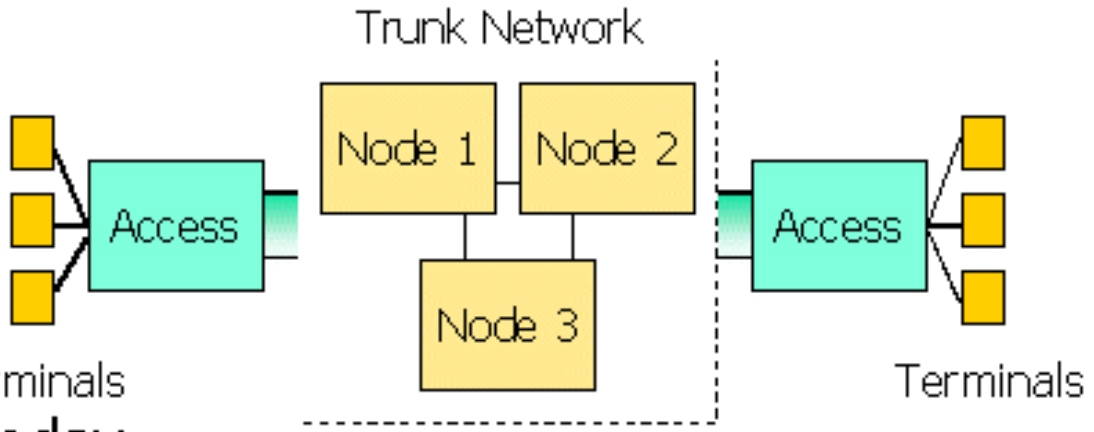
Public Switched Telephone Network (PSTN)

Topics in PSTN

- Introduction
  - review of early exchanges
  - PSTN Standards
- User services & terminals (discuss today modems, phones and faxes only)
- Modern exchange technology
  - interface standards
  - access and trunk networks
  - signaling
  - network management
  - internetworking between networks



Introduction

- PSTN switching is based on circuit switching by duplex connections
- Temporary bidirectional connections
- Originally for speech (voice) only at 300-3400 Hz
- Earlier two subscribers connected by a purely physical connection
- Nowadays by time slots~ISDN integrated to PSDN
- PCM is the TDMA standard for the A/D conversion
- PCM time slots consist of 8 bit samples
- For voice digital exchange sets up 64 kbit/s connections
- Data connections by (1) modems in old PSTN, by (2) ISDN interface (3) leased lines as X.25 or (4) ADSL

PCM: pulse coded modulation

History

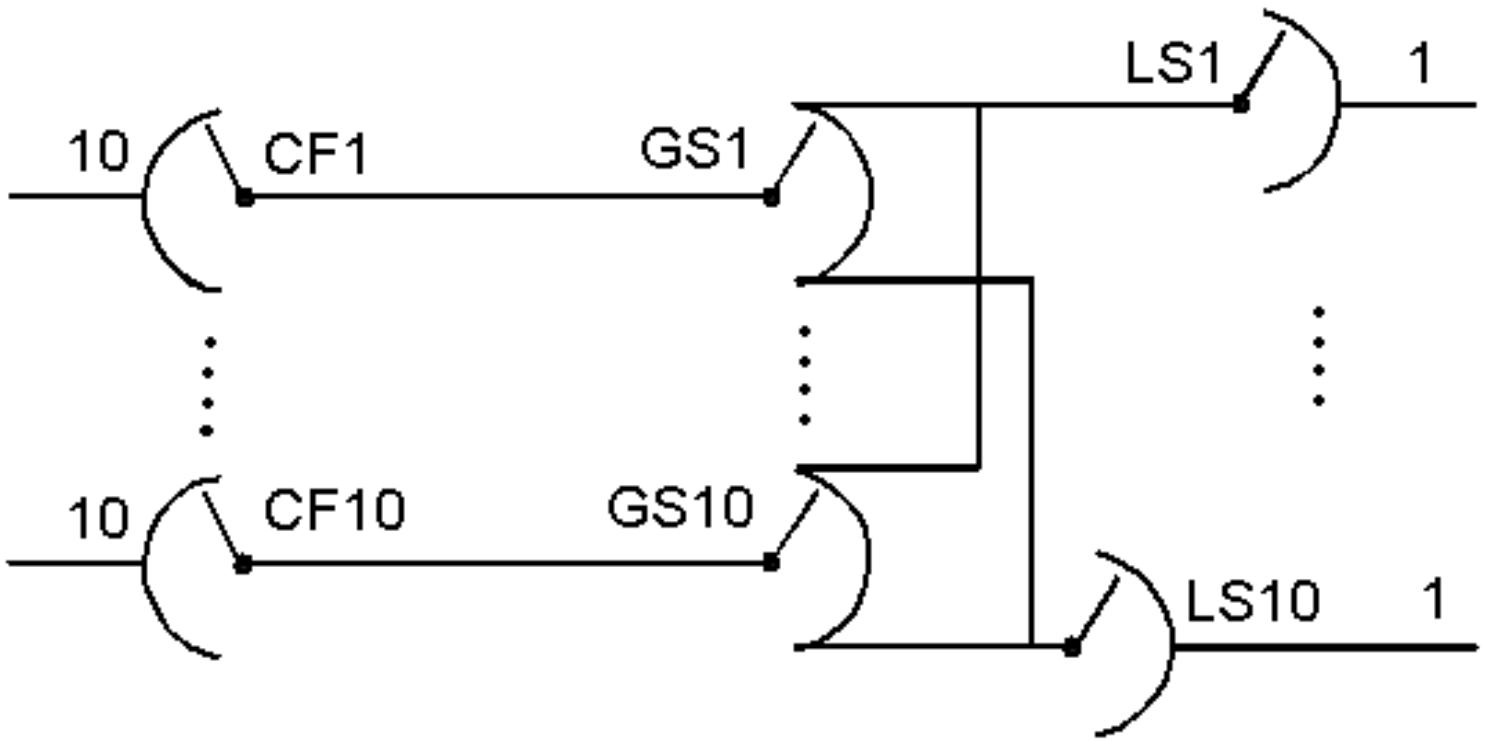
- 1878 The first exchange constructed in La Porte, the US
  - could connect any two of the 21 subscribers
  - manual switching (!)
- 1890 first automatic exchange: Strowger Switch
  - Almon B. Strowger: an undertaker in Kansas City
- 1960s and 1970s processor controlled, semi-automatic switches: Stored Program Control (SPC)
  - This allowed new functionality to be build into exchanges for
    - supervision
    - charging
    - gathering statistics

PSTN Exchange development stages

- Register-controlled setup
  - B-subscriber number receiver by a register
  - register controls all the remaining call setup stages
- Distributed control
  - Markers indicate idle switches
  - Thus markers control path routing
- Stored program control (SPC)
  - New services
  - Integrated charging
  - Easier updating and maintenance

1960 and before

An early exchange: 100 subscriber exchange (Subscriber controlled call set-up)



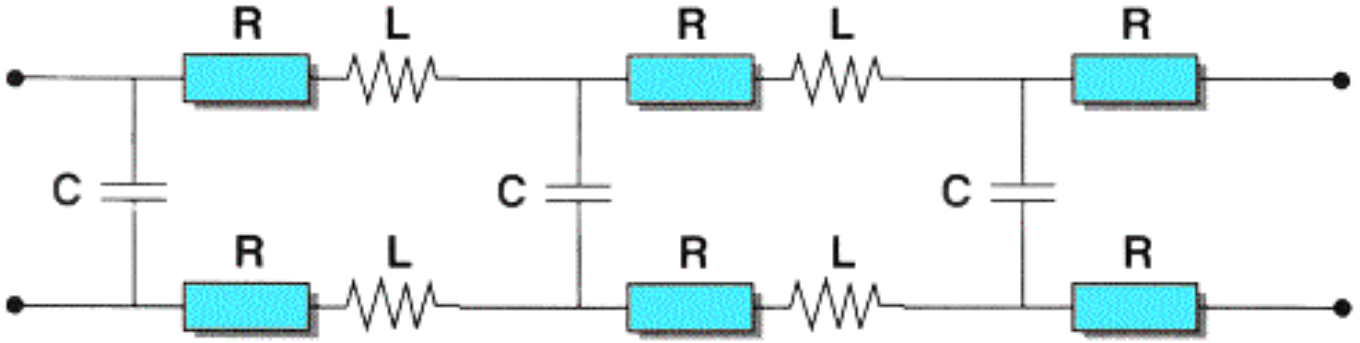
Main parts of the switch: Call finders (CF), Group selectors (GS) and Line selectors (LS)

An early exchange, call setup

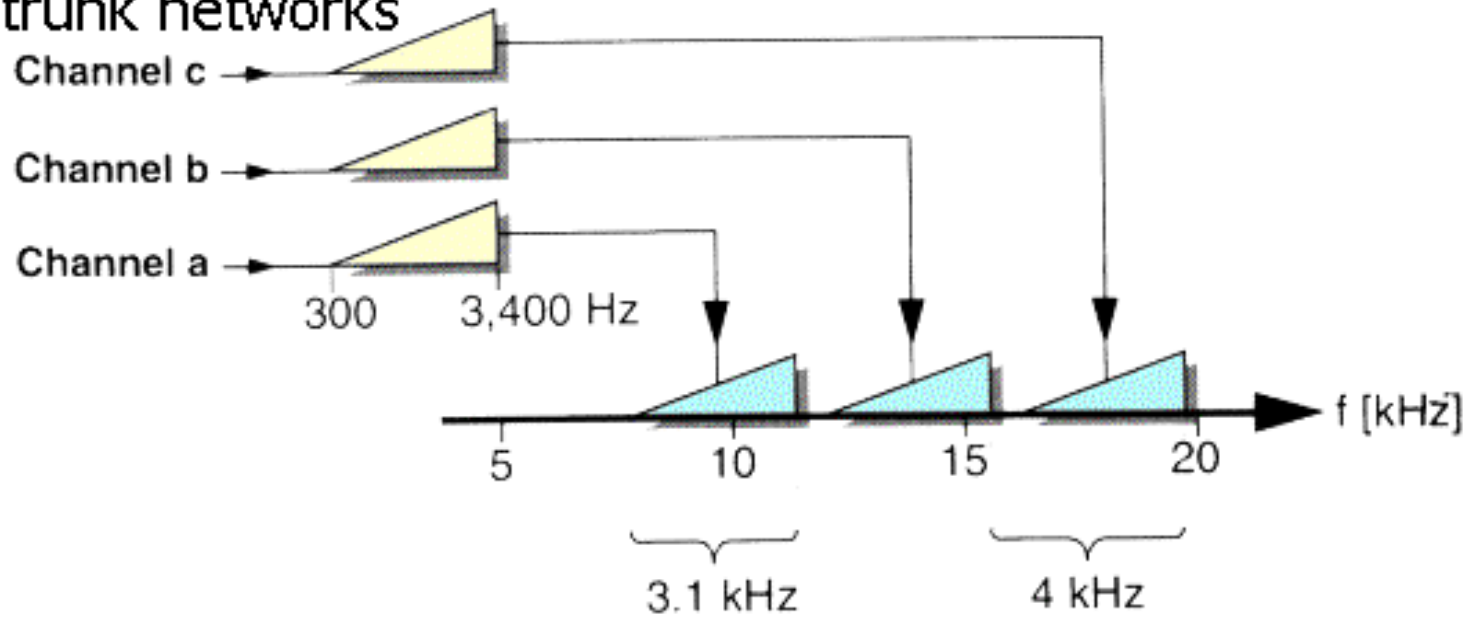
- One of the 100 subscribers lifts his handset -> Call finder is activated to search the line.
- After the line is located other relays connect the dial-tone generator.
- The subscriber selects two digits.
- The first digit selects the subscriber group by using the group selector.
- The second digit selects the line selector.
- Selection is done by sending pulses that move the selectors stepwise.
- When connection is established a ringing tone is sent.

Some features in PSTN of ´60

- Coil loading was used to enhance higher frequency range



- Frequency division multiplexing with SSB was used in trunk networks



Some features of PSTN of ´60 (cont.)

- Network intelligence and value-added service
  - not supported as such
  - operators were anyhow intelligent :)
    - value added services by tracking what happens in the area!
- Inter-exchange signaling
  - call setup took about 15 seconds
  - channel-associated signaling
  - about 10% of trunk line capacity was taken by signaling
- Operation and maintenance
  - using local info-bases and local workforce
  - network maintenance was based on on-field check-ups

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...

- Series O Recommendations - Specifications of measuring equipment
- Series P Recommendations - Telephone transmission quality, telephone installations, local line networks
- Series Q Recommendations - Switching and signaling
- Series V Recommendations - Data communication over the telephone lines

Example: E-recommendations on ITU-T´s homepage

International Telecommunication Union

Highlights
Radiocommunication
Standardization
Development
TELECOM Events
Publications
Databases
Search
Sponsors

Series E Recommendations - Overall network operation, telephone service, service operation and human factors

List of ITU-T E-Series Recommendations in force (05/99)

[E.100] Recommendation E.100 (11/88) - Definitions of terms used in international telephone operation	20 CHF
[E.104] Recommendation E.104 (02/95) - International telephone directory assistance service and public access	20 CHF
Summary of Recommendation E.104 (02/95)	
[E.105] Recommendation E.105 (08/92) - International telephone service	20 CHF
[E.109] Recommendation E.109 (02/95) - International billed number screening procedures for collect and third-party calling	20 CHF
Summary of Recommendation E.109 (02/95)	
[E.110] Recommendation E.110 (11/88) - Organization of the international telephone network	20 CHF
[E.111] Recommendation E.111 (11/88) - Extension of international telephone services	20 CHF
[E.112] Recommendation E.112 (11/88) - Arrangements to be made for controlling the telephone services between two countries	20 CHF
[E.113] Recommendation E.113 (05/97) - Validation procedures for the international telecommunications charge card service	20 CHF
Table of Contents and Summary of Recommendation E.113 (05/97)	
[E.114] Recommendation E.114 (11/88) - Supply of lists of subscribers (directories and other means)	20 CHF
[E.115] Recommendation E.115 (02/95) - Computerized directory assistance	20 CHF
Summary of Recommendation E.115 (02/95)	
[E.116] Recommendation E.116 (05/97) - International telecommunication charge card service	20 CHF

E-Recommendations... (cont.)

- Sometimes recommendations may end up showing simple set of instructions in non-technical matters: Example: Recommendation E.134 (03/93) - Human factors aspects of public terminals: Generic operating procedures

Terminal type	User action					
	Initialization	Means of payment	Identification	Communication	Next	End
Payphone	Lift handset	Insert means of payment	Input number (Address)	Transfer information	Press desig-nated button	Replace handset
Public fax (Sendmode)	Place document	Insert means of payment	Input number	Transfer information	Press desig-nated button	Automatic
Public fax (Receive mode)	Place document	Insert means of payment	Input number (of Network Node)	Transfer information	Press desig-nated button	Automatic
Public Videotex		Insert means (if required)	Select option	Transfer information	Select another option	

Connecting into PSTN

- Users can connect into PSTN by
  - Fixed-line phone (analog, voice)
  - Cordless phone (analog with A/D converter in the terminal, also DECT based access)
  - Fax (digital data with a build-in modem providing an analog signal)
  - Computer (digital via modem, ISDN or ADSL techniques)
  - Pay phone (analog or digital)
  - PBX (PCM link to the local exchange, A/D conversion in the business network)

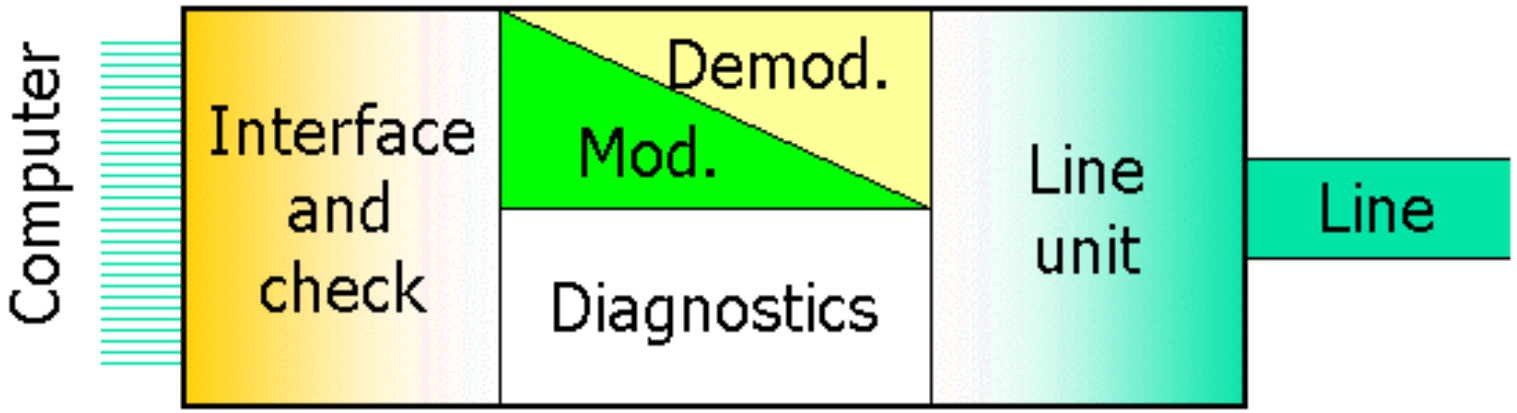
DECT: Digital Enhanced Cordless Telecommunications
ADSL: Asynchronous Digital Subscriber Line
PBX: Private Brach Exchange

Modems

- 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.27ter (11/88) - 4800/2400 bits per second modem for use in the general switched telephone
  - 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

Basic modules of a modem

- 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 such that transmission quality criteria can be met

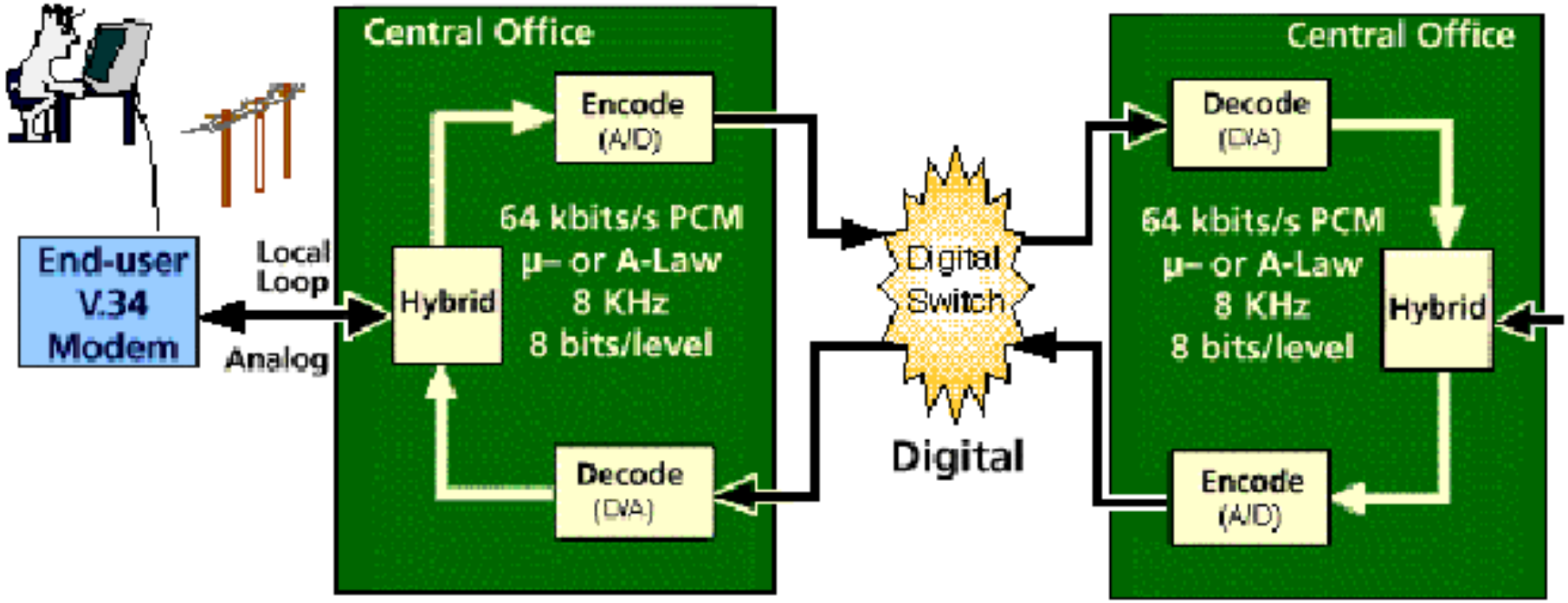


What is specified in a modem recommendation?

- Data signaling rates, symbol rates, carrier frequencies pre-emphasis, scrambler, framing, encoder
- Interchange circuits
- Start-up signals and sequences
- Operating procedures
- Testing facilities
- There are two kind of modems specified by ITU-T:
- Digital modems: Generates G.711 signals and receives V.34 signals passed through a G.711 encoder. Connected to a digital switched network through a digital interface
- Analog modems: Generates V.34 signals and receives G.711 signals that have been passed through a G.711 decoder in an analog PSTN local loop

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

Example of a V.34 (33.6 kbit/s) connection

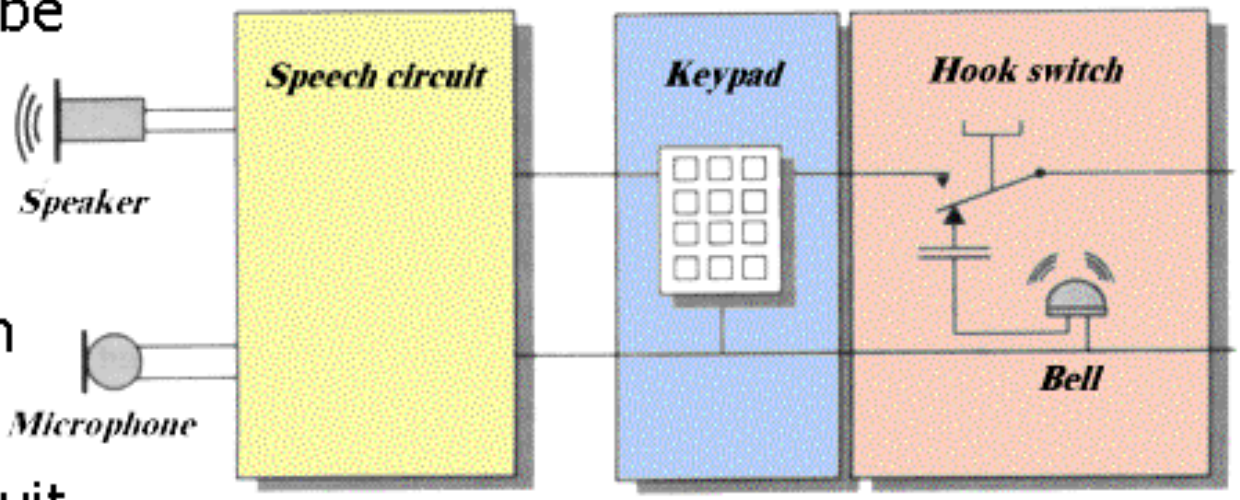


Fax communications over PSTN

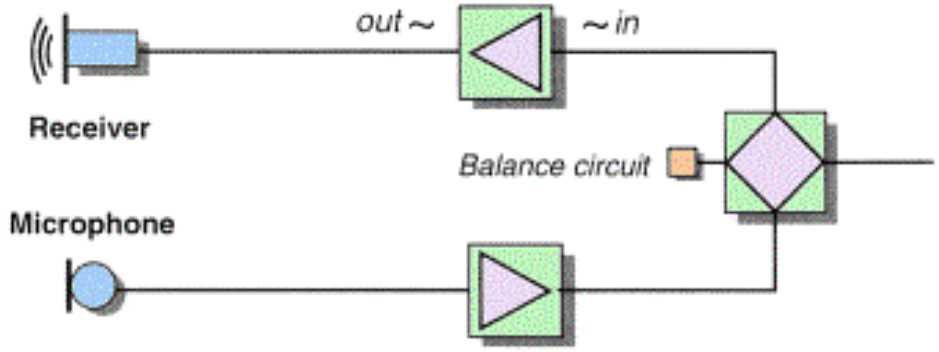
- Faxes follow standard PSTN modem communications recommendations or recommendation V.17 *(02/91) (- Wire modem for facsimile applications with rates up to 14 400 bit/s)*
- Faxes are divided into groups:
  - Group 1 (´68): Analog scanning, 2400 bits/s
  - Group 2 (´76): Analog scanning, 4800 bits/s
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

Basic telephone terminal

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

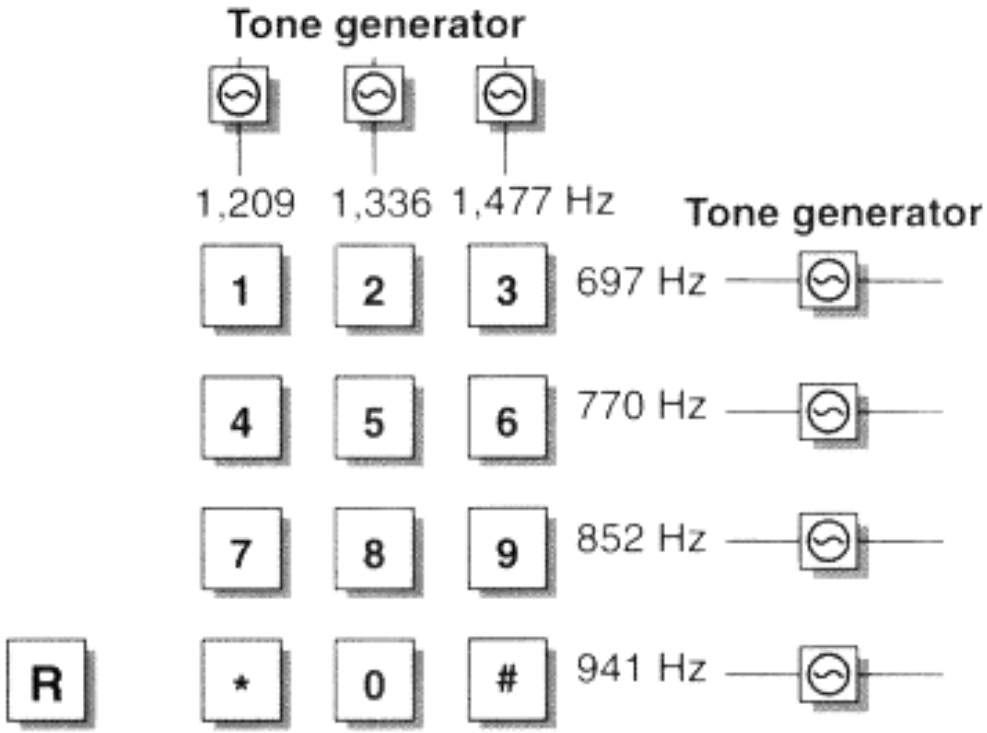


- Modern keypads use dual-tone dialing
- The speech circuit adapts voice levels and isolates mic and speaker

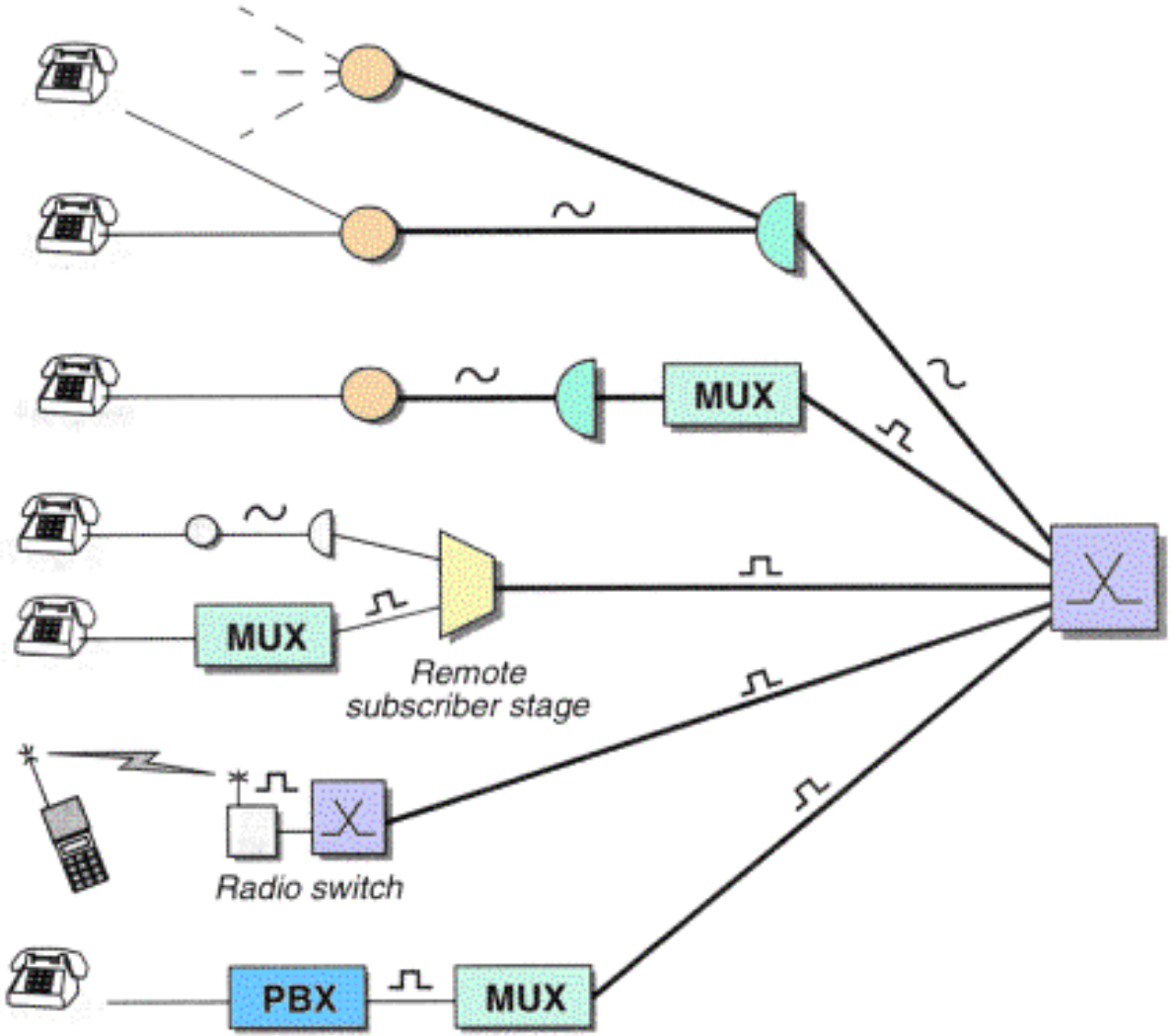


Dual-tone dialing

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

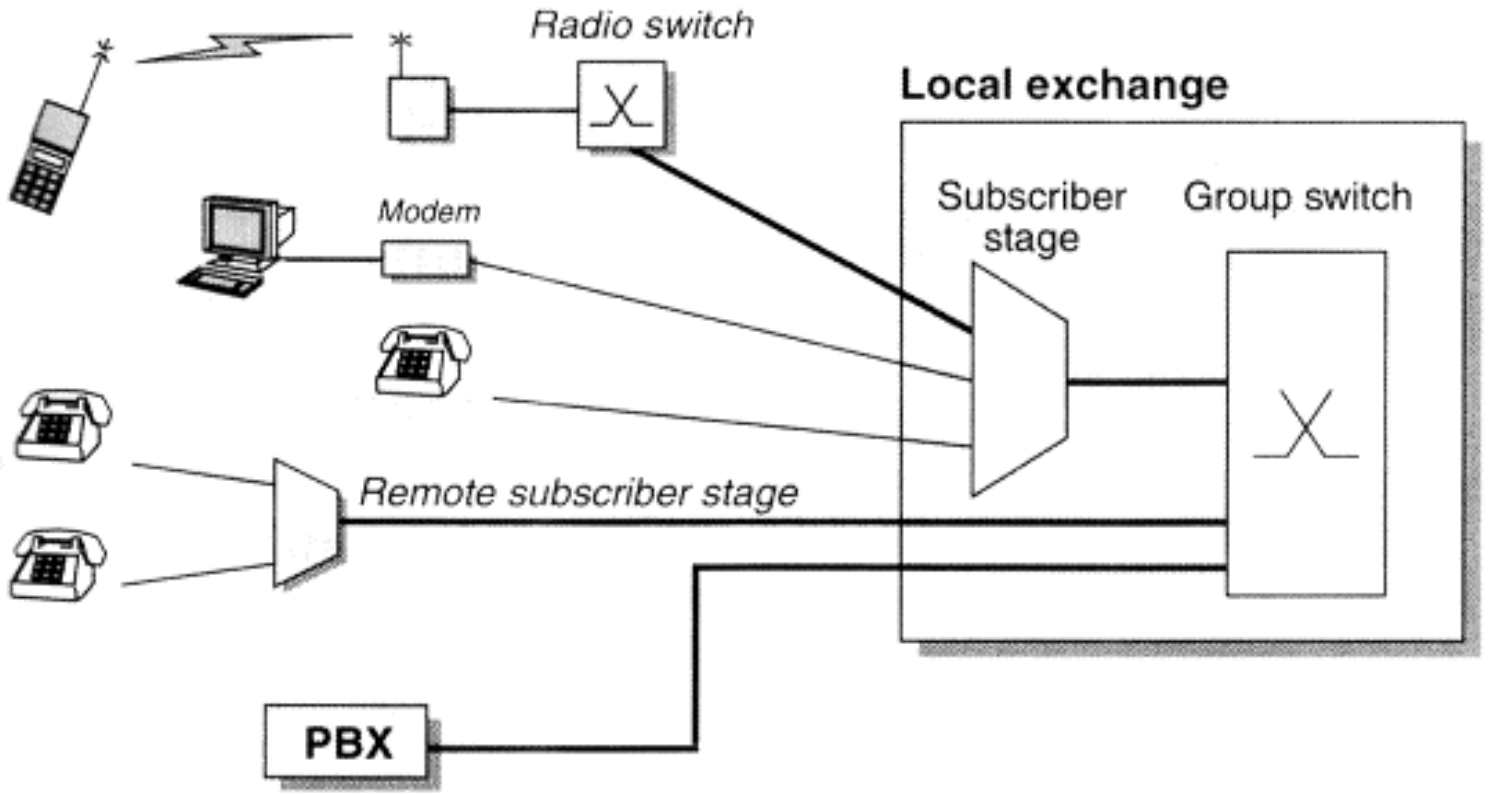


Connecting into PSTN: Equipment in the access network

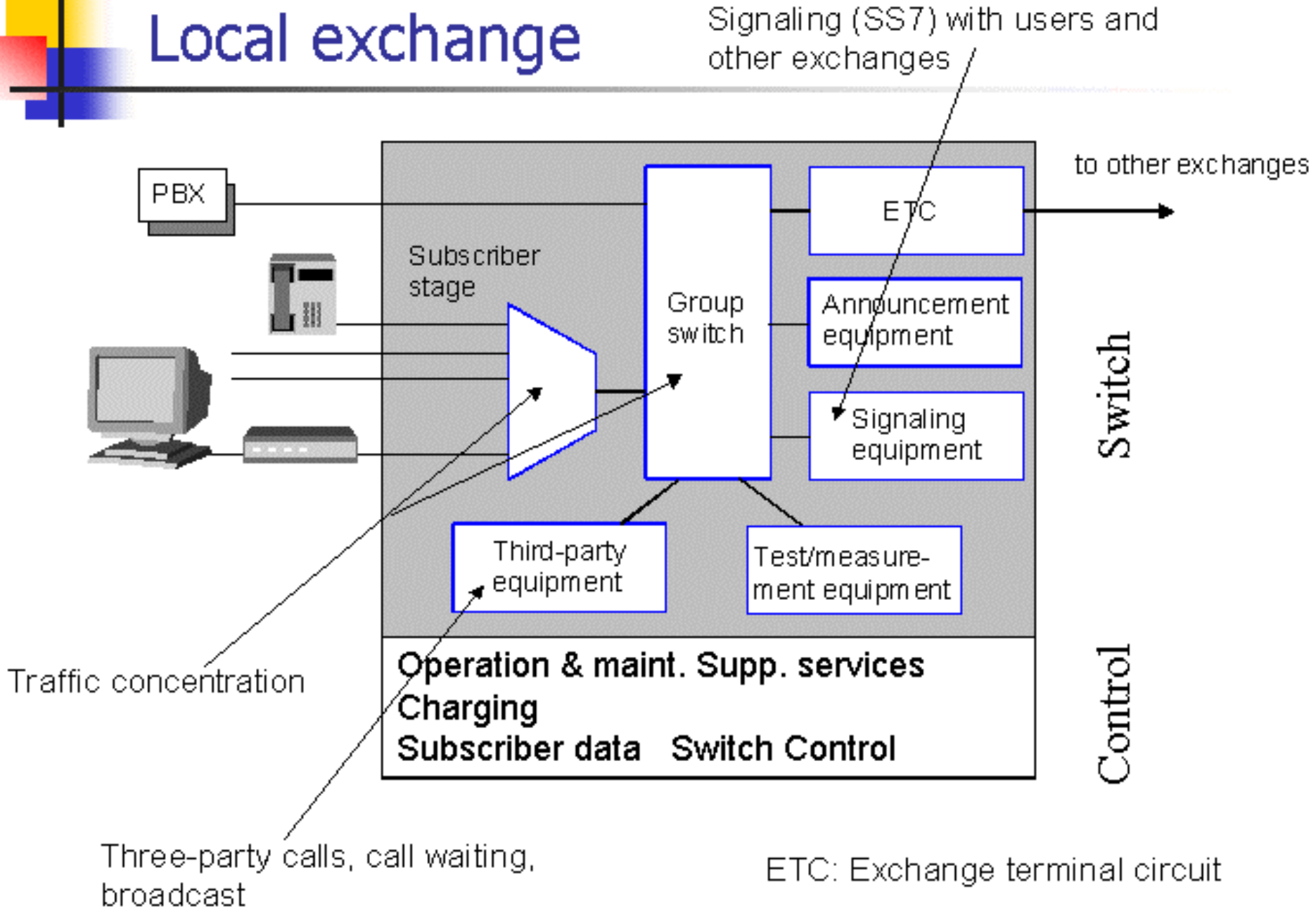


Connection of a remote subscriber stage

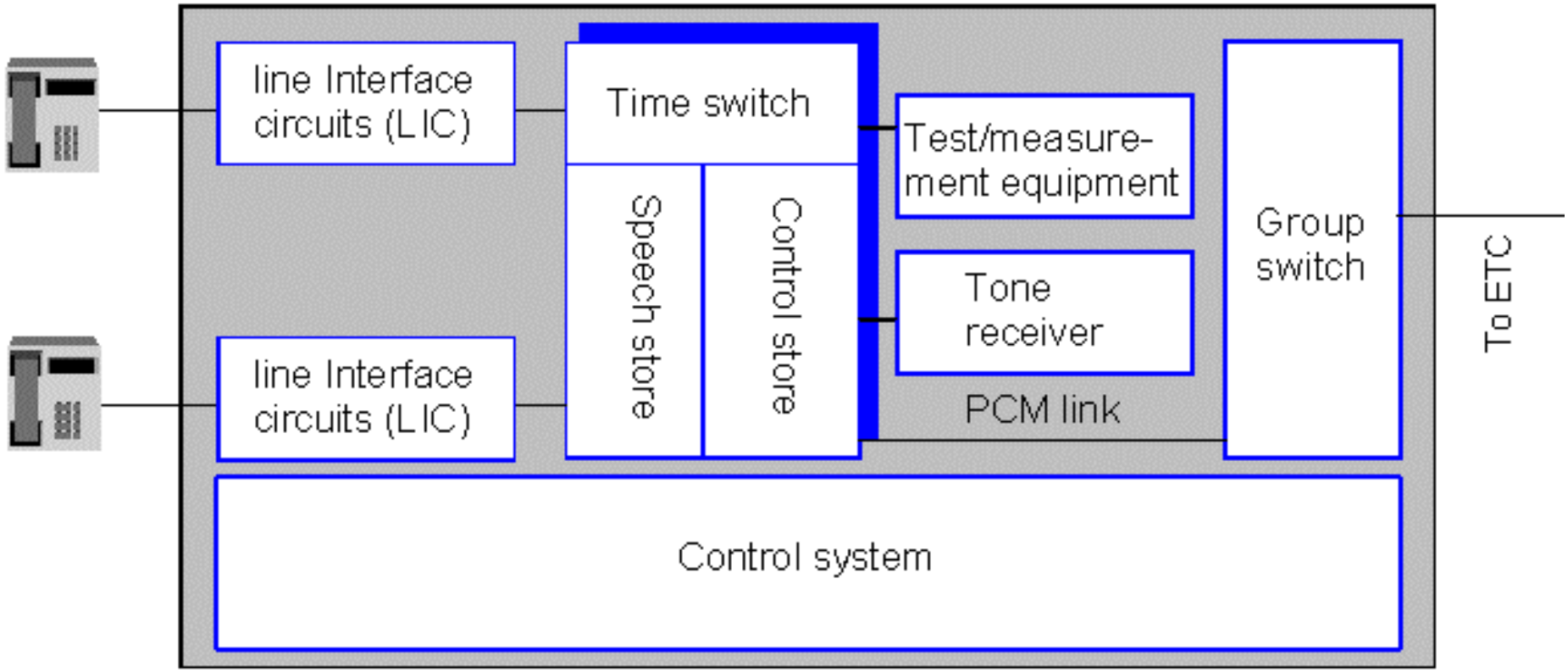
- Remote subscriber stage is connected directly to the group switch (to be soon discussed)



Local exchange

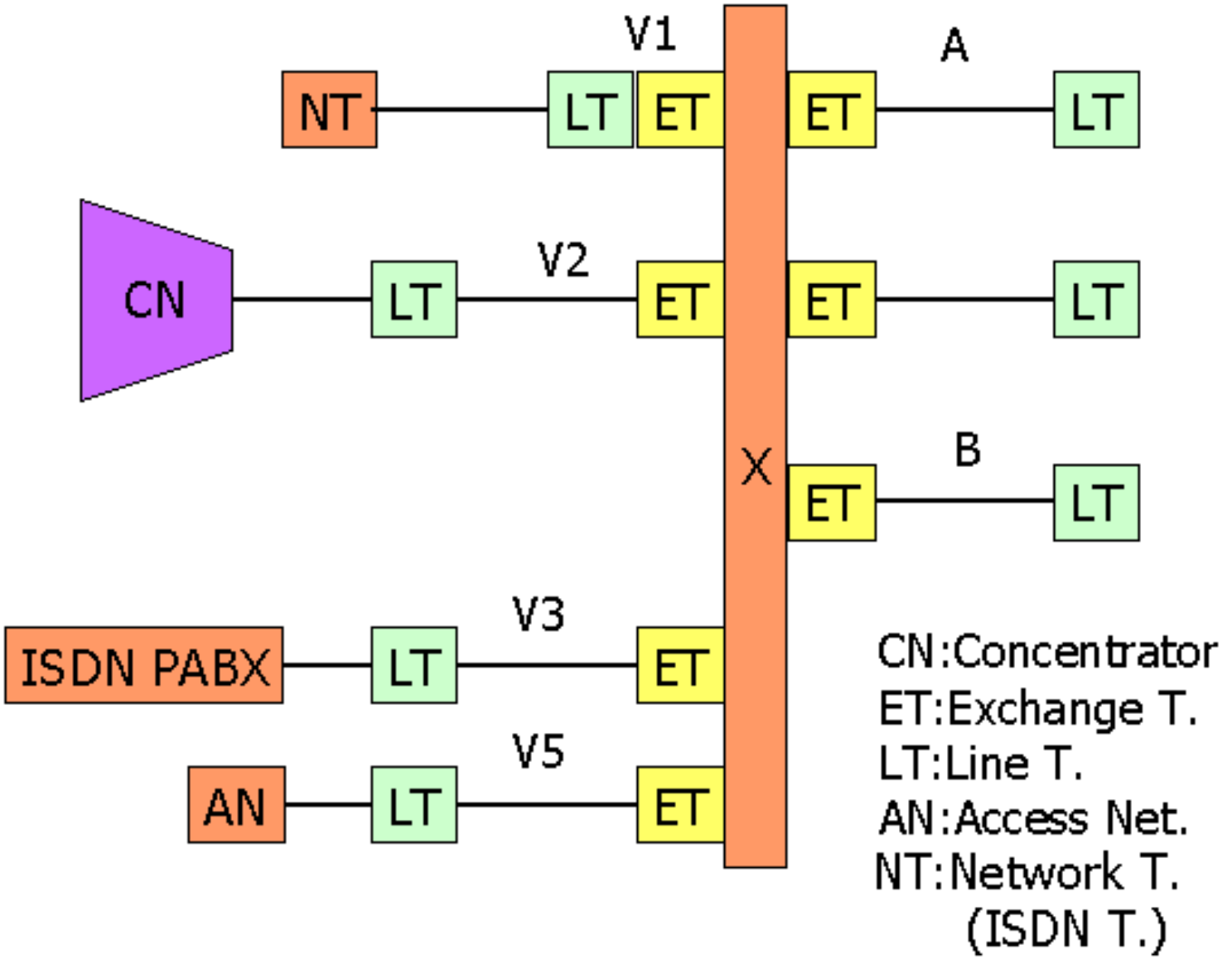


Subscriber stage



ETC: Exchange terminal circuit

PSTN ISDN exchange interfaces (Q.512)



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

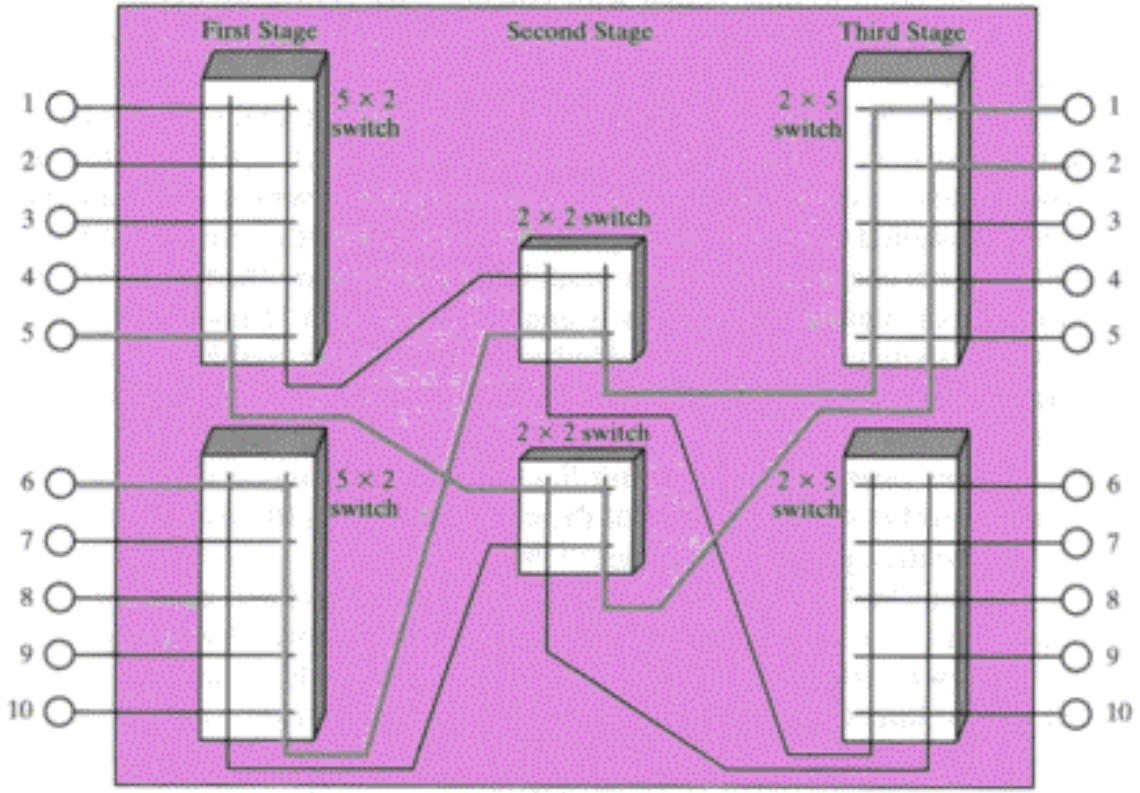
Exchange interfaces and tasks, V2-V4

- V2: Interface serves typically concentrators
  - 2048 kbit/s and
  - 30 B + D
  - Electrical Standard G.704
- V3: Resembles V2 but intended for interface other exchanges
- V4:Interface to private networks

Exchange interfaces and tasks, V5

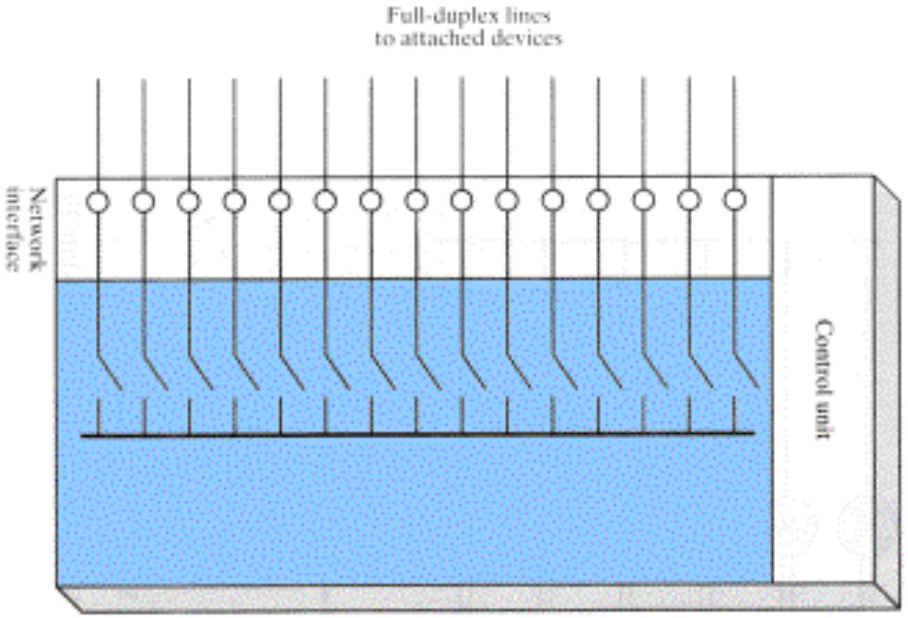
- Between access network and exchange
- Specifies basic interfaces for
  - Analog access
  - ISDN-access
- Electrical interface G.703
- Channel control and signaling
- V5 supports interface rates 2048 kbit/s … 8448 kbit/s.

The space-switch



- Number of cross-connections reduced if a simple space division matrix of NxM (input x output) would be used
- Blocking possible
- Same signal can be routed via different paths: increased reliability

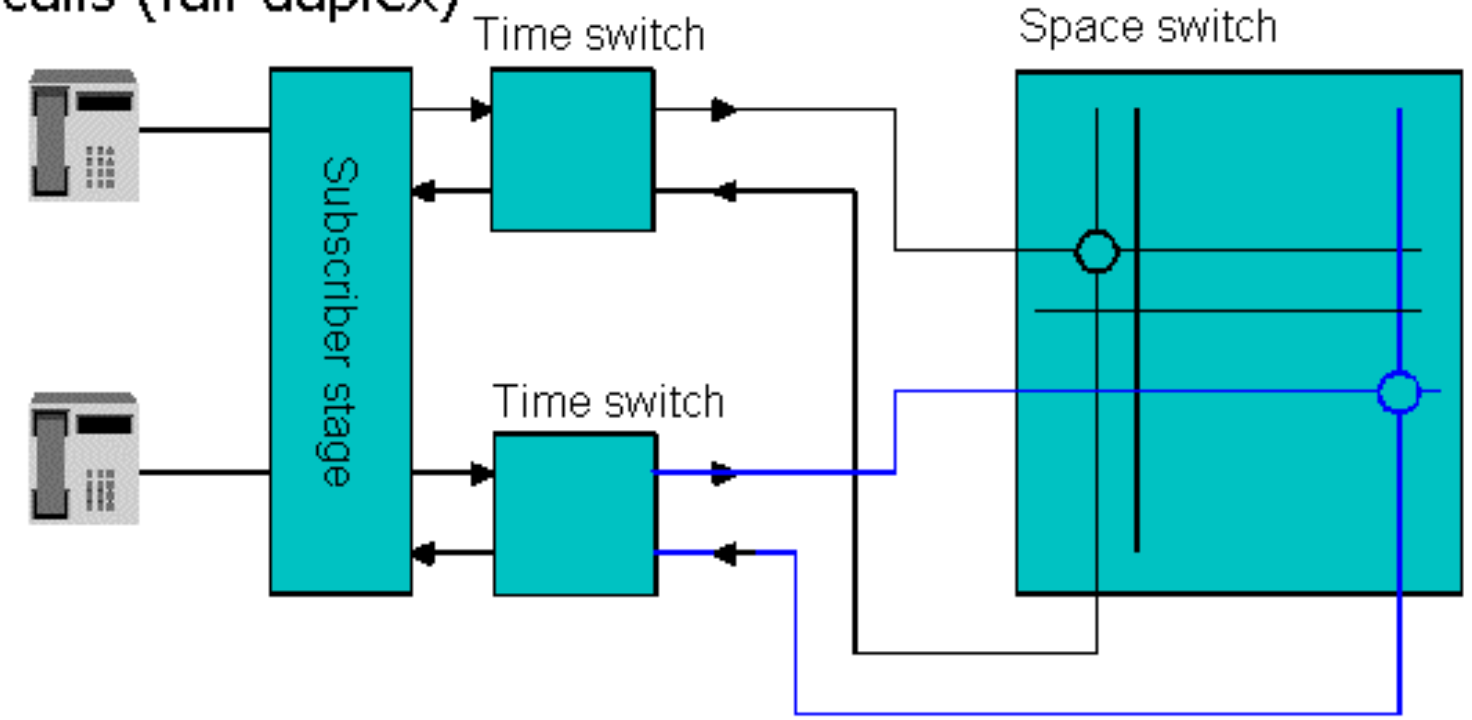
The time-switch



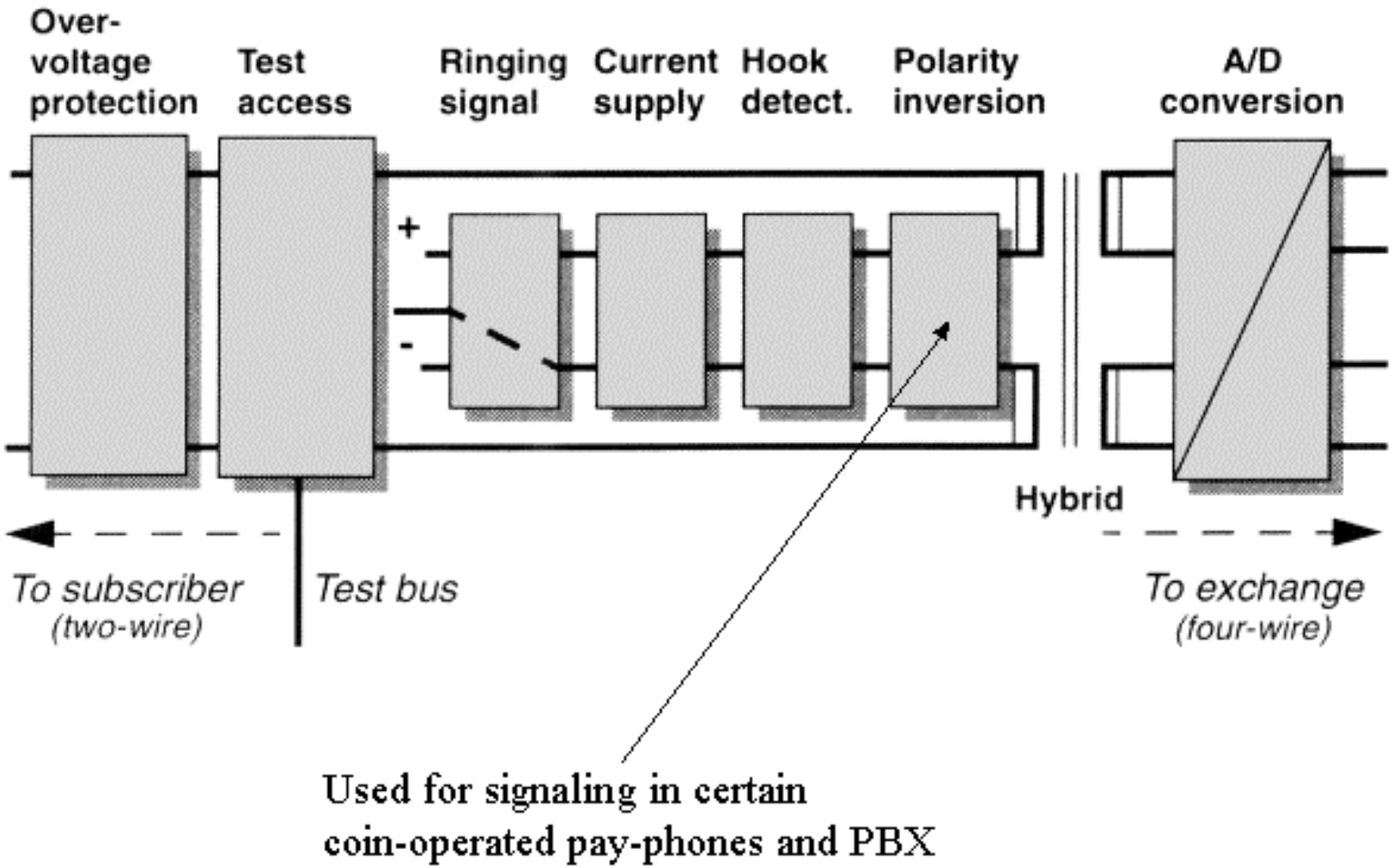
- One of the time slots of any full-duplex lines is connected to the line (at the time)
- Thus two switches / time slot connect a line
- For 100 full-duplex lines at 19.6 kbps a 1.92 Mbps bus is thus required for no blocking
- If no fixed assignment of input lines to time slot but on demand allocation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

The time-space switch

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



Connecting the local loop: Line interface circuit (LIC)

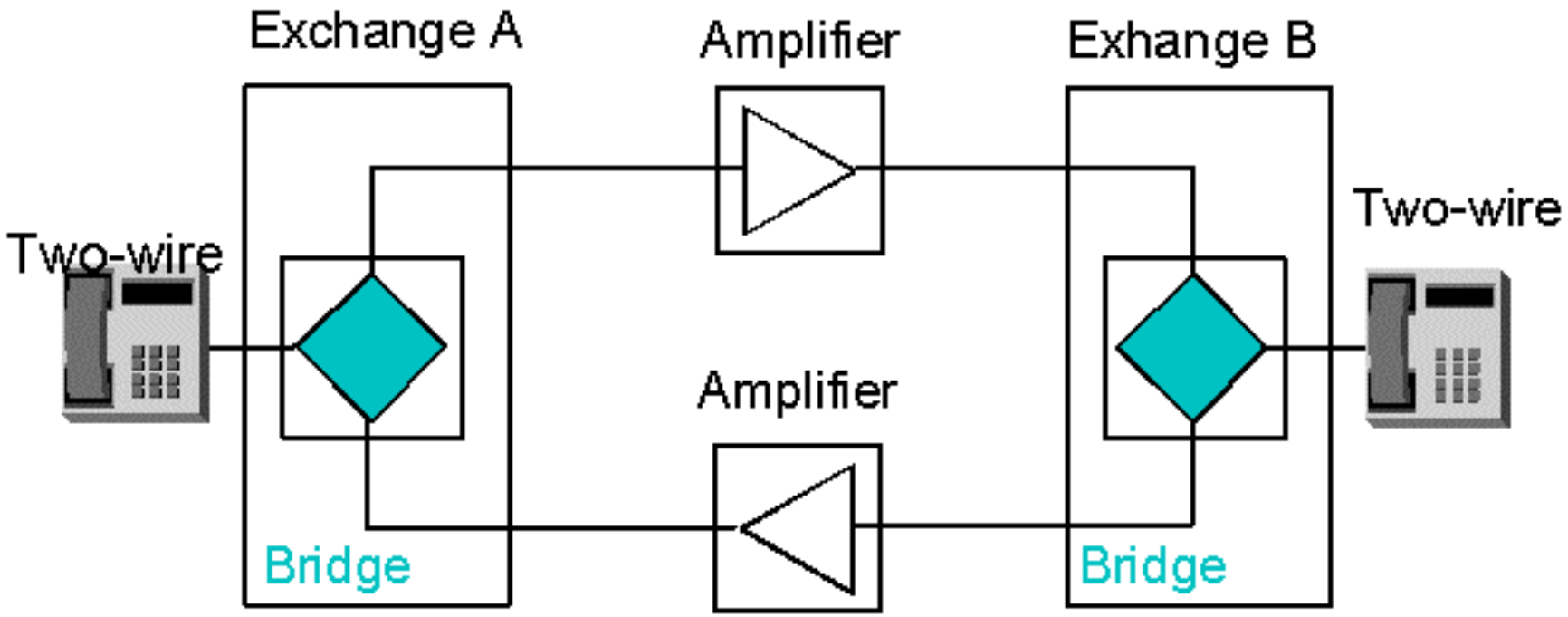


Line interface circuit components

- 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 DTM 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 left

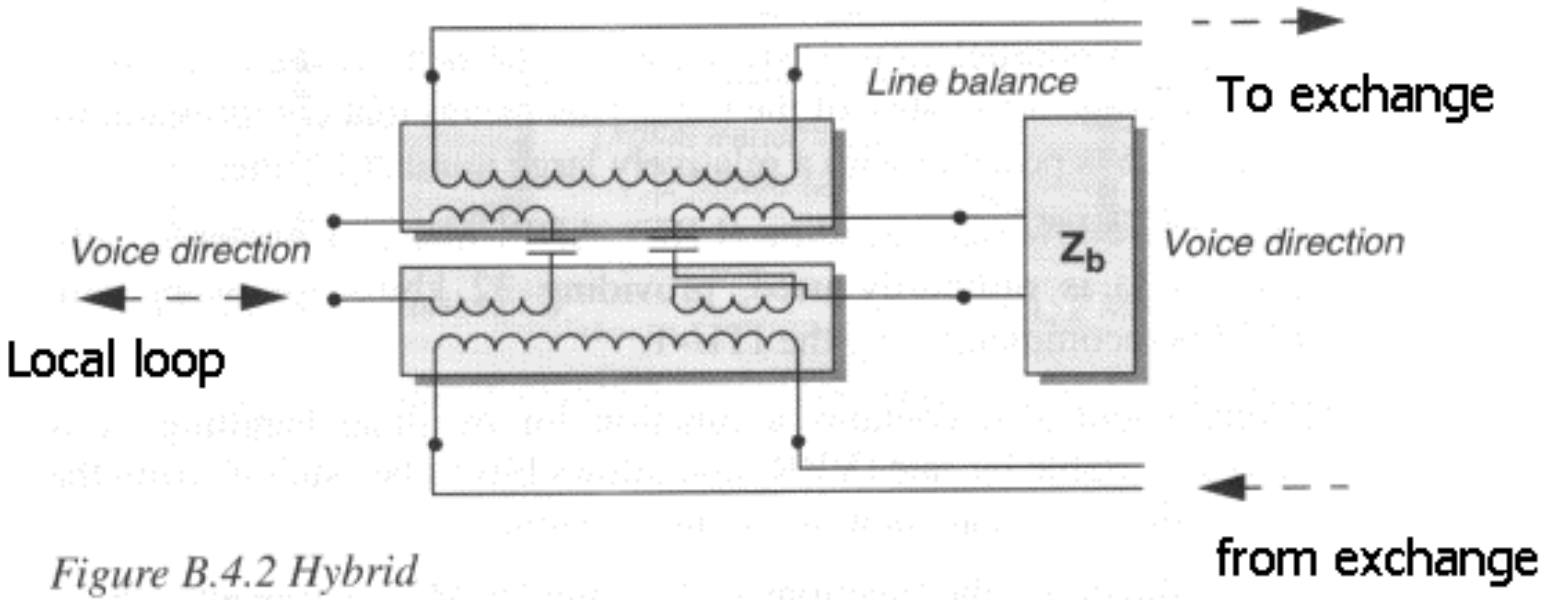


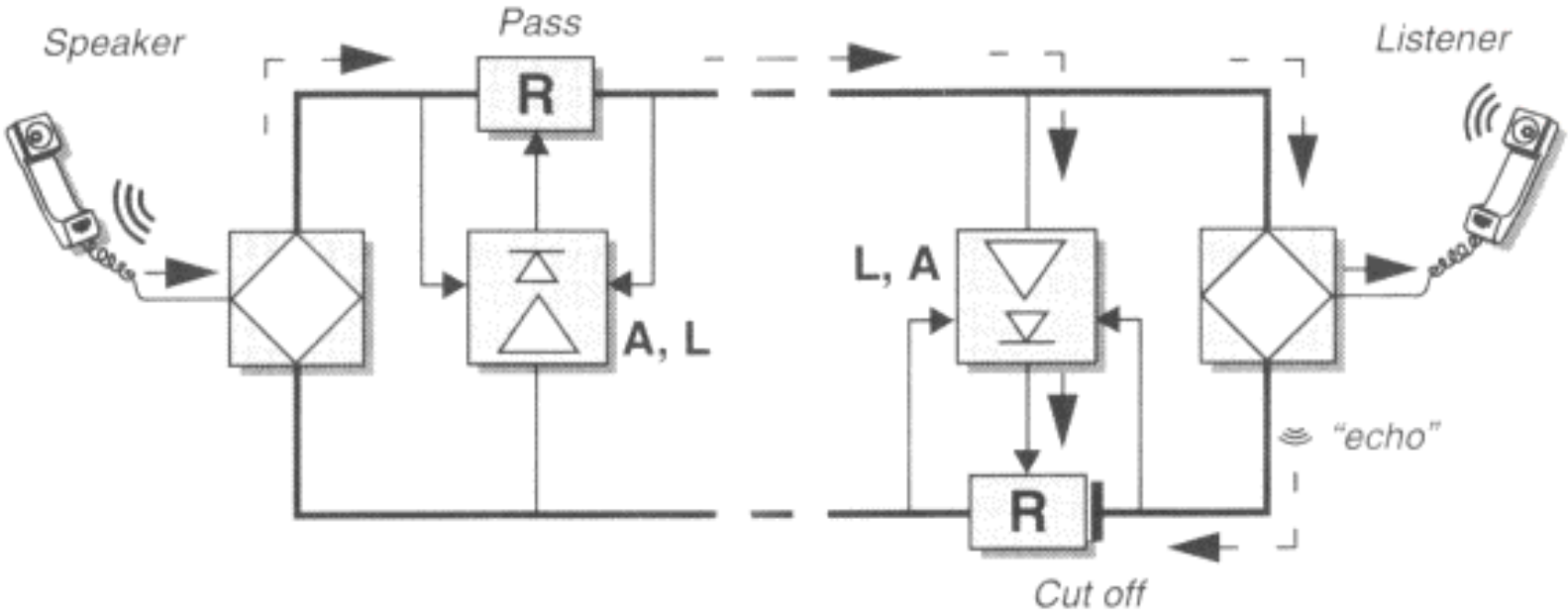
Figure B.4.2 Hybrid

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

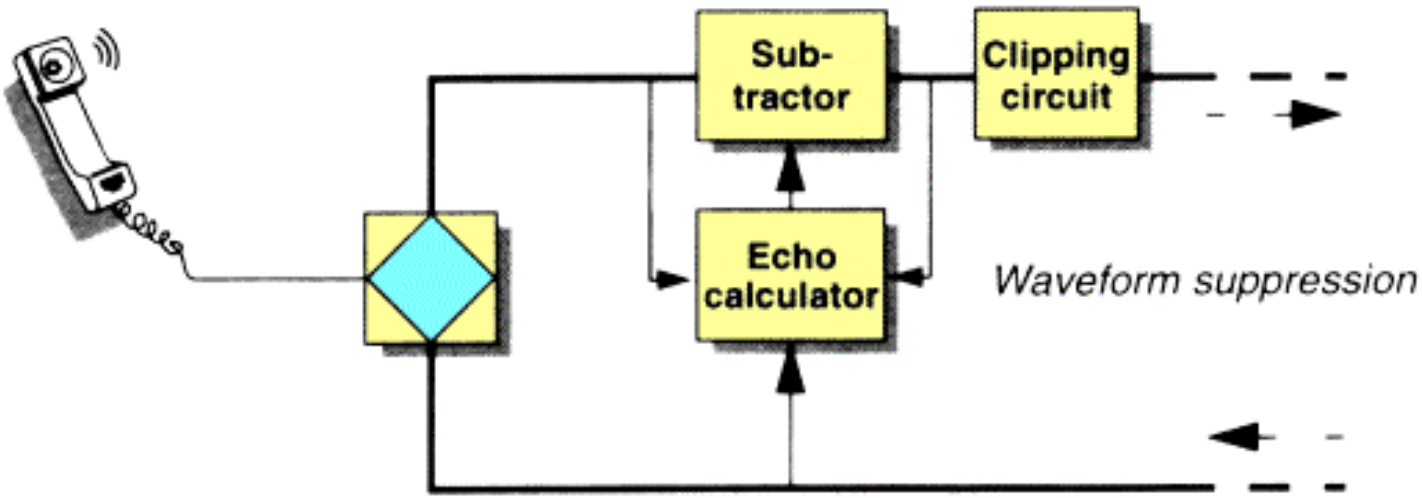
Network echo suppressor (NES)

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



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.



Exchange control functions summarized

- 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
- The control function produces many exchange services:

Important exchange services summarized

- Traditional
  - Absent-subscriber services as the answering machine
  - Call booking: connection at the desired time
  - Person-to-person call: ensured that call goes to a right person
  - Serial call: setting up several calls
  - Telephone conference: several persons participate simultaneously
  - Directory inquiries: also speech recognition, recorded messages

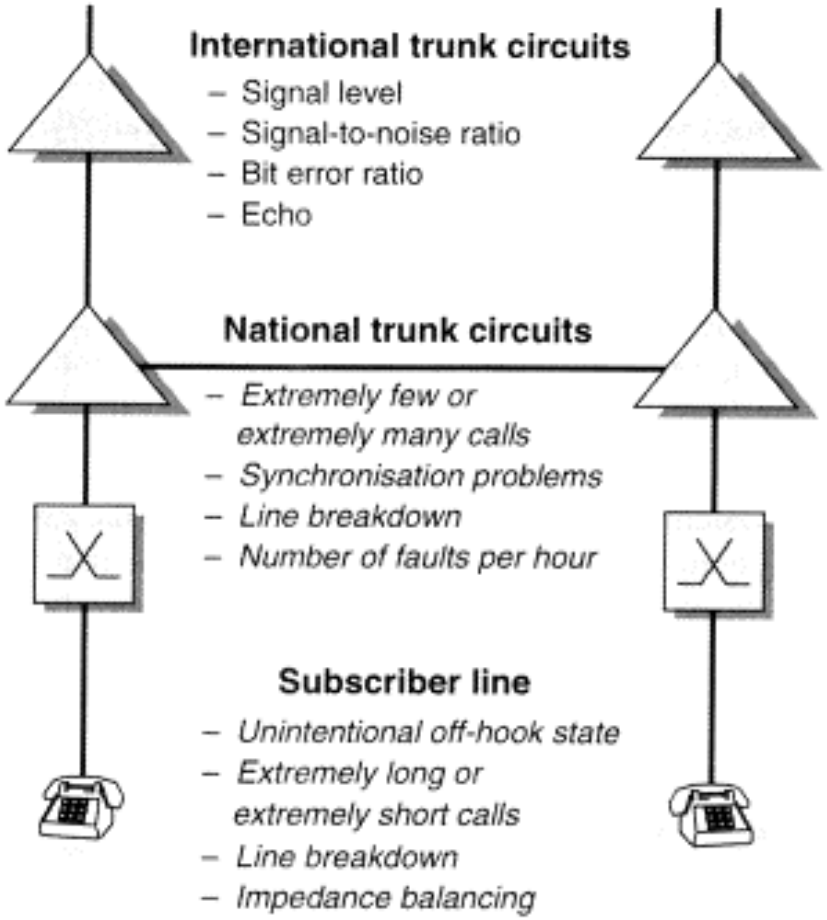
Exchange services (cont.)

- Do not disturb (reply by recorded messages or tone)
- Wake-up/reminder
- Call forwarding: rerouting, variants:
  - unconditional: all calls are rerouted
  - forward when no reply
  - forward when busy
- Callback: queued to the busy number, variants:
  - busy line callback
  - no answer callback
- Last number redial
- Remote control of services: other phone is used to program services to customers own phone

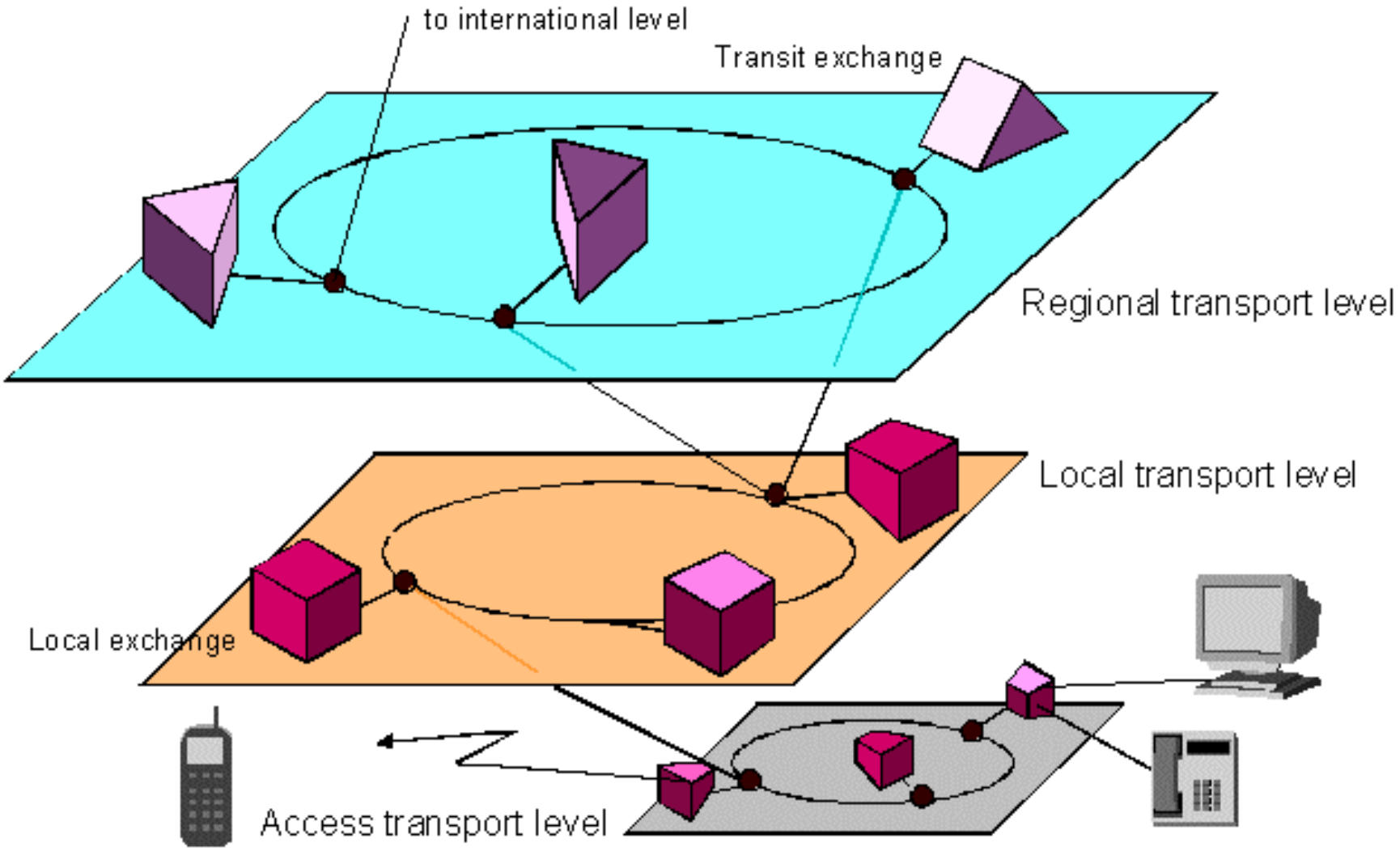
PSTN operation and maintenance

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

A supervision plan by network levels:



Modern PSTN hierarchy



PSTN Hierarchy cont.

- Local (example, within Espoo)
  - Subscriber connections
  - Switching within the local exchange
  - Switching to other exchanges
- Transit (within Finland, say between Tampere and Helsinki)
  - Switching traffic between different geographical areas within one country
- International
  - Gateway-type traffic between
    - different countries
    - different operators

PSTN basic call routing

- Phase 1: The A-subscriber lifts the handset
- Phase 2: The exchange receives B-subscriber number
- Phase 3: The exchange sets up the outgoing call
- Phase 4: The subscribers concludes the call

Phase 1: The A-subscriber lifts the handset

- Subscribers' lines are scanned and off-hook is detected
- Subscriber database checked for sending the dial-tone (depends on service class as for instance are the outgoing calls allowed)
- Memory reserved for the number to be dialed in the control system
- A tone receiver for the dual-tone dialing signaling is connected through the time switch in the subscriber stage
- The dial tone is sent

Phase 2: The exchange receives B-subscriber number

- If dual-tone dialing is used
  - Tone receiver sends the received B subscriber number to the control function
- If pulses are used
  - They are interpreted by the line interface circuit
- The control system decides:
  - Where the call is going (under same or another exchange)
  - Which charging method is used
    - time of the day, weekday, billing agreements, B-subscriber number
  - What will be the length of the number

Phase 2: B-number at the same exchange or at a different exchange?

- At the same exchange:
  - Query to subscriber database:
    - is the subscriber banned for incoming calls?
    - is the subscriber entitled for the service he is using?
    - is the user in "call diversion unconditional" or "call waiting" status
- At a different exchange:
  - perform routing analysis
    - depends on user category, time of the day

Phase 3: The exchange sets up the outgoing call

- When the analysis is finished, an outgoing time slot is reserved in the group switch
- Exchange starts signaling the next exchange
  - If SS7 is used signaling takes different bearer net that the call (Common ch. signaling)
- Call path is selected based on
  - congestion condition
  - was B-subscriber line reserved?
- When B is free the B-subscriber exchange signals: "B-subscriber free"

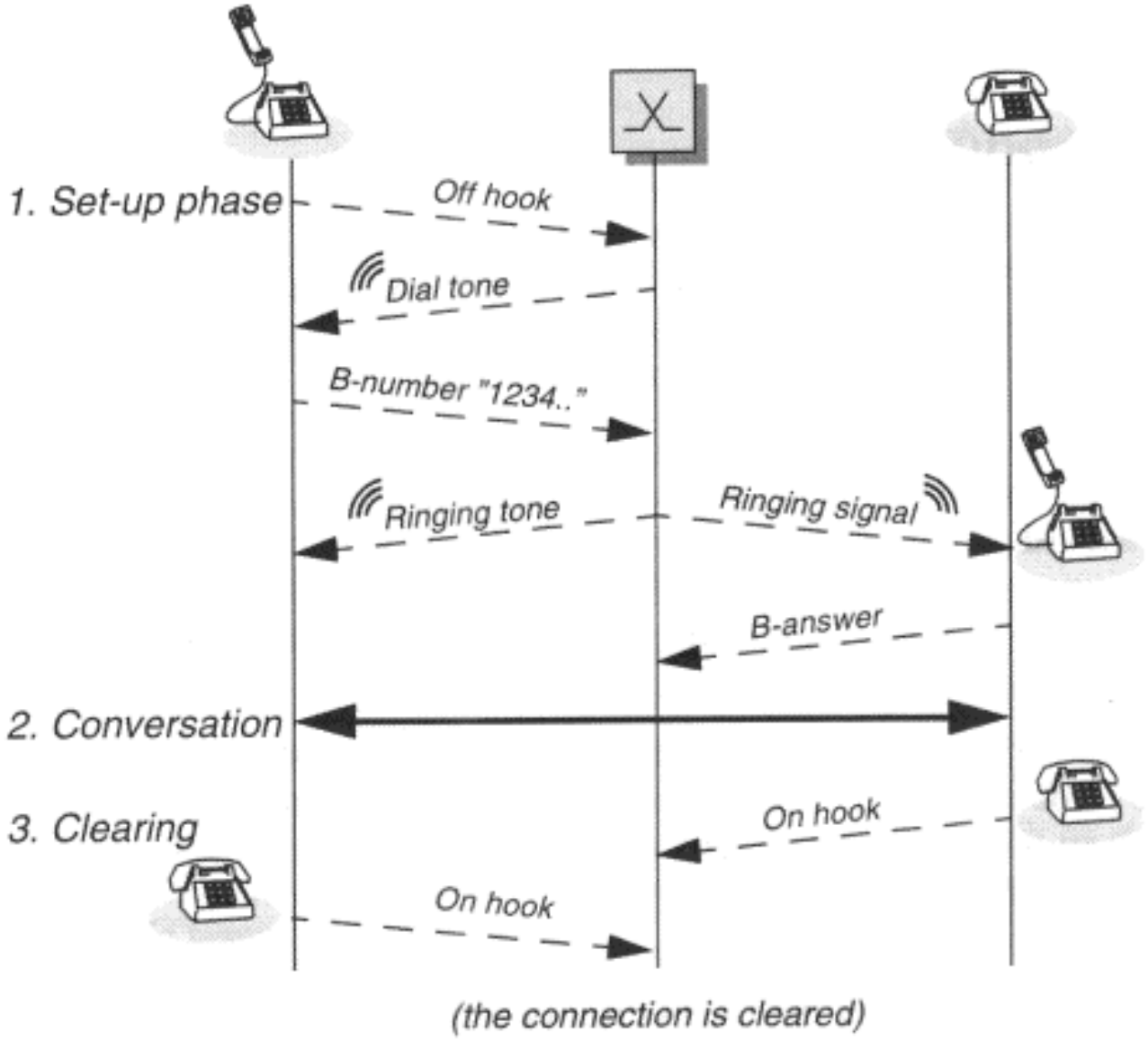
Phase 3: The exchange sets up the outgoing call (cont.)

- The control function orders the group switch to reserve a PCM time slot for A and B subscribers at the outgoing PCM link
- The dual-tone receiver is disconnected
- The subscribers are connected to the correct time slot
- The B-subscriber exchange send a ringing tone to B and the respective tone to A-subscriber
- The control function starts to monitor the call for
  - charging
  - for observing when the call is about to end

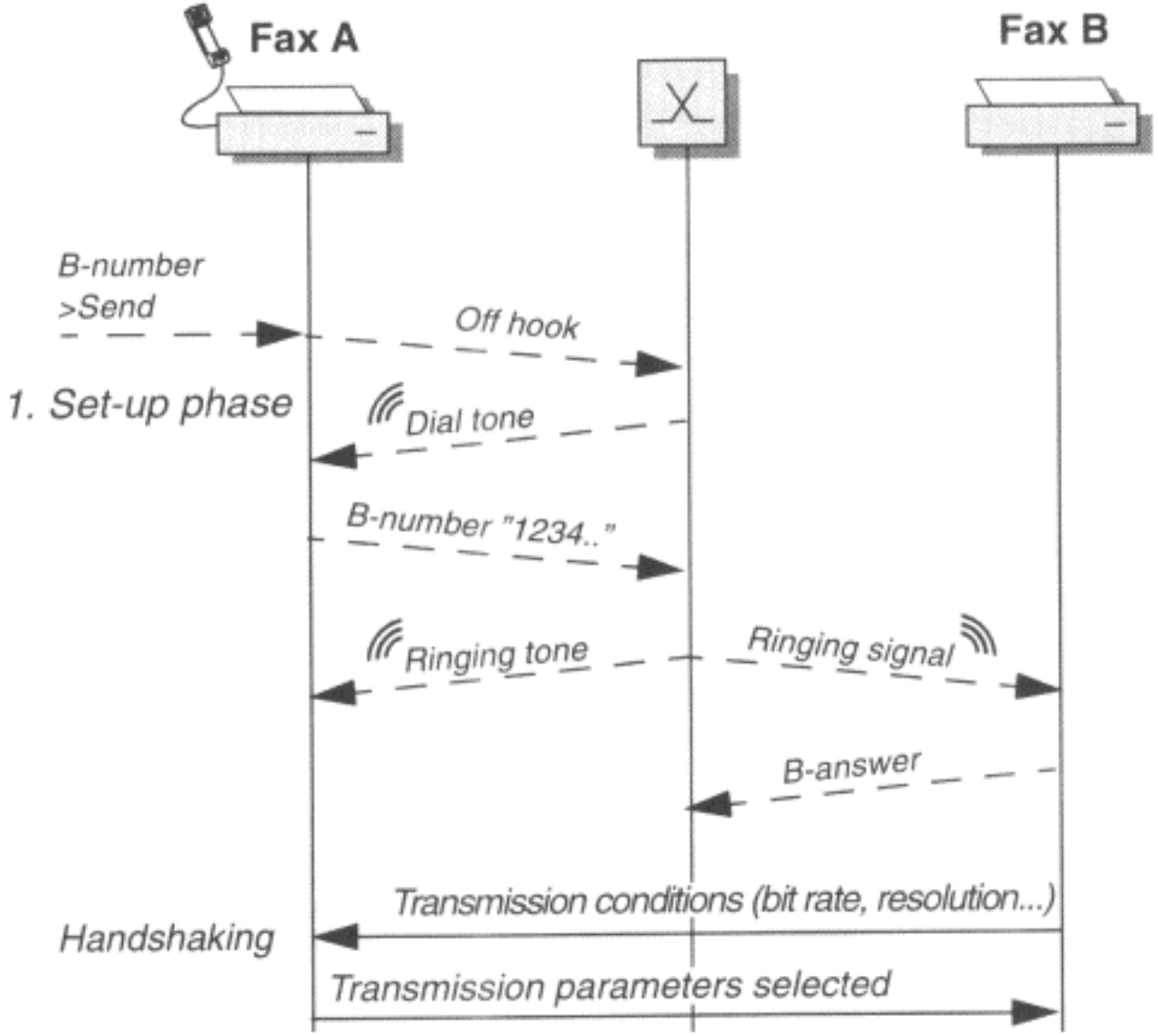
Phase 4: The subscribers concludes the call

- The call can be concluded by the A or B subscriber
- If A closes first the call is concluded immediately
- If B closes first a timeout is applied (usually 90 seconds)
- When the call is terminated
  - the control function tells the charging to be stopped
  - frees the circuits and timeslots reserved for the call in the pathway by using a signaling system

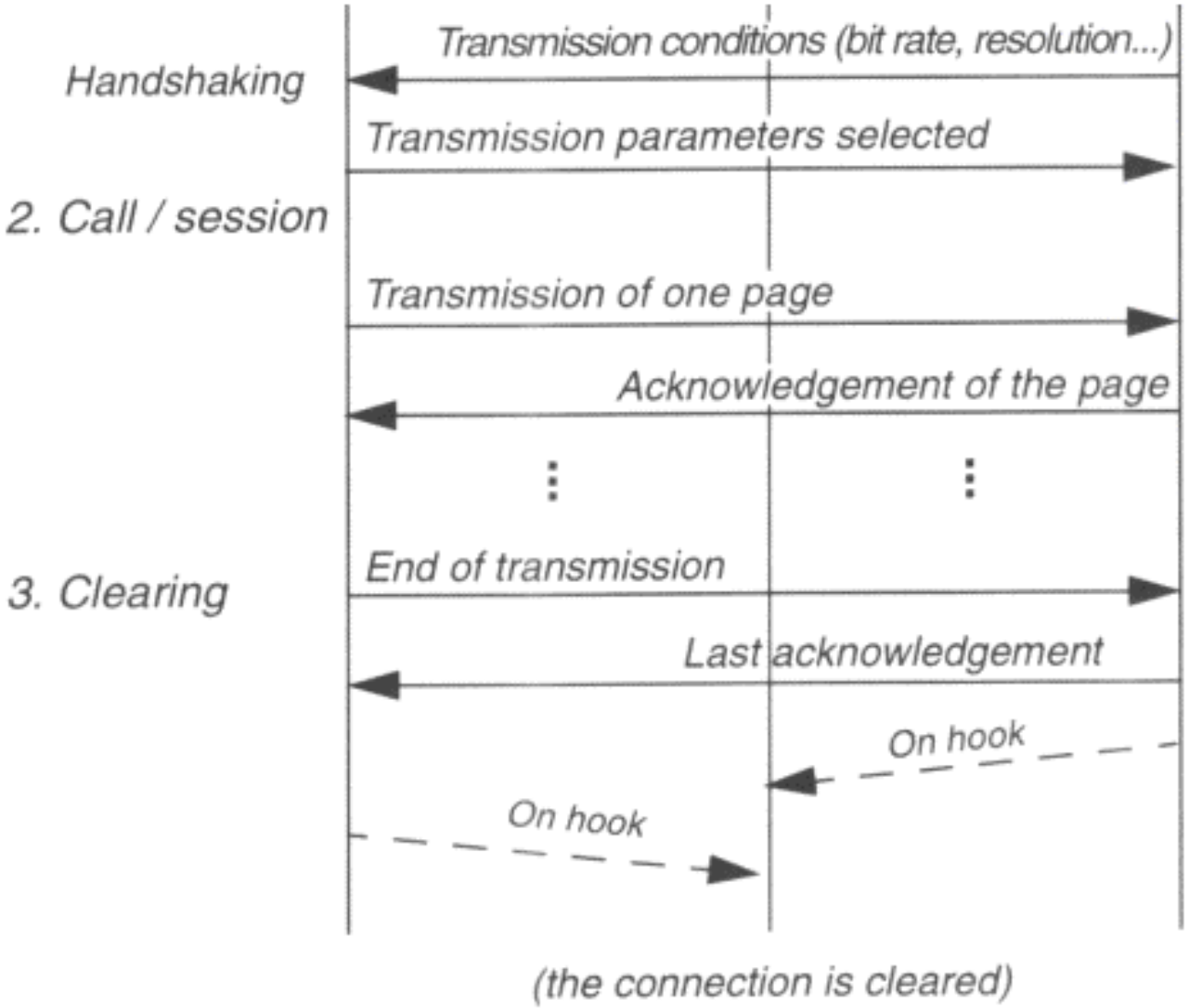
Subscriber signaling flowchart



Subscriber signaling for a fax



Subscriber signaling for a fax (cont.)



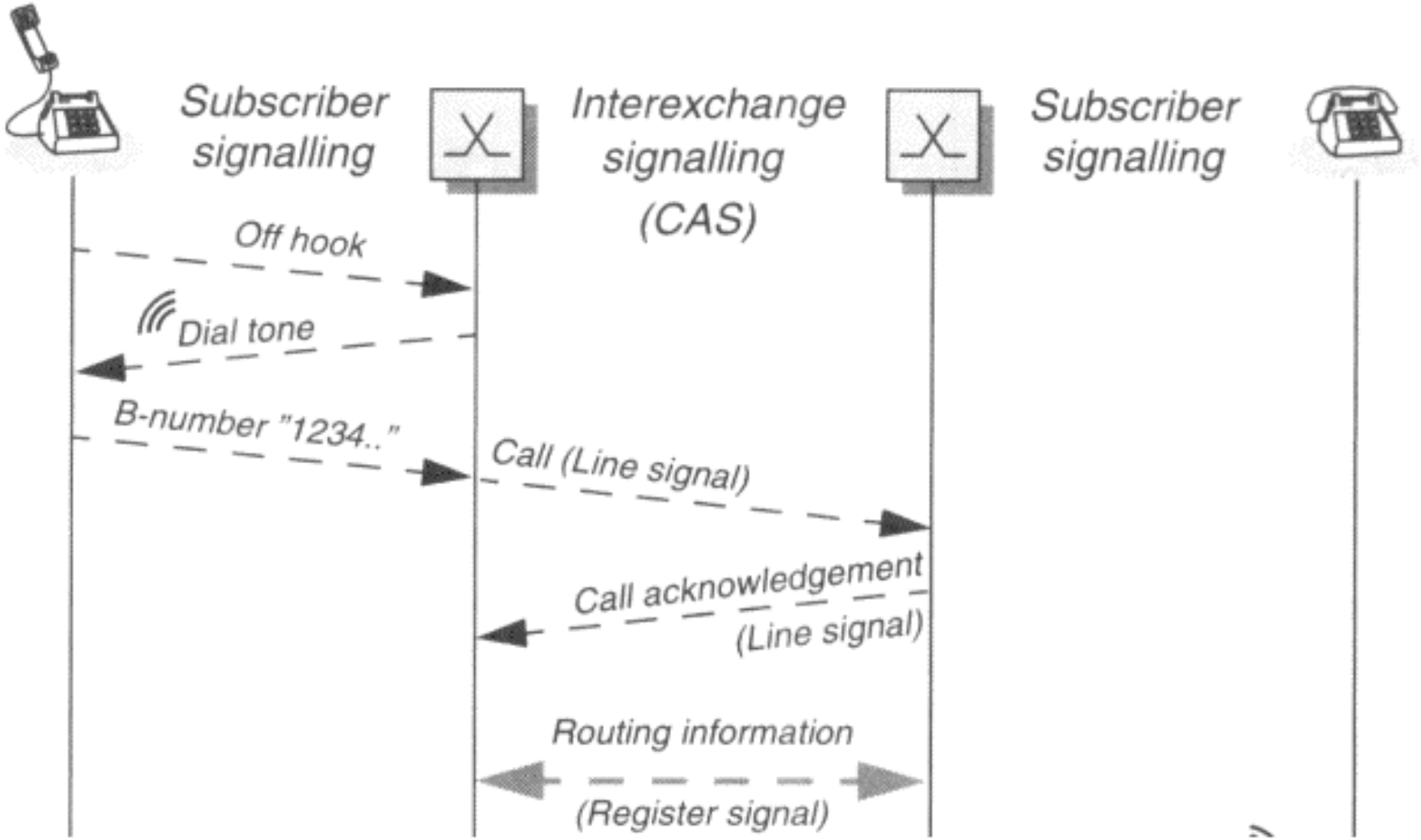
Inter exchange signaling

- 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

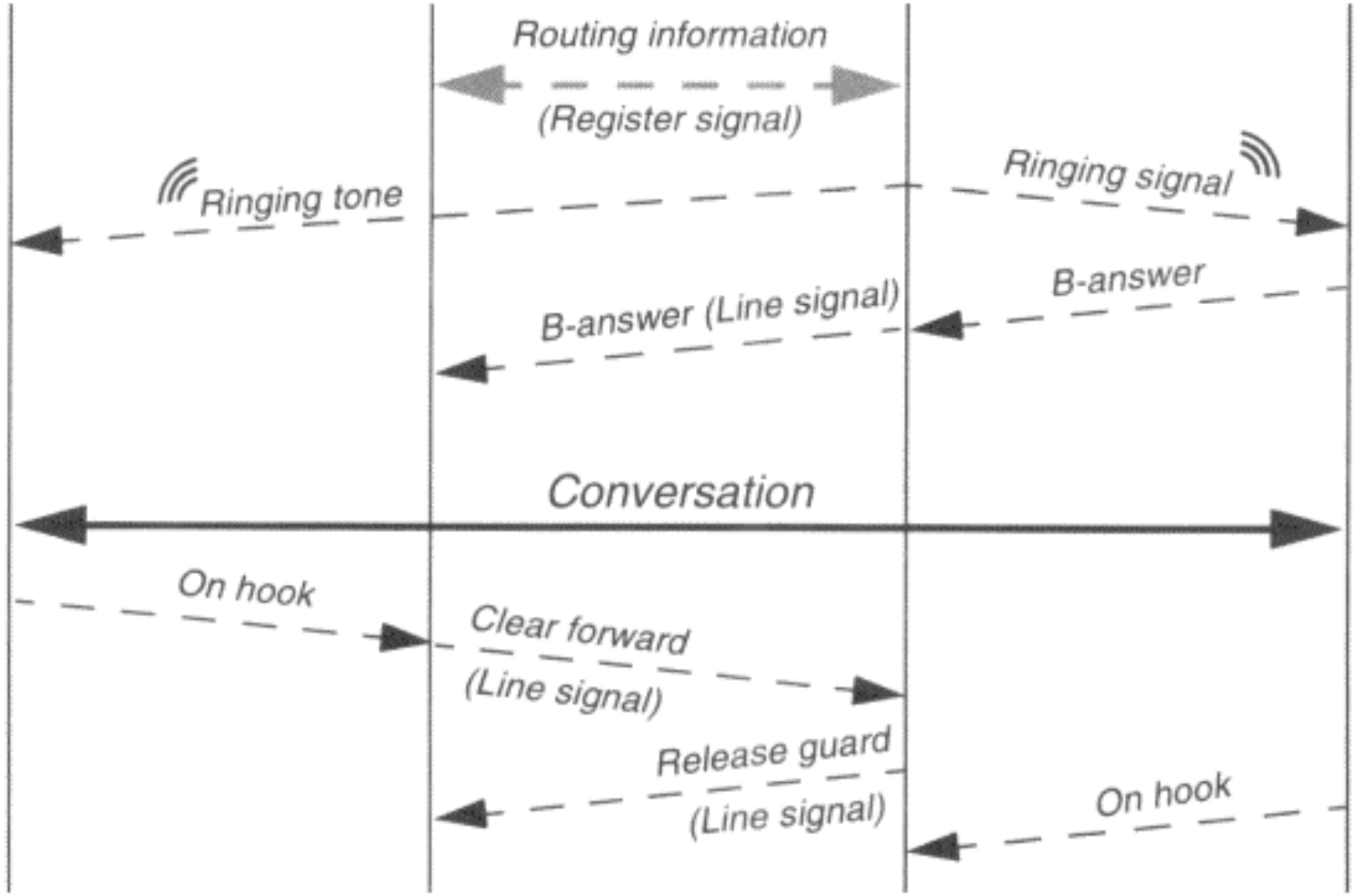
Inter exchange signaling (cont.)

- 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

Example of inter-exchange signaling



Inter-exchange signaling (cont.)

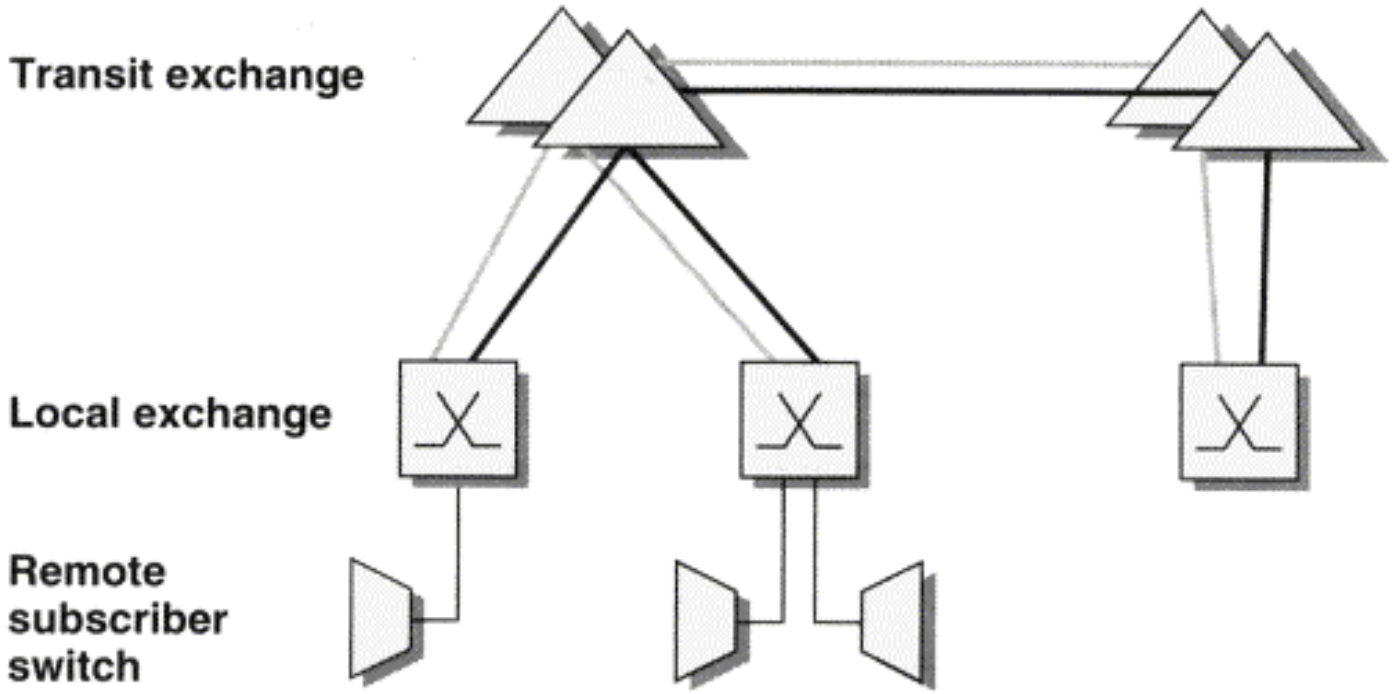


Alternative routing

- Different PSTN traffic types, phone, fax and data require different properties from the transmission media
- Hence they are sometimes routed via different routes
- Exchange makes analysis based on B-subscriber number which route is to be selected
- In dynamic routing exchange "learns" from its mistake
  - if a direct connection is available it is selected first
  - if too much congestion is encountered then the last successful route is selected
- Alternative routing aims to utilize network capacity better than load sharing

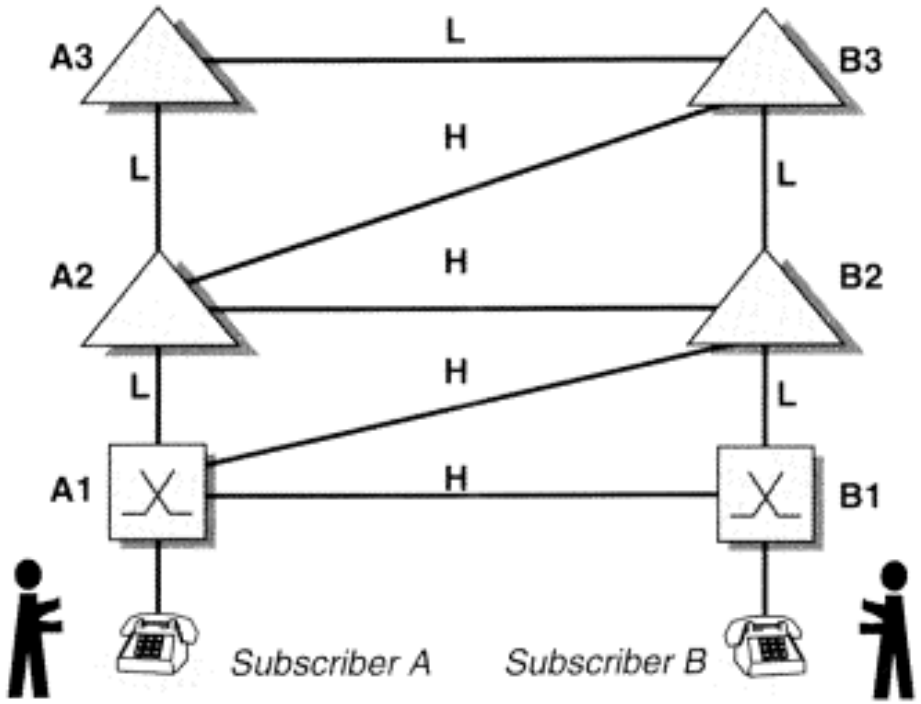
Load sharing

- Dedicated exchanges are connected via fixed, different rate connections



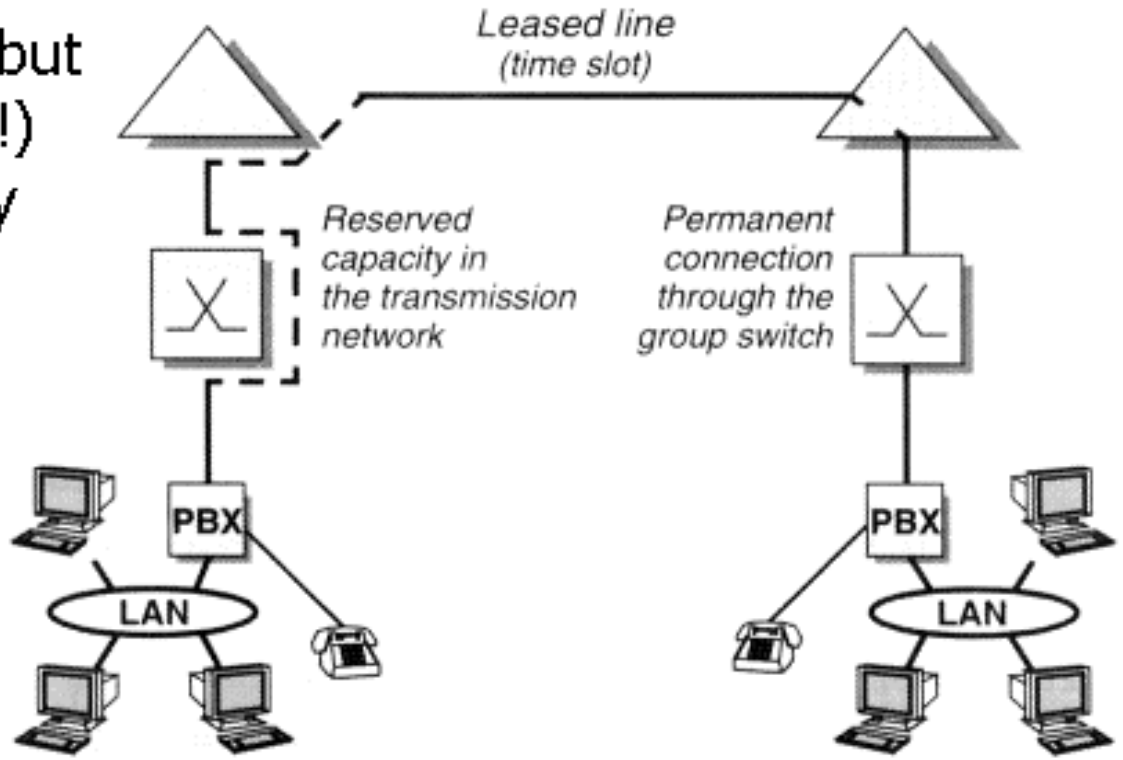
Alternative routing (cont.)

- The H (high congestion route is the first choice)
- The alternatives: A1-B1, A1-B2-B1, A1-A2-B2-B1, A1-A2-B3-B2-B1,A1-A2-A3-B3-B2-B1



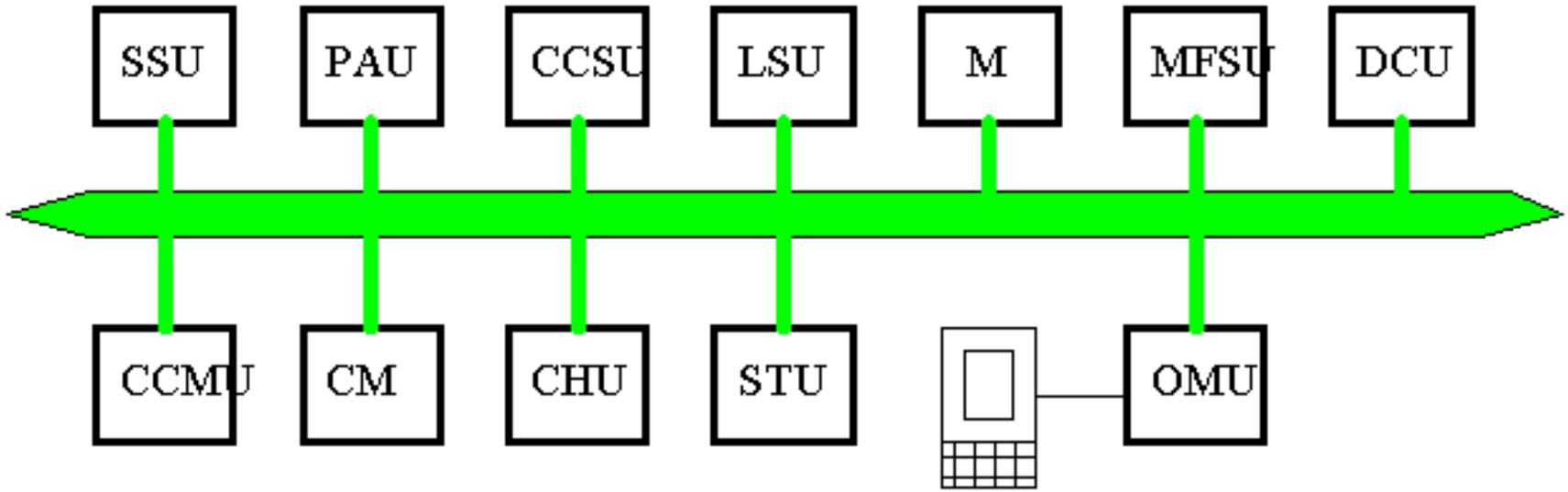
Leased lines are used in semi-permanent and secured routing plans

- Advantages: predictable quality, low price provided service is used, high availability
- Disadvantages: First setting up can take weeks, high price if the customer cannot predict usage
- Restricted (but guaranteed!) line capacity



A case study: DX 200 Exchange

- Various control units apply common busses to control the exchange



A case study: DX 200 Exchange

- SSU: Subscriber Signaling Unit: controls access network
- CCSU:Common Channel Signaling Unit (SS7).
- CCMU: Common Channel Signaling Management Unit: (as MTP, SCCP)
- PAU: Primary Rate Access Unit: controls basic (64 kbit/s) system interfaces
- LSU: Line Signaling Unit: takes care of signaling between transit exchanges and access networks
- MFSU: MULti-frequency Service Unit: Takes care of signaling when multiple frequency signals are used

A case study: DX 200 Exchange (cont.)

- BCDU:Basic Data Communication Unit: Serves various data services to OMU as access to X.25 and LANs
- M: Marker Unit: Controls concentrators / space switches
- CM: Central Memory: Contains user database, charging, signalling, routing and exchange ensemble.
- STU: Statistical Unit: Collects statistical information on traffic and charging.
- CHU:Charging Unit: Maintains charging database obtained from signalling units.
- OMU:Operation and Maintenance Unit: Allows personnel access to exchange memory, perform tests an traffic measurements.

Overview to ITU-T G.703

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(10/98)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Digital transmission systems – Terminal equipments – General

Physical/electrical characteristics of hierarchical digital interfaces

CONTENTS

Table 6/G.703 – Digital interface at 44 736 kbit/s

Parameter	Specification
Nominal line rate	44 736 kbit/s
Line rate accuracy	In a self timed, free running mode, the line rate tolerance shall be ±895 bits/s (±20 ppm) or better.
Line code	B3ZS (bipolar with three-zero substitutions)
Frame structure	The signal shall have the frame structure defined in Recommendation G.752 to ensure transmission through all types of 44 736 kbit/s transport equipment. The frame structure is not required for multiplexing to higher level DSN signals.
Medium	One unbalanced coaxial line shall be used for each direction of transmission.
Test load impedance	A resistive test load of 75 ohms ± 5% shall be used at the interface for the evaluation of pulse shape and the electrical parameters specified below.
Pulse amplitude	The amplitude (Note 1) of an isolated pulse shall be between 0.36 V and 0.85 V peak.
Pulse shape	The shape of every pulse that approximates an isolated pulse (is preceded by two zeros and followed by one or more zeros) shall conform to the mask in Figure 14. See 5.2 for allowable procedures to be followed in checking conformance. This mask includes an allowance of ±3% of the peak pulse amplitude at any point on the mask relative to the pulse mask in the earlier version. Equations defining the various line segments making up the mask are listed below the figure.
Power level	A wideband power measurement of an AIS signal (as defined in Recommendation G.704) using a power level sensor with a working frequency range of 200 MHz shall be between –4.7 dBm and +3.6 dBm, including the effects of a range of connecting cable lengths between 68.6 meters (225 feet) and 137.2 meters (450 feet). A low-pass filter having a flat passband and cutoff frequency of 200 MHz shall be used. The rolloff characteristics of this filter are not important; or an alternate power level specification of the power of an all-ones signal (Note 2) is useful for some equipment qualifications. It requires that the power in a 3 kHz ± 1 kHz band centered at 22 368 kHz be between –1.8 dBm and +5.7 dBm. It further requires that the power in a 3 kHz ± 1 kHz band centered at 44 736 kHz be at least 20 dB below that at 22 368 kHz.

Return to V5