchange interfaces Q.512



Peek to Q-recommendations

Q.511	Exchange interfaces towards other exchanges
Q.512	Digital exchange interfaces for subscriber access
Q.513	Digital exchange interfaces for operations, administration and maintenance
Q.521	Digital exchange functions
Q.522	Digital exchange connections, signalling and ancillary functions
Q.541	Digital exchange design objectives - General
Q.542	Digital exchange design objectives - Operations and maintenance
Q.543	Digital exchange performance design objectives
Q.544	Digital exchange measurements

Exchange interfaces and tasks, V1

- Purpose of exchange is to organizes connection between exchange terminators!
- V1: Access to basic ISDN (This is user's ISDN-u interface that can be used to connect small PBX also)
- Basic ISDN V1-functions:
  - 2 B + D (2x64 kbps + 16 kbps) channeling structure
  - timing and frame synchronization
  - activate and deactivate terminator
  - operation and maintenance
  - feeding power supply
  - ISDN basic access parameters defined in G.961

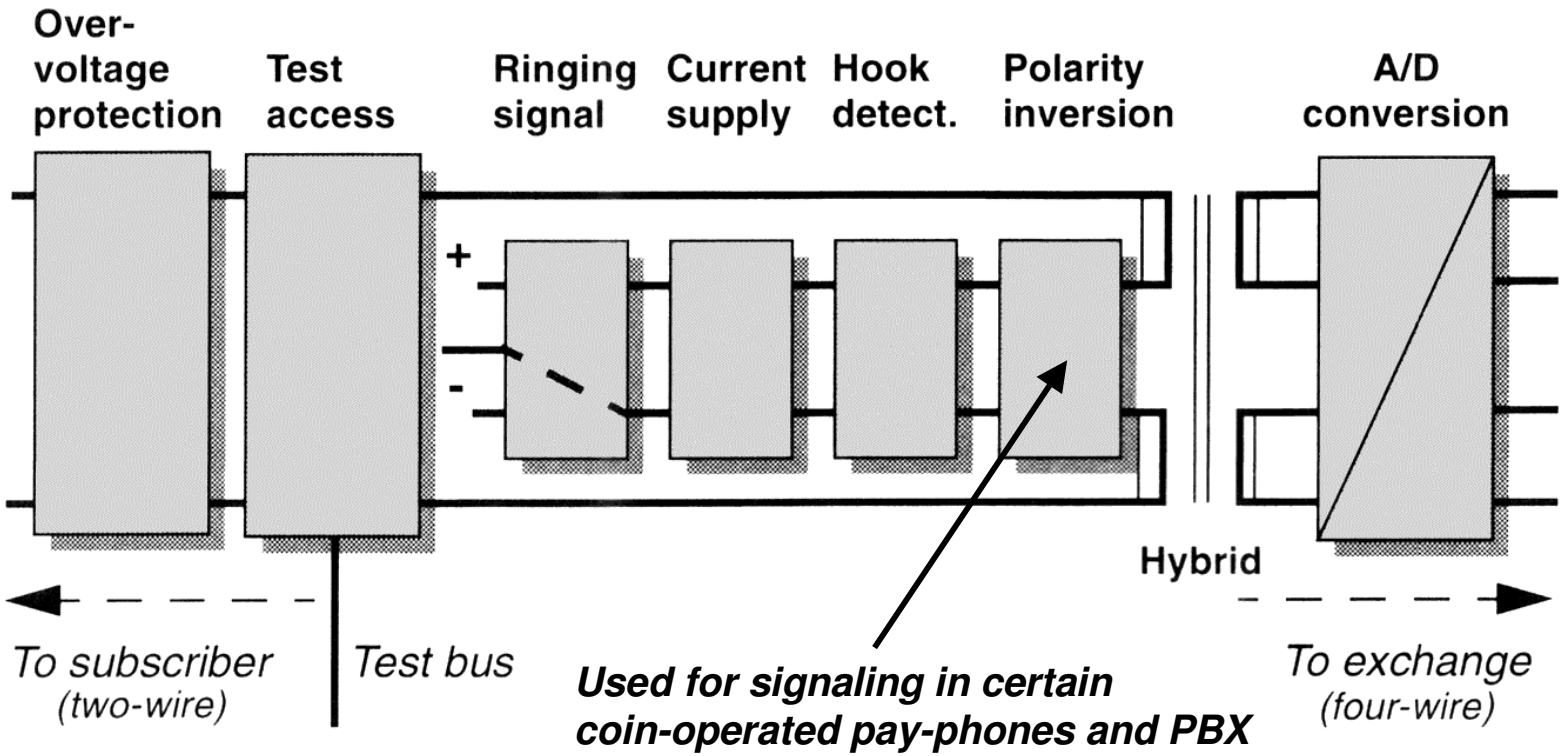
Exchange interfaces and tasks, V2-V4

- V2: Interface serves typically concentrators
  - 2048 kbit/s eg
  - 30 B + D
  - Electrical standard G.704 (frames, signaling...)
- V3: Resembles V2 but intended for interface other exchanges (PABX)
  - Electrical standard G.703
  - 30 B + D at 2048 kb/s (SDH E-1, Europe)
  - also 23 B +D at 1544 kb/s (I.431) (SDH T-1, US)
- V4:Interface to private networks (as such not ITU-T specified), for instance DSLAM (ADSL-interface specified by ADSL-forum - ANSI T1.413 , ITU-T: G.992)

Exchange interfaces and tasks, V5

- Between access network and exchange
- 2048 kbit/s basic rate
- Specifies basic interfaces for
  - Analog access
  - ISDN-access
- Electrical interface G.703
- Channel control and signaling
- V5 supports interface rates 2048 kbit/s ... 8448 kbit/s

Connecting the local loop: Line interface circuit (LIC)

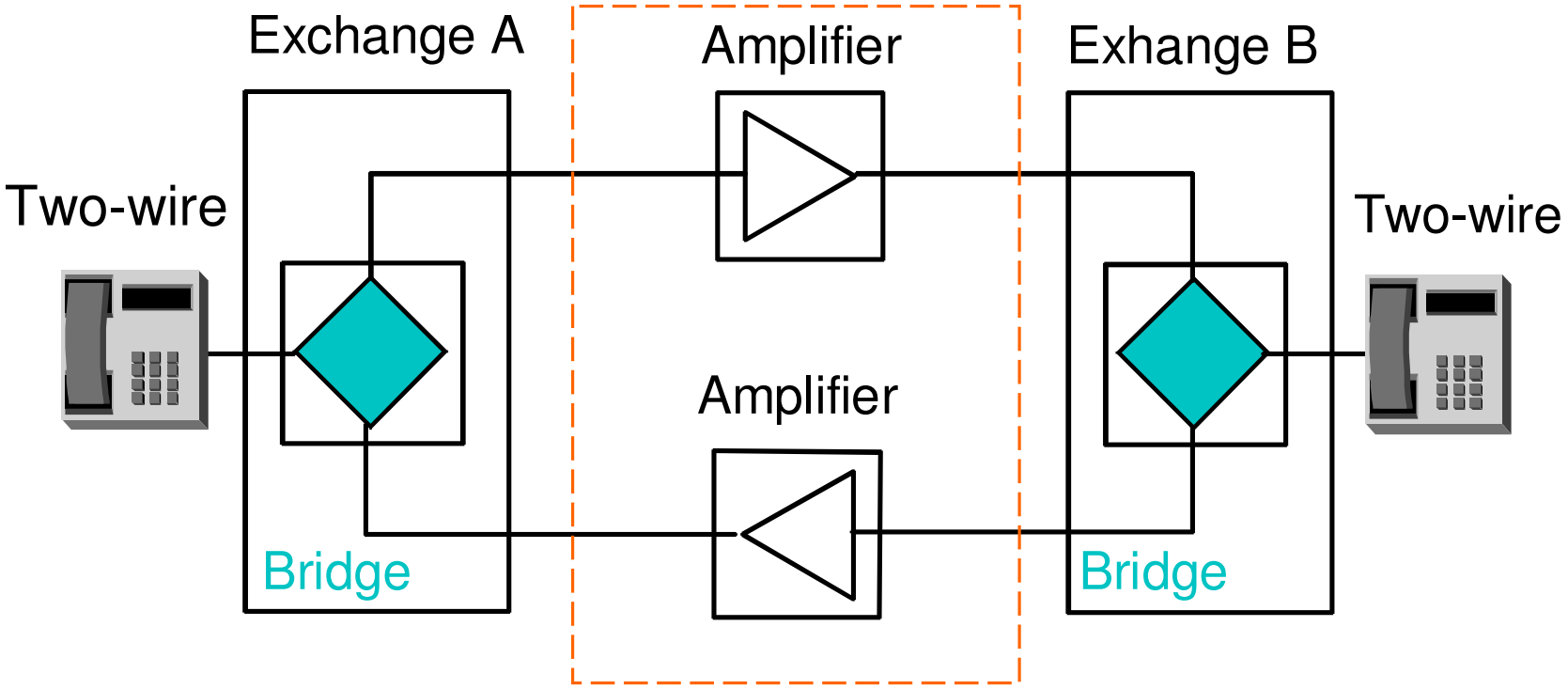


Line interface circuit components

- Over-voltage protection
- Test equipment to connect to monitor the line condition faults
- Voltage feed
  - ringing
  - telephone current supply
- Detection of
  - hook stage, pulse generated, or dual-tone receiver
- The hybrid junction (2 wire - 4 wire interface)
- An A/D converter (uses PCM techniques at 64 kbps)

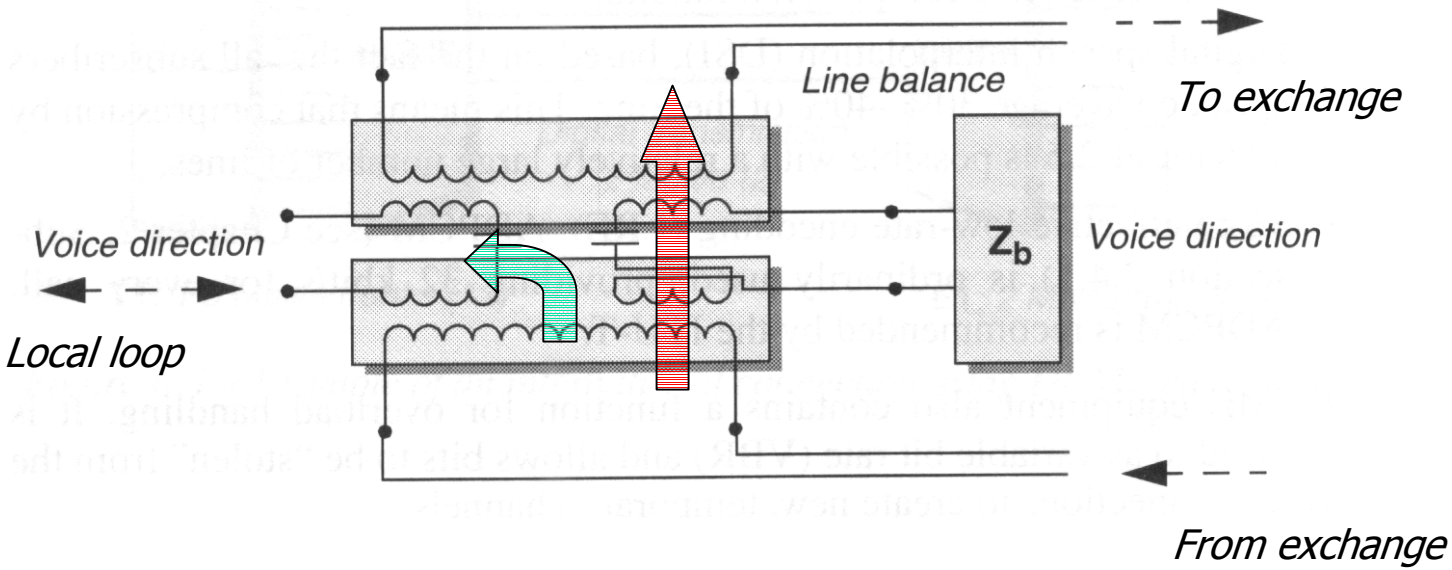
The hybrid-circuit

- 4-wire connection is used between exchanges and 2-wire connections from exchange to subscribers



The hybrid-circuit

If the impedance Z_b equals the line impedance no incoming voice (down right) leaks to outgoing voice (up right) but the signal goes via the two wire connection on the left

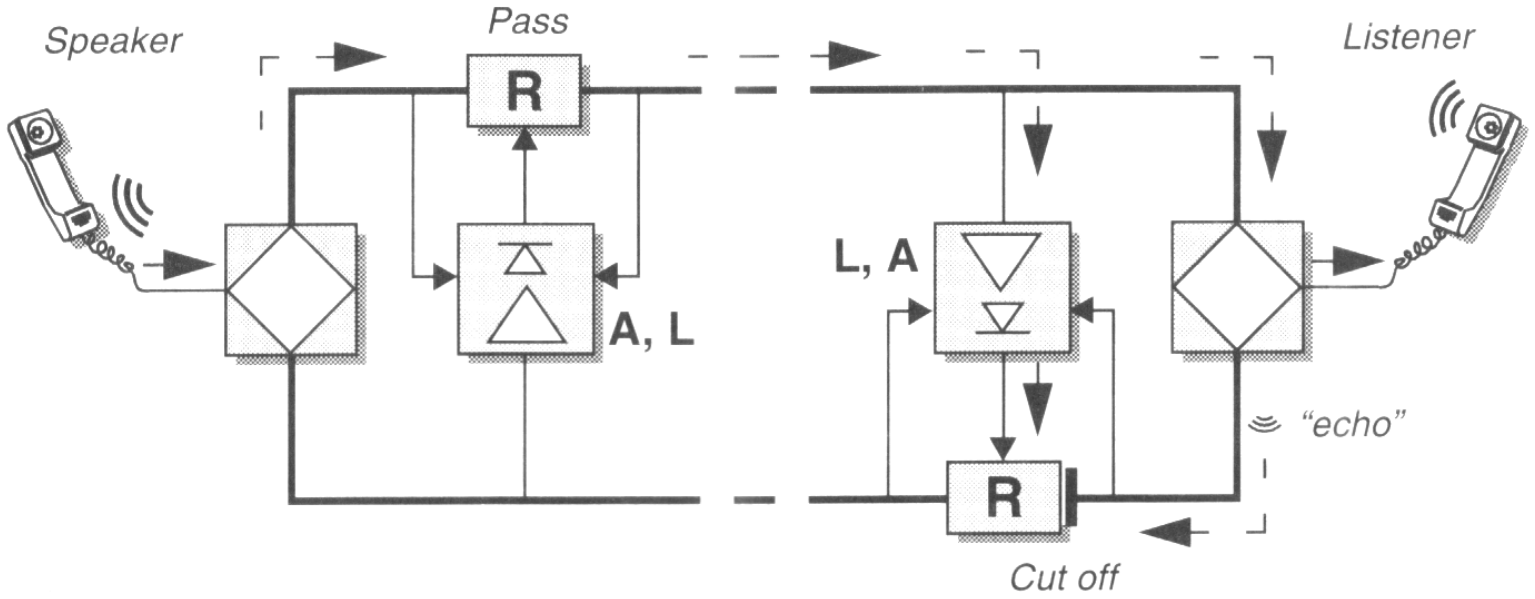


The hybrid-circuit summarized

- The hybrid circuit **transforms** two-wire connection into 4-wire connection.
- If the hybrid is unbalanced **echo** will result
  - Hybrid is **balanced** when no own voice is leaked into own loudspeaker
- Hybrid unbalance can result from **line impedance** changes due to weather conditions
- Unbalance results **echo**
- Echo **cancellation** circuits are harmful in data connections
- Nowadays realized by **operational amplifier** based circuitry that automatically monitors line impedance changes

Network echo suppressor (NES)

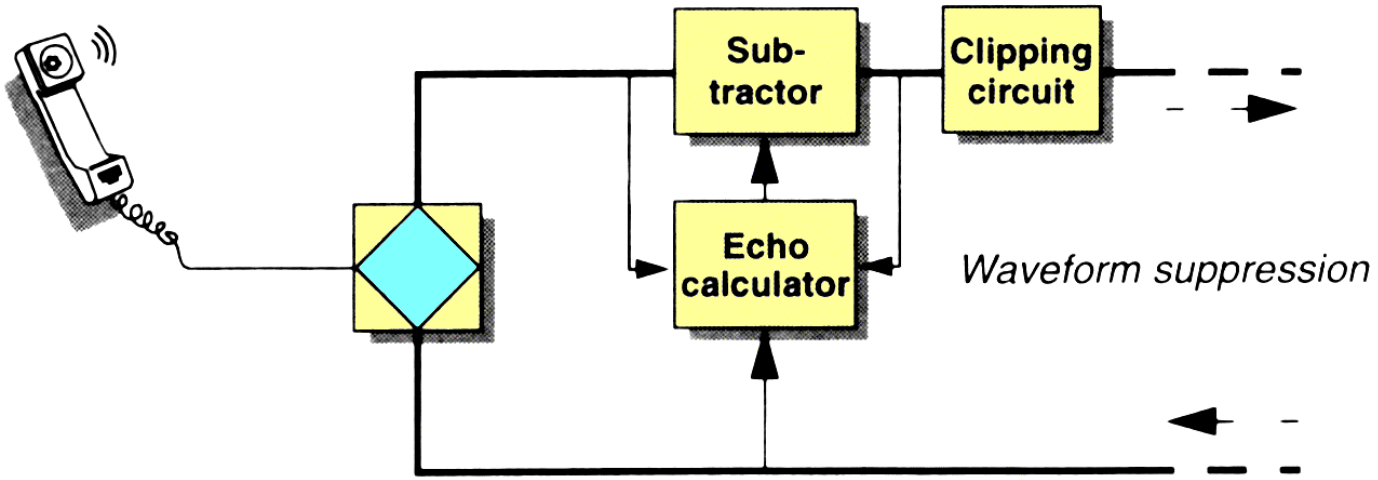
- R: transmission gate, A: attenuator, L: logic circuit
- When the signal is present on the receiving line the transmitting line is **cut-off**



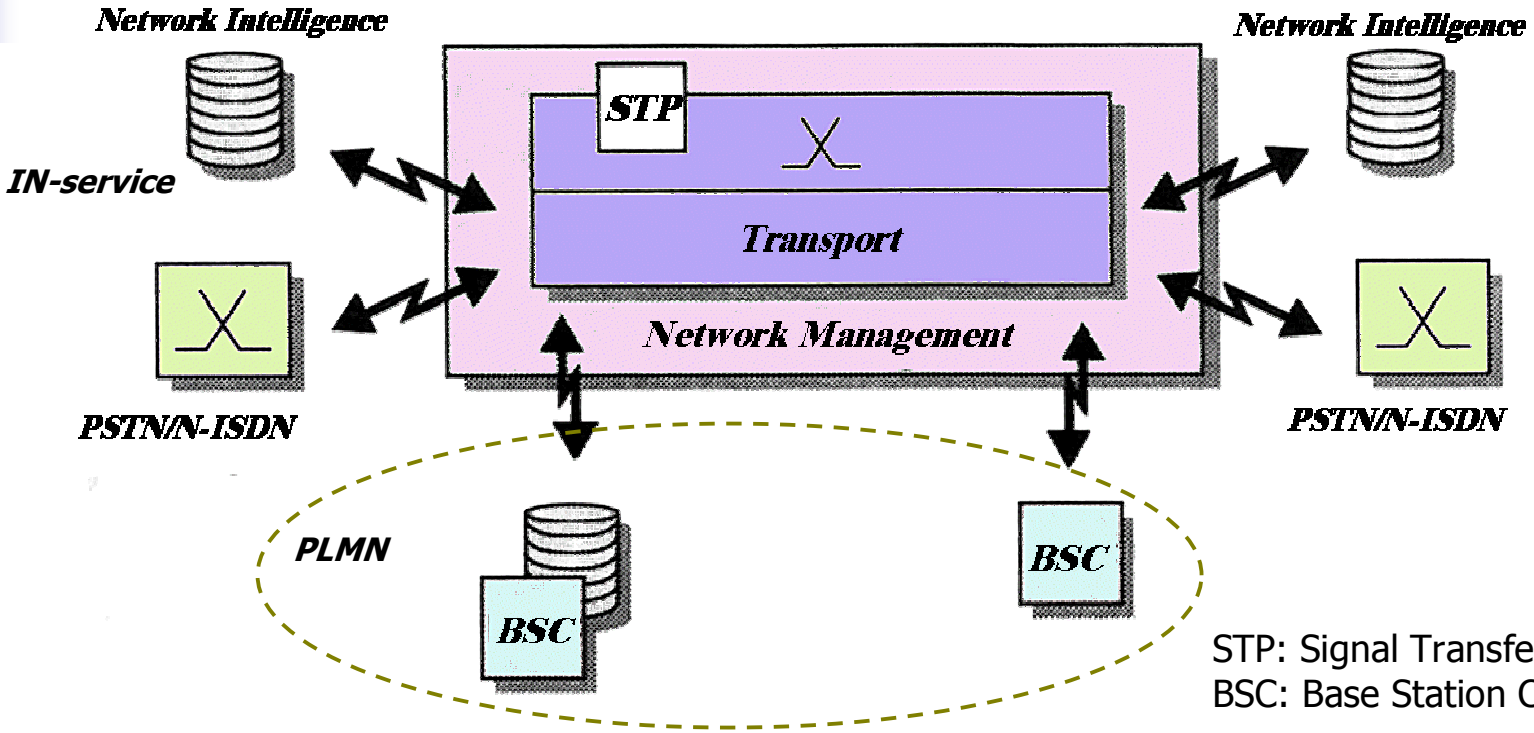
- A kind of semi-duplex approach to solve the echo problem

Network echo canceller (NEC)

- Signal echo is extracted and **subtracted** from the received signal
- More effective than echo suppressor. Often NEC and NES are however both used



Signaling



STP: Signal Transfer Point
BSC: Base Station Controller

- Telecom nets require more and more processor capacity:
  - More subscribers
  - Setting up connection is getting increasingly complex
  - Number of supplementary services increasing
- Signaling in PSTN divided to user signaling in local loop and to inter-exchange signaling

PSTN signaling

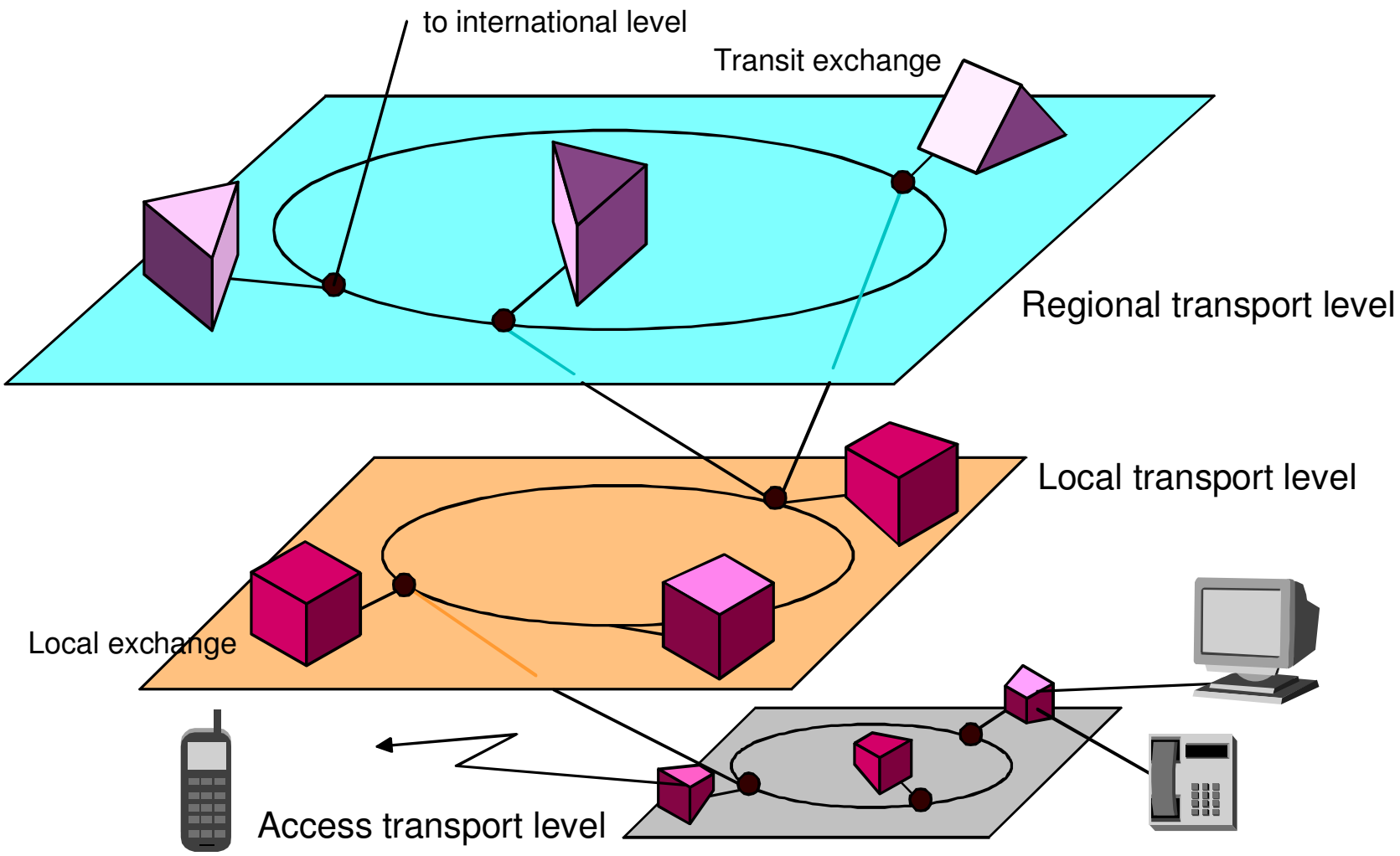
- Channel associated signaling (**CAS**) as No.5, R1, R2
  - analog and digital connections
- Modern ISDN exchanges apply SS7(digital), that is a common channel signaling method (**CSS**) that is discussed later in its own lecture
- **CAS** is divided into line and register signaling:
  - **Line** signaling:
    - line state between the trunk-links as
      - answer, clear-forward*, clear-back
  - **Register** signaling:
    - routing information as
      - B-number, A-category, B-status

*A-subscriber's on-hook message transmitted to B exchange

Signaling phases

- Three categories of information is transmitted:
  - **setup**, supervision clearing
  - **service** related information as
    - forwarding, callback, charging
  - **status** change information
    - transmission network congestion
    - neighborhood exchange congestion

Modern PSTN hierarchy



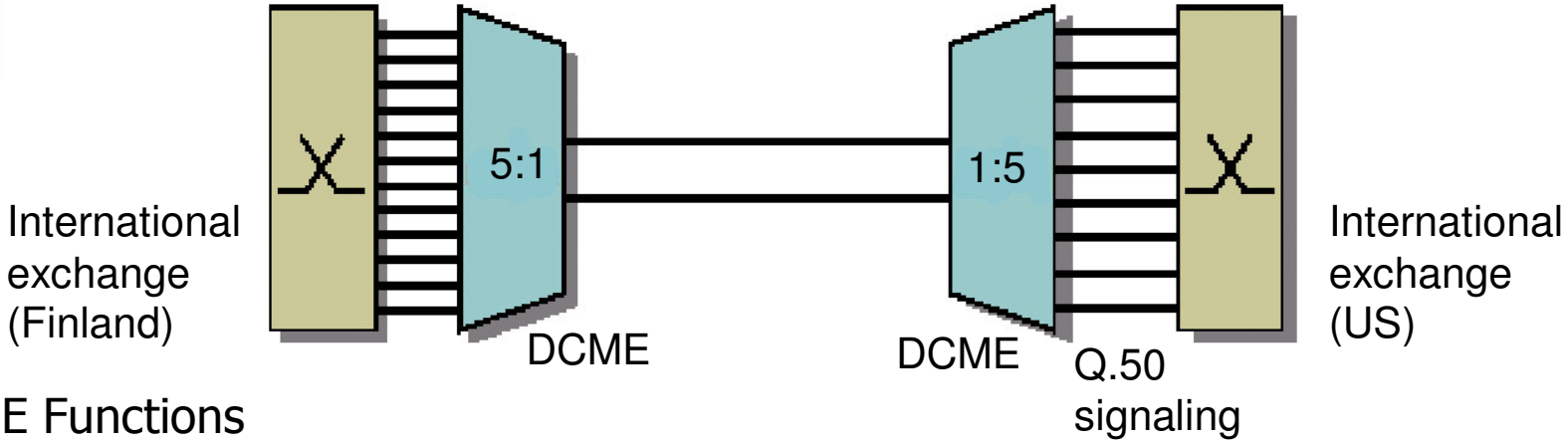
PSTN Hierarchy cont.

- **Local** (example, within a city)
  - Subscriber connections
  - Switching within the local exchange
  - Switching to other exchanges
- **Transit** (county level, say between Tampere and Helsinki)
  - Switching traffic between different geographical areas within one country
- **International**
  - Gateway-type traffic between
    - different countries
    - DWDM (Dense Wavelength Division Multiplexing) routes
- Rates can follow SONET or SDH standard

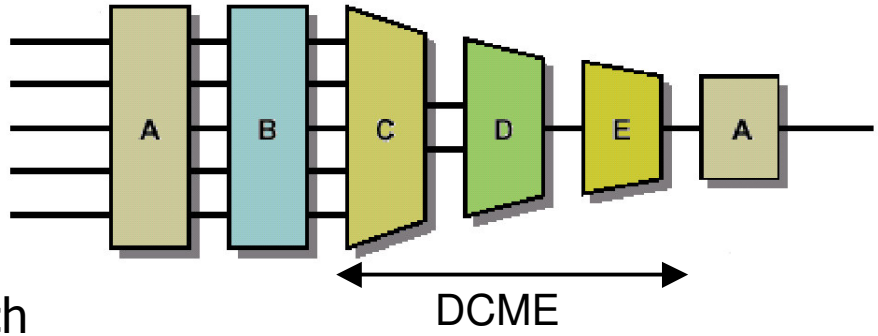
SDH

- transport of 1.5/2/6/34/45/140 Mbps within a transmission rate of 155.52 Mbps
- carries for instance ATM and IP within rates that are integer multiples of 155.52 Mbps

Digital Circuit Multiplexing Equipment DCME (G.763)



- DCME Functions
  - Digital speech interpolation (**DSI**) 2.5:1 + **ADPCM** of 32 kb/s
  - Overload handling: Extra system capacity can be allowed to variable bit rate (**VBR**) channels (capacity taken from unused compressed speech channels)
  - Option to **make conversions**
    - between T1 (1.5 Mb/s, US) and E1 (European 2 Mb/s) connections
    - between μ- and A-law compressions

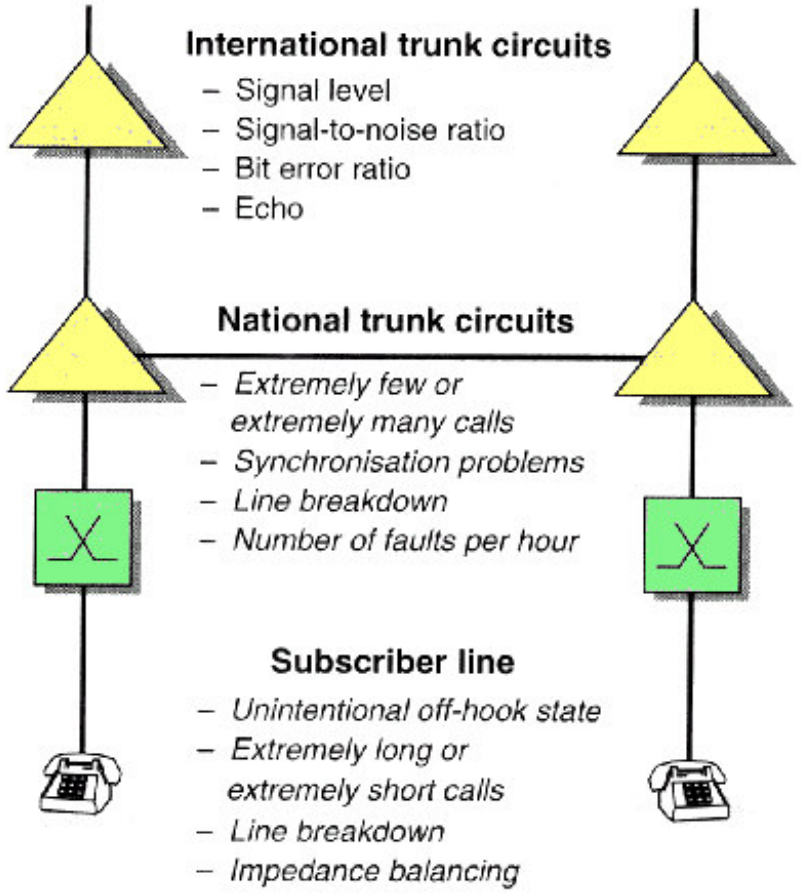


A: Digital line interface
B: Time-slot switching
C: Voice interpolation (DSI)
D: ADPCM
E: Variable bit rate (for overload)

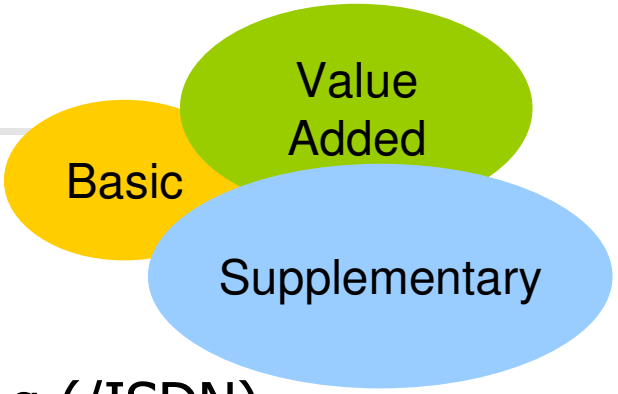
PSTN operation and maintenance (Q.513)

- Different alarm classes
- Vital functions and circuits (as SS7 and group switch) use secured paths and backups
  Procedures provided for:
  - troubleshooting
  - fault diagnostics
    - hardware faults can be isolated
- Supervision is realized also by connecting maintenance units to the network
- Important switches have extensive backup equipment

A supervision plan by network levels:

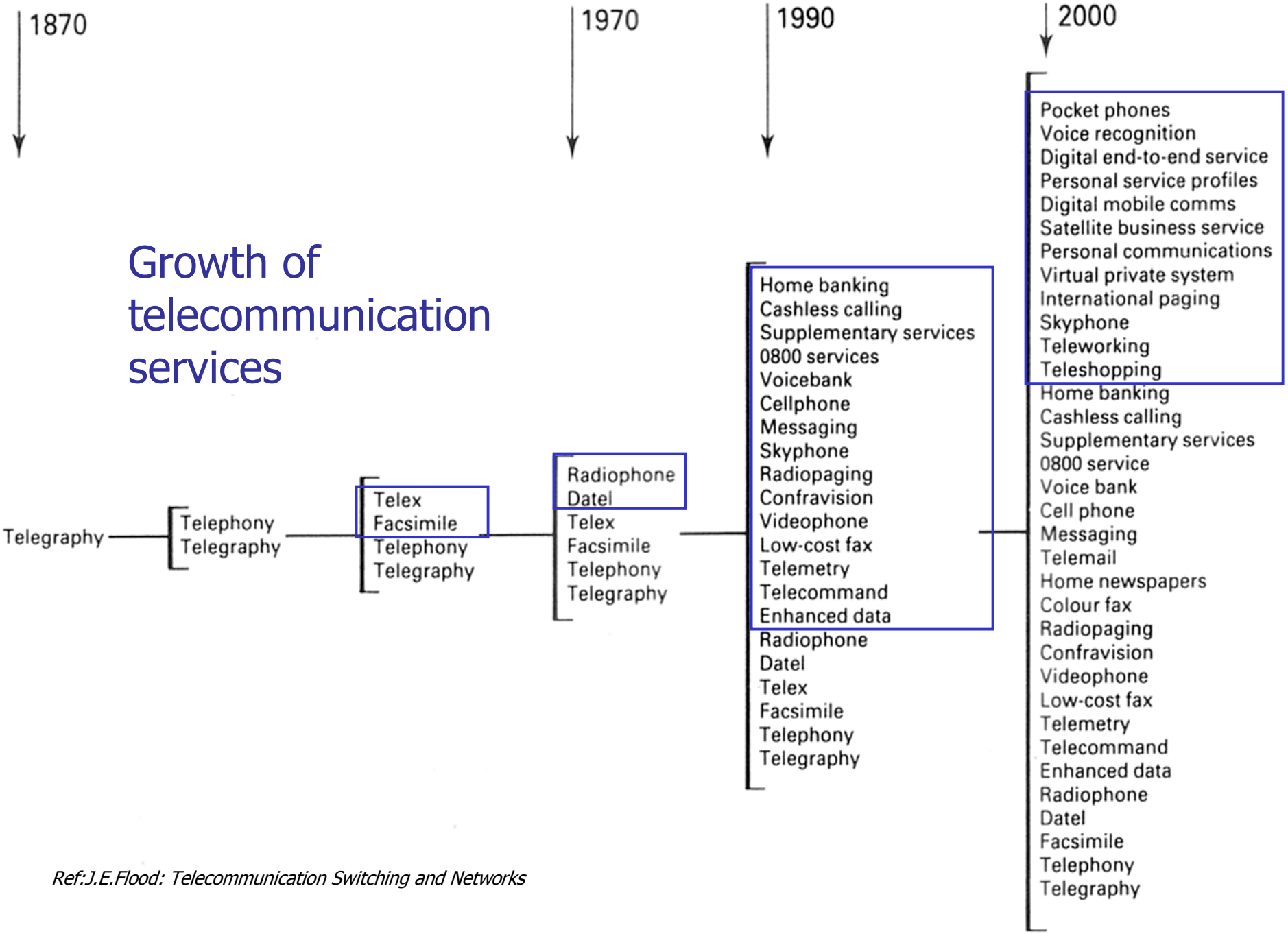


PSTN user services



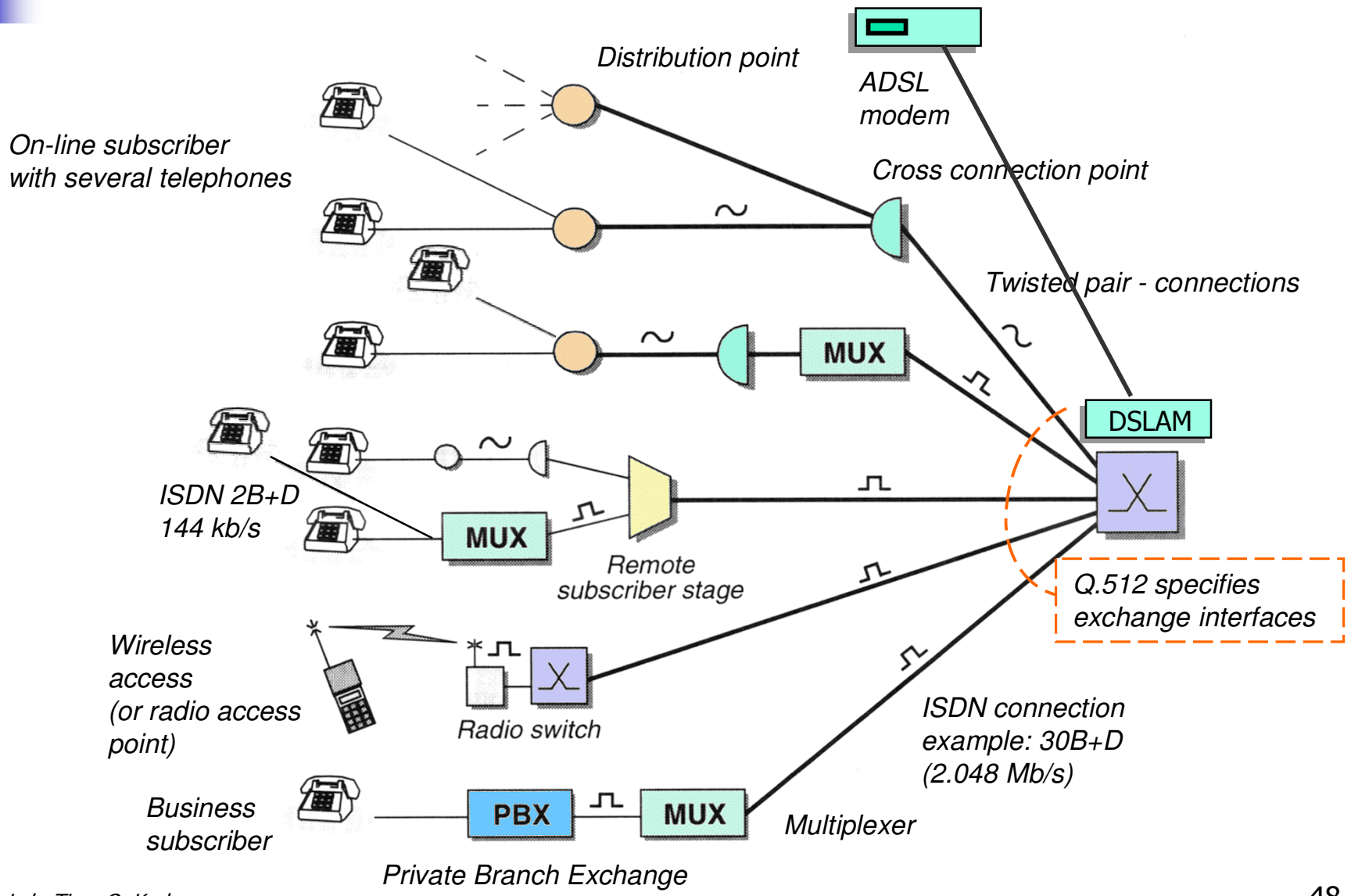
- **Basic** service
  - bearer service (*local loop access*): analog (/ISDN)
- **Value-added** services (*telephonist-originated*) services as
    - directory inquiry (118)
    - weather, stock exchange, ticket reservation ...
- **Supplementary** services (*Intelligent Terminal (IN) implementation*)
  - distributed supplementary as 'call forwarding unconditional' (Q.82.2), 'call waiting', 'queuing' ...
  - centralized supplementary services (IN) use specialized routing & charging as VPN, credit card calls, free phone (receiver pays), universal access number (connected automatically to the nearest office), ...

Growth of telecommunication services



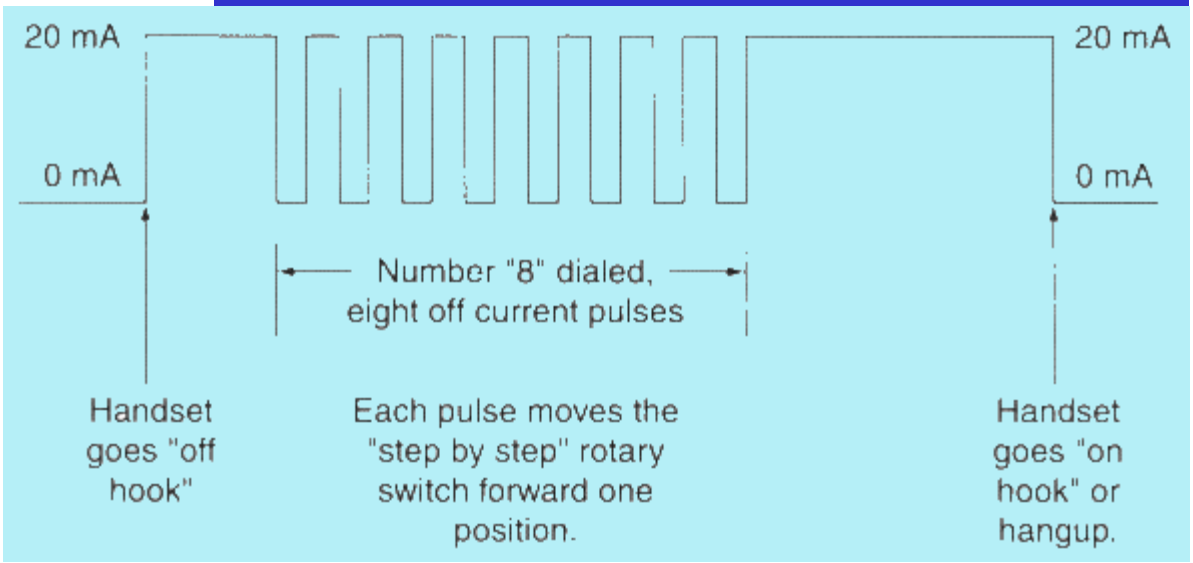
Ref:J.E.Flood: Telecommunication Switching and Networks

Connecting into PSTN exchange: Equipment in the access network

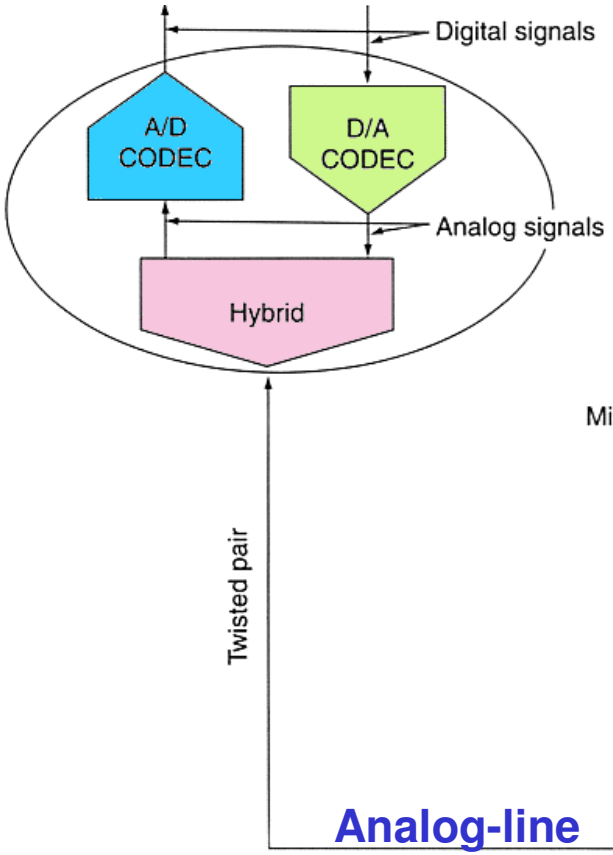


Analog local loop interface

Loop current used for signaling & message



Digital-lines to ISDN central office

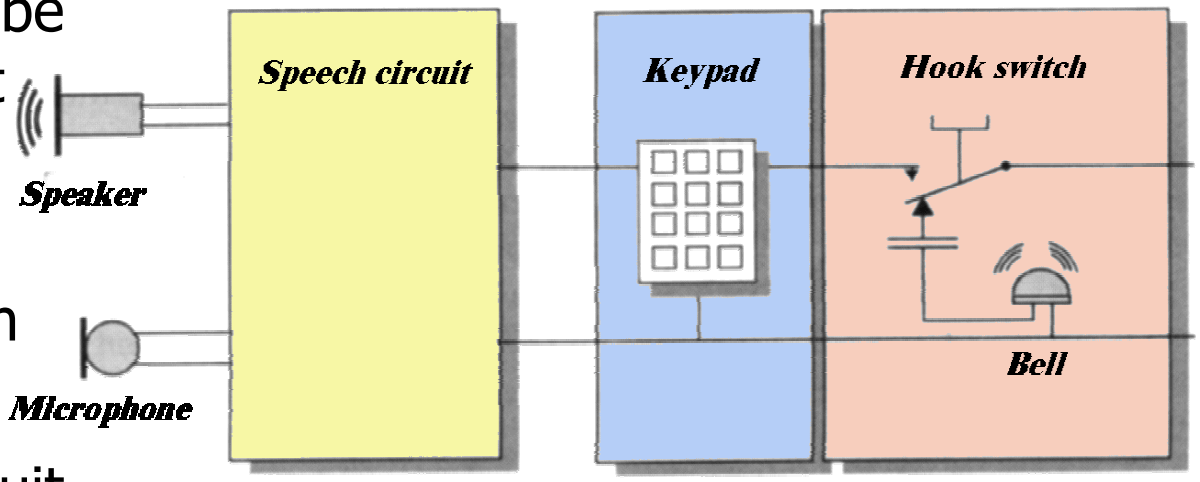


per trunk signaling in local loop:

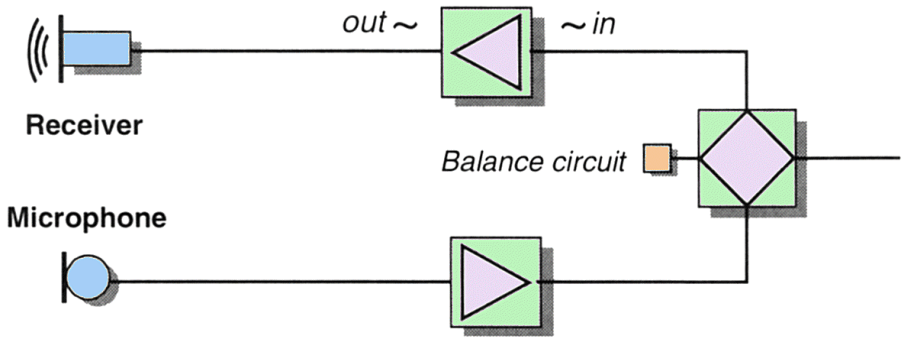
- long setup time
- hacking easy
- voice grade circuits
- interference & cross-talk sensitive
- expensive

Basic telephone terminal

- A basic phone can be made by using just four units
  - The bell
  - The hook switch
  - The keypad
  - The speech circuit

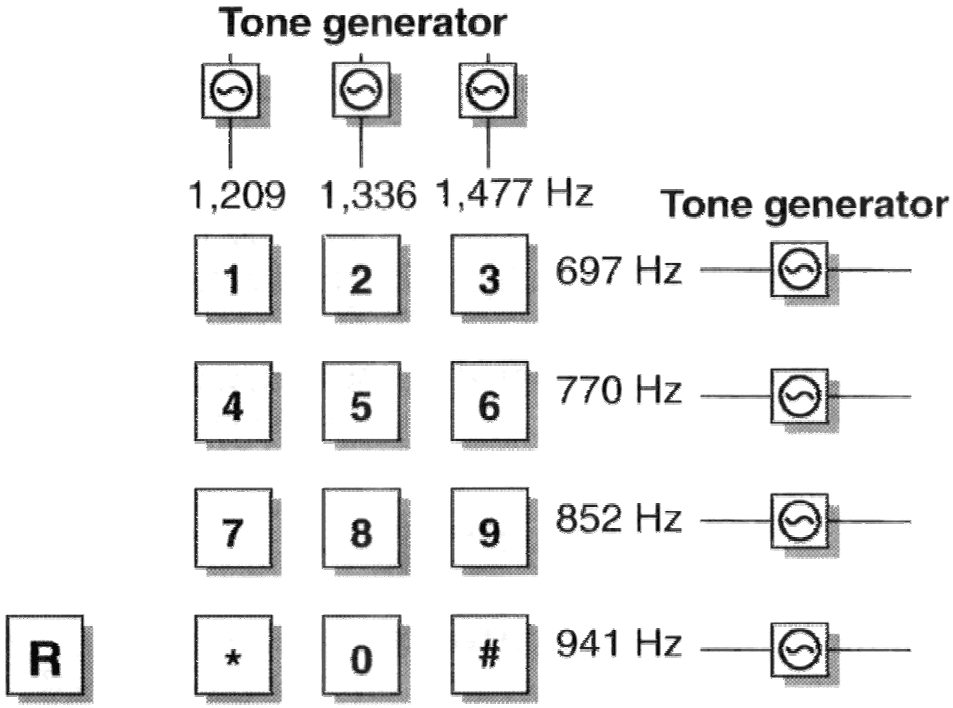


- Modern keypads use dual-tone dialing
- The speech circuit adapts voice levels and isolates mic and speaker



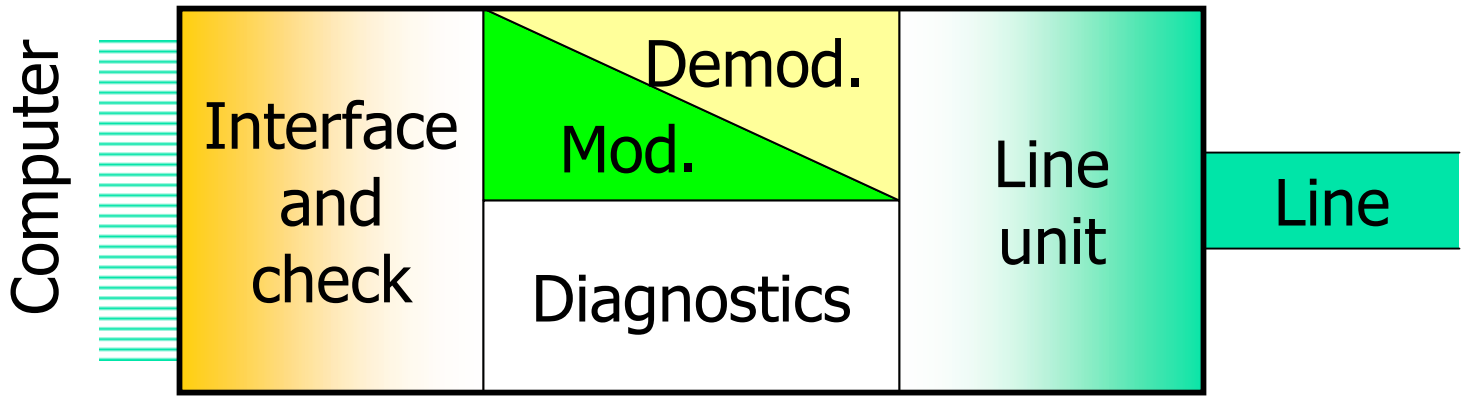
Dual-tone dialing

- Dual-tone dialing is used in subscriber loop to transmit the selected B-subscriber number
- Earlier pulse selection was applied (very rare nowadays)



Modems

- Diagnostic unit
  - Checks faults and controls the modem
- Interface and line units
  - Adapt the modem and terminal
- Modem performs A/D and D/A conversion and selects rate such that transmission quality criteria (error rate) can be meet



Modem recommendations

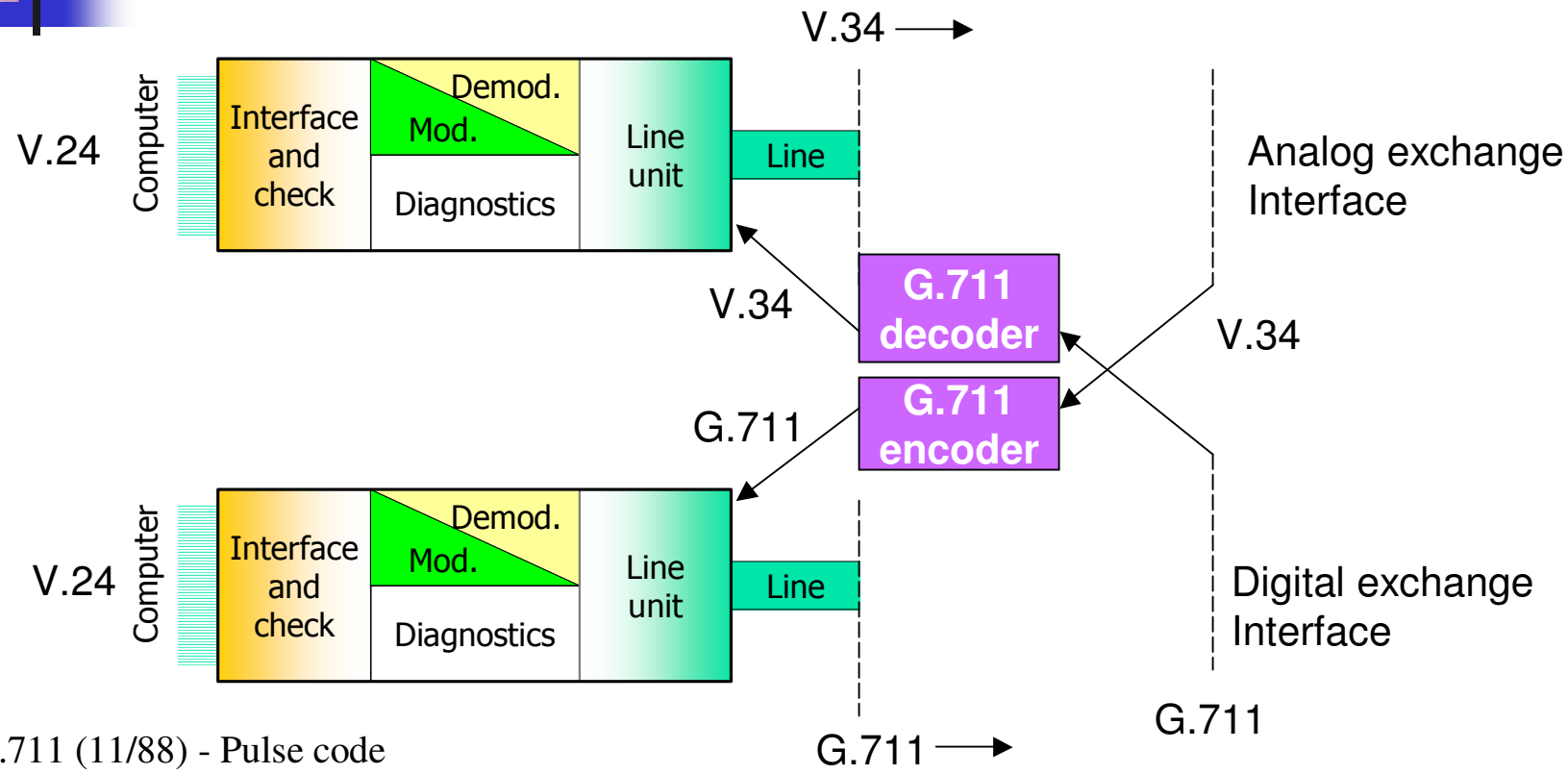
- ITU-T specifies several modem standards as
  - V.26 (11/88) - 2400 bits per second modem for use on 4-wire leased lines
  - V.27 (11/88) - 4800 bits per second modem for use on leased lines
  - V.29 (11/88) - 9600 bits per second modem for use on point-to-point 4-wire leased lines
  - V.90 (09/98) - 56 000 bit/s downstream and up to 33 600 bit/s upstream modem for use in the general switched telephone
  - V.36, V.37 - 48 kbit/s & up at 60-108 kHz

300 Hz - 3.6 kHz

Modem recommendation specifications

- Data signaling rates, symbol rates, carrier frequencies pre-emphasis, scrambler, framing
- Encoder (for instance TCM (Trellis coding) in V.90)
- Interface circuits (terminal-modem interface:V.24)
- Rate adaptation (real-time, at steps of 2.4 kb/s)
- Data compression (V.42bis, MNP 5)
- Error correction (V.42, MNP 10)
- PCM quantization curve ;μ (US) or A-law (Europe)
- Start-up signals and sequences
- Operating procedures
- Testing conditions

Analog and digital interfaces of modems



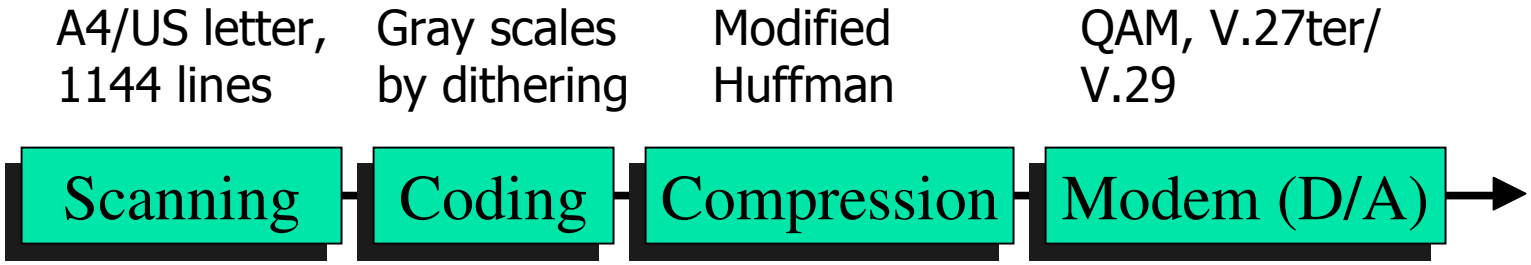
G.711 (11/88) - Pulse code modulation (PCM) of voice frequencies

V.34 (02/98) - A modem operating (up to 33 600 bit/s) for use in 2-wire analog PSTN

Digital modems: Generate G.711 signals and receive V.34 signals passed through G.711 encoder.
Connected to a digital switched network through a digital interface
Analog modems: Generate V.34 signals and receive G.711 signals that have been passed through G.711 decoder in an analog PSTN local loop

Fax communications over PSTN

- Faxes follow standard PSTN modem communications recommendations or IEEE recommendations, as V.17 *(02/91) (- Wire modem for facsimile applications with rates up to 14 400 bit/s)*
- Faxes are divided into groups:
  - Group 1 (´68): Analog scanning, 2400 bits/s
  - Group 2 (´76): Analog scanning, 4800 bits/s
  - Group 3 (´80): Digital scanning, 14400 bits/s
  - Group 4 (´84): Digital scanning, 64 kbit/s (ISDN)
- Example of modules in group 3 transmitting fax:



PSTN in ITU-T standards *(www.itu.org)*

- Series D Recommendations - General tariff principles
- Series E Recommendations - Overall network operation, telephone service, service operation and human factors
- Series G Recommendations - Transmission systems and media, digital systems and networks
- Series I Recommendations - Integrated services digital network (ISDN)
- Series M Recommendations - Network maintenance: international transmission systems, telephone circuits, telegraphy, facsimile, and leased circuits

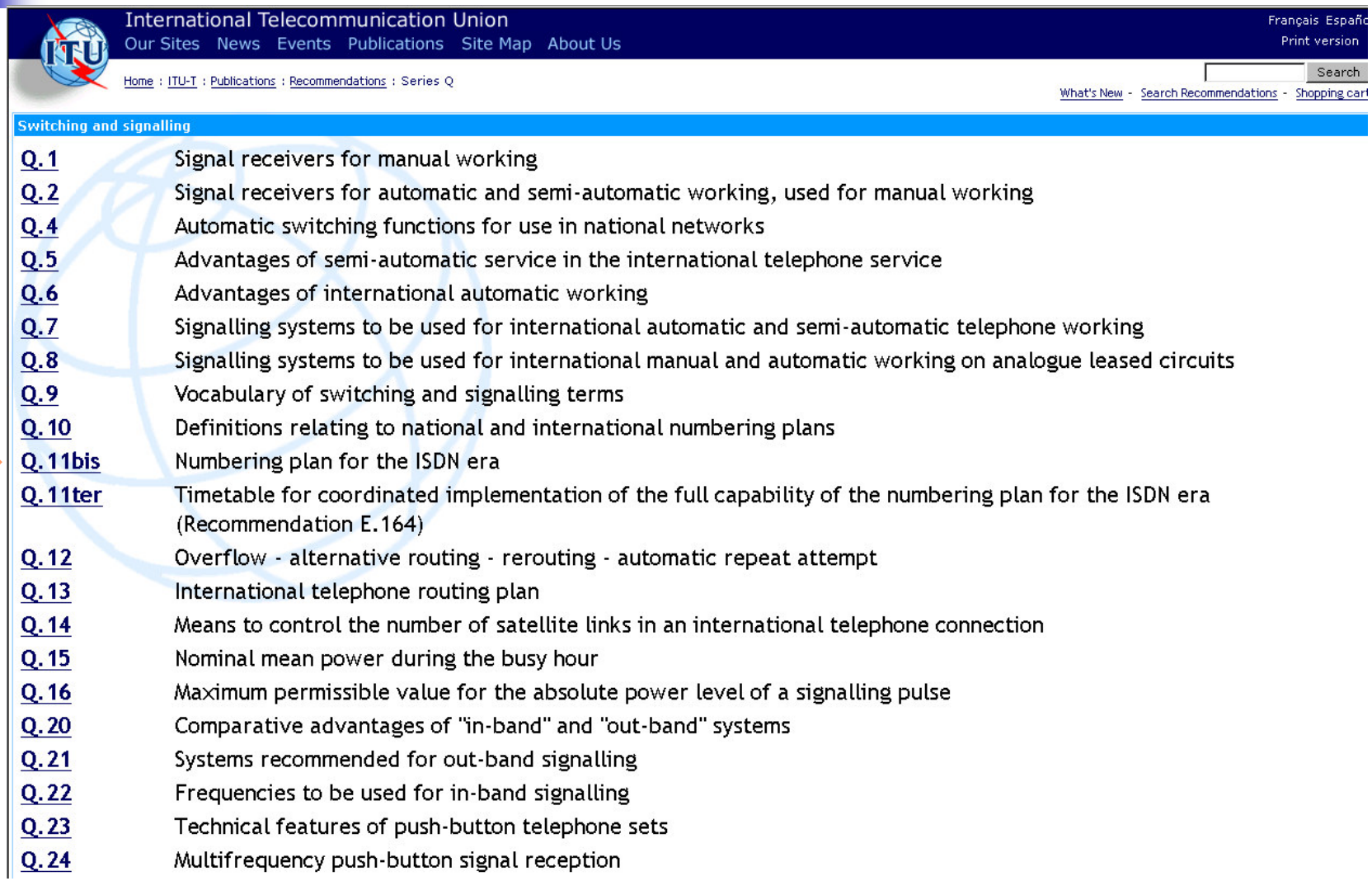
ITU: International Telecommunications Union

More PSTN standards *(www.itu.org)*

- Series O Recommendations - Specifications of measuring equipment
- Series P Recommendations - Telephone transmission quality, telephone installations, local line networks
- Series Q Recommendations - Switching and signaling (Signaling Systems no:4,5,6, and 7, Register Signaling no: R1, R2, IN - Service)
- Series V Recommendations - Data communication over the telephone lines

Example: Q-recommendations: Switching and signalling*

(Illustrative examples denoted by arrows)



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Switching and signalling

Q.1	Signal receivers for manual working
Q.2	Signal receivers for automatic and semi-automatic working, used for manual working
Q.4	Automatic switching functions for use in national networks
Q.5	Advantages of semi-automatic service in the international telephone service
Q.6	Advantages of international automatic working
Q.7	Signalling systems to be used for international automatic and semi-automatic telephone working
Q.8	Signalling systems to be used for international manual and automatic working on analogue leased circuits
Q.9	Vocabulary of switching and signalling terms
Q.10	Definitions relating to national and international numbering plans
Q.11bis	Numbering plan for the ISDN era
Q.11ter	Timetable for coordinated implementation of the full capability of the numbering plan for the ISDN era (Recommendation E.164)
Q.12	Overflow - alternative routing - rerouting - automatic repeat attempt
Q.13	International telephone routing plan
Q.14	Means to control the number of satellite links in an international telephone connection
Q.15	Nominal mean power during the busy hour
Q.16	Maximum permissible value for the absolute power level of a signalling pulse
Q.20	Comparative advantages of "in-band" and "out-band" systems
Q.21	Systems recommended for out-band signalling
Q.22	Frequencies to be used for in-band signalling
Q.23	Technical features of push-button telephone sets
Q.24	Multifrequency push-button signal reception

*http://www.itu.int/rec/recommendation.asp?type=products&lang=e&parent=T-REC-Q

Switching and signalling (cont.)

Q.52	Signaling between international switching centers and stand-alone echo control devices
Q.55	Signalling between signal processing network equipment (SPNE) and international switching centres (ISC)
Q.56	Signalling between signal processing network equipment (SPNE) and international switching centres (ISC) over an IP network
Q.65	The unified functional methodology for the characterization of services and network capabilities
Q.68	Overview of methodology for developing management services
Q.71	ISDN circuit mode switched bearer services
Q.72	Stage 2 description for packet mode services
Q.76	Service procedures for Universal Personal Telecommunication - Functional modelling and information flows
Q.80	Introduction to stage 2 service descriptions for supplementary services
Q.81.1	Direct dialling-in
Q.81.2	Multiple subscriber number
Q.81.3	Calling line identification presentation (CLIP) and calling line identification restriction (CLIR)
Q.81.5	Connected line identification, presentation and restriction (COLP) and (COLR)
Q.81.7	Malicious call identification (MCID)
Q.81.8	Sub-addressing (SUB)
Q.82.1	Call transfer
Q.82.2	Call forwarding
Q.82.3	Call deflection
Q.82.4	Line hunting
Q.82.7	Explicit call transfer
Q.83.1	Call waiting (CW)
Q.83.2	Call hold
Q.83.3	Stage 2 description for call completion supplementary services : Completion of call to busy subscriber
Q.83.4	Terminal portability
Q.84.1	Conference calling (CONF)