Digital Communication Systems

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Topics in Digital Communications

- Digital communication system advantages and disadvantages
- Digital communication system classification
- Digitization of analog signals
- Digital transmission systems
- Data communication systems
- Integrated Services Digital Network and other advanced digital communication systems
Digital Communication advantages

bullet Reliable communication; less sensitivity to changes in environmental conditions (temperature, etc.)
bullet Easy multiplexing
bullet Easy signaling
  ■ Hook status, address digits, call progress information
bullet Voice and data integration
bullet Easy processing like encryption and compression
bullet Easy system performance monitoring
  ■ QOS monitoring
bullet Integration of transmission and switching
bullet Signal regeneration, operation at low SNR, superior performance
bullet Integration of services leading to ISDN
Digital Communication System Disadvantages

• Increased bandwidth
  ■ 64 KB for a 4 KHz channel, without compression (However, less with compression)
• Need for precision timing
  ■ Bit, character, frame synchronization needed
• Analogue to Digital and Digital to Analogue conversions
  ■ Very often non-linear ADC and DAC used, some performance degradation
• Higher complexity
## Types of Digital Communication Systems

<table>
<thead>
<tr>
<th>Signal Type</th>
<th>Transmission</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog</td>
<td>Analog</td>
<td>Classical telephony</td>
</tr>
<tr>
<td>Analog</td>
<td>Digital</td>
<td>PCM TDM</td>
</tr>
<tr>
<td>Digital</td>
<td>Analog</td>
<td>Modems</td>
</tr>
<tr>
<td>Digital</td>
<td>Digital</td>
<td>ISDN, LANs</td>
</tr>
</tbody>
</table>
Digitization of analogue signals

- Signal sampling
Nyquist Criterion, Aliasing

Original signal

Aliased signal

Nyquist sampling rate $f_s > 2 \cdot f_b$
Spectrum of baseband signals

Amplitude

Frequency

-S

+S

Spectrum of the properly sampled base band

Spectrum of the under sampled base band
Speech signal digitisation

Input signal → Pulse train → PAM samples \[\xrightarrow{\times}\] LPF → Output signal

Pulse amplitude modulation
Pulse Code Modulation (PCM)

Analog input → Low pass filter → Sample clock → A/D → Digitally encoded samples → D/A → Low pass filter → Analog Output

PAM samples
Quantisation of speech signal samples

Quantisation of analog samples
Quantisation error in PCM

Quantisation error as a function of amplitude

Input signal

Quantized output signal

Input amplitude
PCM system - Typical parameters

4 KHz Speech signal
8 KHz Sampling
8 bits / sample digitising
per speech channel 8 x 8 bits = 64 kbps

T1 carrier: 24 channels. 8 bits in 125 μs / channel
24 x 8 = 192 bits in 125 μs / frame, 1 bit per frame for sync
193 bits in 125 μs, Line rate 193/125 μsec = 1.544 Mbps

ITU (EUROPEAN)
32 Channels 8 bits/ 125 μss / channel
32 x 8 bits / 125 μs = 2.048 Mbps
30 channels info; 2 channels management
Idle channel noise minimisation

**Idle channel noise:** Caused by uncertainty in coding a sample near zero value.
Signal to quantizing noise of uniform PCM

![Graph showing SNR (dB) vs. A/Amplitude (dB) for different number of bits/sample: 9, 11, 13.](image)
Non-linear AD conversion
Compression law - $\mu$ law
Compression law - A law
Non linear AD conversion laws used in PCM for speech

\[ F_z(x) = \text{sgn}(x) \ln \left( 1 + z |x| \right) \]

\( \mu \) law

\[ F_\mu(x) = 2^\mu \text{sgn}(x) \frac{1 + \mu |x|}{\mu |x|} \]

\( A \) law
Low bit rate coding: DPCM, Differential PCM

Speech signal

Band limiting filter

Differentiator

Σ

Sampler quantizer encoder

A/D

Encoded difference samples

D/A

Previous input estimate

Accumulator
DPCM implementation

LPF → Sigma → ADC → DAC → Sigma → S & H → Decoder → LPF

S & H → Sigma → Encoder → DAC
Delta modulation

Input \[ \rightarrow \text{LPF} \rightarrow + \rightarrow \Sigma \rightarrow - \rightarrow - \rightarrow + \rightarrow \text{"1"} \rightarrow \rightarrow \rightarrow \text{Integrator} \rightarrow \rightarrow \rightarrow \rightarrow \text{LPF} \rightarrow \rightarrow \rightarrow \rightarrow \text{Output} \]

Decoder

Integrator

Pulse generator

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Slope overload distortion in Delta modulation

Slope overload

Granular noise
Low Data Rate Modulation

**CVSD (Continuous Variable Slope Delta Modulation)**

![Diagram of CVSD (Continuous Variable Slope Delta Modulation)]
Conceptual view of ISDN

Telephone
Data terminal
PBX
Alarm

Customer ISDN interface
"Digital pipe"
"Digital pipes"

Subscriber loop and ISDN channel structures

Local area network
Packet switched network
Circuit switched network
Other networks
Data bases
Other services
Block diagram of ISDN functions

- Common physical interface
- ISDN central office
- Digital circuit - switched backbone
- Packet-switched backbone
- Network-based processing services
- Integrated Digital Network

Subscriber loop to ISDN channel structures:
- Basic = 64 kbps + 64 kbps + 16 kbps
- Primary = multiplexed 64 kbps channels
ISDN principles

- ISDN is based on concepts developed for telephony. Therefore, evolutionary changes

- Transition from the present network to ISDN may require about one decade.

- End-to-end digital connectivity to be obtained using digital transmission, TDM switching and or SDM switching.

- Present ITU standards part of new standards

- In early development of ISDN interim measures needed for interfacing with present networks
Principles of ISDN (Cont.)

- Supports a wide range of voice and non-voice applications
- Switched and non-switched connections Circuit switching and packet switching
- Based on 64 Kbps channels
- Intelligence for providing service features, maintenance and management integrated
- Layered protocol used
- Flexibility for implementation at specific national situations
ISDN evolution

- Digital exchanges commissioned in late 60's and 70's

Integrated digital transmission and switching established (IDN)

- Integrating services in IDN is the latest step leading to ISDN INTEGRATED SERVICES DIGITAL NETWORK
ISDN services: Definition of attributes

- All services on the ISDN network are characterised by "attributes" defined in ITU 1.130 standards
- Attributes have a definition and allowable values
- Any service has a set of valid attributes
## ISDN services: Attributes

<table>
<thead>
<tr>
<th>Attribute Name</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Info. transfer mode</td>
<td>Circuit, packet</td>
</tr>
<tr>
<td>Info. transfer rate</td>
<td>Bit rate</td>
</tr>
<tr>
<td>Info. transfer capability</td>
<td>Speech,</td>
</tr>
<tr>
<td></td>
<td>3.1 KHz audio</td>
</tr>
<tr>
<td></td>
<td>7 KHz audio</td>
</tr>
<tr>
<td></td>
<td>15 KHz audio</td>
</tr>
<tr>
<td></td>
<td>Video</td>
</tr>
<tr>
<td></td>
<td>Other values</td>
</tr>
<tr>
<td>Connection performance</td>
<td>Bit error rate</td>
</tr>
</tbody>
</table>

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ISDN service classification

Services defined by attributes

- Bearer services
- Teleservices
- Secondary services

Bearer services provide capability to transfer information between ISDN access points and involve only low level layers (1,2 and 3)
ISDN teleservices

- Low layer attributes
- High layer attributes
- Type of user information
- Layer 4 protocols
- Layer 5 protocols
- Layer 6 protocols
- Layer 7 protocols
- General attributes
- Quality of service
Customer access to services supported by ISDN
Functional grouping

- **TE**: Terminal equipment
  - **TE1**: S interface terminal
  - **TE2**: R interface terminal

- **TA**: Terminal adapter
  - adapts TE2 to S interface

- **NT**: Network termination
  - **NT2**: Optional, PBX applications
  - **NT1**: S/T interface to U interface

- **Interface structure**
  - 2B + D 192 Kbps line rate
  - 23B + 4536 Kbps line rate
Network functional principles

- Services to be internationally compatible
- UNI standardised so that TE is portable
- Standardise network capability

<table>
<thead>
<tr>
<th>High Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Layer</td>
</tr>
<tr>
<td>Operation &amp; manage</td>
</tr>
</tbody>
</table>

Layer 1: Physical layer connection activation deactivation, bit transmission channel structure multiplex.

Layer 2: Data link connection establishment, Data link congestion handling. How control, error, sequence control, frame sync.
## Access channel and rate

<table>
<thead>
<tr>
<th>Channel name</th>
<th>Bit rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>16 Kbps</td>
</tr>
<tr>
<td></td>
<td>64 Kbps</td>
</tr>
<tr>
<td>B</td>
<td>64 Kbps</td>
</tr>
<tr>
<td>H0</td>
<td>384 Kbps</td>
</tr>
<tr>
<td>H1</td>
<td>1536 Kbps</td>
</tr>
<tr>
<td>H11</td>
<td>1920 Kbps</td>
</tr>
</tbody>
</table>
Bearer services

- 64 Kbps unrestricted, 8 KHz structured
- 64 Kbps 8 KHz structured, speech
- 64 Kbps 8 KHz structured, 3.1 KHz audio
- 384 Kbps unrestricted
- 1536 Kbps unrestricted
- 1920 Kbps unrestricted
- Packet - mode services
ISDN subscriber premises connections

(a) Point-to-point

(b) Short passive bus

TR = Terminating Resistor
Extended passive bus

< 500m

< 25-50m

TR

TE

TE

TR

TR

NT
NT1 star

<1 km

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User - Network Interface: Layer 1 specifications

B channel: 64 Kbps, two channels
Bit timing and rate: 192 Kbps
   Octet timing
   Frame alignment
D channel: 16 Kbps
Power feeding: 40 V DC 1–mW max.
   Activating and deactivating
   Frame structure and organisation
Line code: Pseudo - ternary
D channel access control: Similar to HDLC
Layer 1 functions

- Encoding of digital data for transmission across the interface.
- Full-duplex transmission of B channel data
- Full-duplex transmission of D channel data.
- Multiplexing of channels to form basic or primary access transmission structure.
- Activation and deactivation of physical circuit.
- Power feeding from network termination to the terminal.
- Terminal identification.
- Faulty terminal isolation.
- D channel contention access
ISDN Layer 2

Traffic over D channel (control Info and data over D) Q 921

Q921 services

- Convey user Info between layers entities using D channel
- Support multiple terminals at user-NW installation
- Multiple layer 3 entity support two types of transfer
  - Unacknowledged transfer (un no: frames)
  - Acknowledged transfer (like X 25) HDLC
Function of other layers

layer 3: routing
        network connection establishment
        release
        multiplexing
        congestion control
        addressing

layer 4: error detection / recovery
        flow control
        layer 4 connection, release, muxing

Layer 5: session connection, etc.
        management
        session - transport management

layer 6: encryption / decryption
        compression / expansion

Layer 7: application related functions
Modelling of basic and supplementary services

Terminal Call Processing
- Basic Service Protocol (Q.931)
- Supplementary Services Protocol (Facility)
- Q.931 Messages
- LAPD
- 1.430/1.431

Exchange Call Processing
- Basic Service Protocol (Q.931)
- Supplementary Services Protocol (Facility)
- Q.931 Messages
- LAPD
- 1.430/1.431
Basic Call Control

- interact with layer 2 (LAPD) to transmit / receive messages
- generate & interpret layer 3 messages
- admin of times and logical entities (call reference) used in control
- admin of resources (like B ch1)
- check to provide proper service consistent with user requirements
- routing / relaying
- network connection control
- error detection (sequences)
- error recovery
- sequencing layer 3 information
Protocol reference model I 320

1. Protocol reference model I320

- Circuit - switched connection under common channel signalling
- Packet - switched comm over B/D/H
- Signalling between users and network based facilities (data base fores.)
- End - to - end signalling for users
- Combinations for multimedia comm.

2. Types of Info flow

1. User Info: digitised voice, data between users. Transmitted transparently through ISDN or processed (encrypted for e.g.)

2. Control Info: acted upon this Info switching a connection / clearing change service characteristics
Frame format in ISDN layer 2

(a) Frame format

<table>
<thead>
<tr>
<th>FLAG</th>
<th>ADDRESS</th>
<th>CONTROL</th>
<th>INFORMATION</th>
<th>FCS</th>
<th>FLAG</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 bits</td>
<td>16</td>
<td>8 or 16</td>
<td>Variable</td>
<td>16</td>
<td>8</td>
</tr>
</tbody>
</table>

C/R is Command/response
SAPI is Service access point identifier
TEI is Terminal endpoint identifier
LAPD format

<table>
<thead>
<tr>
<th>N(S)</th>
<th>P/F</th>
<th>N(R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 0</td>
<td>SS0</td>
<td>0 0 0</td>
</tr>
<tr>
<td>1 1</td>
<td>M M</td>
<td>M M M</td>
</tr>
</tbody>
</table>

Information transfer
Supervisory
Unnumbered

N(S) = Transmitter send sequence number
N(R) = Transmitter receive sequence number
S = Supervisory function bit
M = Modifier function bit
P/F = Poll/final bit
# LAPD commands and responses

<table>
<thead>
<tr>
<th>Name</th>
<th>Control Field</th>
<th>C/R</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information format</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I (Information)</td>
<td>0-N(S)--P-N(R)--</td>
<td>C</td>
<td>Exchange user data</td>
</tr>
<tr>
<td>Supervisory Format</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RR (Receive Ready)</td>
<td>10000000*-N(R)--</td>
<td>C/R</td>
<td>Positive ack; ready to receive \l-frame</td>
</tr>
<tr>
<td>RNR (Receive Not Ready)</td>
<td>10100000*-N(R)--</td>
<td>C/R</td>
<td>Positive ack; not ready to receive</td>
</tr>
<tr>
<td>REJ (Reject)</td>
<td>10010000*-N(R)--</td>
<td>C/R</td>
<td>Negative ack; go back N</td>
</tr>
</tbody>
</table>
### Unnumbered format

<table>
<thead>
<tr>
<th>Command</th>
<th>Code</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SABME (Set Asynchronous Balanced Mode)</td>
<td>1111P110</td>
<td>C</td>
<td>Request logical connection</td>
</tr>
<tr>
<td>DM (Disconnected Mode)</td>
<td>1111F000</td>
<td>R</td>
<td>Unable to establish or maintain logical connection</td>
</tr>
<tr>
<td>UI (Unnumbered Information)</td>
<td>1100P000</td>
<td>C</td>
<td>Used for unacknowledged information transfer service</td>
</tr>
<tr>
<td>DISC (Disconnect)</td>
<td>1100P010</td>
<td>C</td>
<td>Terminate logical connection</td>
</tr>
<tr>
<td>UA (Unnumbered Acknowledgement)</td>
<td>1100F110</td>
<td>R</td>
<td>Acknowledge SABME or DISC</td>
</tr>
<tr>
<td>FRMR (Frame Reject)</td>
<td>1110F001</td>
<td>R</td>
<td>Reports receipt of unaccept-able frame</td>
</tr>
<tr>
<td>XID (Exchange ID-Identification)</td>
<td>1111*101</td>
<td>C/R</td>
<td>Exchange identification information</td>
</tr>
</tbody>
</table>
Q931 message types

Circuit - mode connection control functions needed for circuit-switched B channel calls

Packed - mode connection control functions needed for circuit-switched connections to ISDN packet-switched node.

User - user signalling messages with global call reference functions are 4 types

- call establishment set up a call on B chl.
- call information user-NW Info transfer after set-up
- call clearing
- miscellaneous
Messages

Signalling exchanged between user - network, network - network.

Protocol discriminator (0001000) for Q931 call reference message type

length (1 for BRI, 2 for PRI)
call reference call reference value
(assigned by TE for 0/9 NT for calls)
(local significance) flag: 0: originator , 1: remote end

call reference length = 0 supp.services Q932
CRF = φ global CRF
# SAPI and TEI assignments

## (a) SAPI Assignments

<table>
<thead>
<tr>
<th>SAPI Value</th>
<th>Related Protocol or Management Entity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Call-control procedures</td>
</tr>
<tr>
<td>16</td>
<td>packet communication conforming to X.25 level 3</td>
</tr>
<tr>
<td>32-61</td>
<td>Frame relay communication</td>
</tr>
<tr>
<td>63</td>
<td>Layer 2 management procedures</td>
</tr>
<tr>
<td>All others</td>
<td>Reserved for future standardisation</td>
</tr>
</tbody>
</table>

## (b) TEI Assignments

<table>
<thead>
<tr>
<th>TEI Value</th>
<th>User Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-63</td>
<td>Nonautomatic TEI assignment user equipment</td>
</tr>
<tr>
<td>64-126</td>
<td>Automatic TEI assignment user equipment</td>
</tr>
<tr>
<td>127</td>
<td>Used during automatic TEI assignment</td>
</tr>
</tbody>
</table>
### Q931 messages for circuit mode connections

#### Call Establishment Messages

<table>
<thead>
<tr>
<th>Message</th>
<th>Significance</th>
<th>Direction</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALERTING</td>
<td>global</td>
<td>both</td>
<td>Indicates that user alerting has begun</td>
</tr>
<tr>
<td>CALL PROCEEDING</td>
<td>local</td>
<td>both</td>
<td>Indicates that call establishment has been initiated</td>
</tr>
<tr>
<td>CONNECT</td>
<td>global</td>
<td>both</td>
<td>Indicates call acceptance by called TE</td>
</tr>
<tr>
<td>CONNECT</td>
<td>local</td>
<td>both</td>
<td>Indicates that user has been awarded the call</td>
</tr>
<tr>
<td>ACKNOWLEDGE</td>
<td>local</td>
<td>both</td>
<td>Reports progress of a call</td>
</tr>
<tr>
<td>PROGRESS set-up</td>
<td>global</td>
<td>both</td>
<td>Initiates call establishment</td>
</tr>
<tr>
<td>PROGRESS set-up</td>
<td>local</td>
<td>both</td>
<td>Indicates that call establishment has been initiated but requests more information</td>
</tr>
<tr>
<td>ACKNOWLEDGE</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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## Call information phase messages

<table>
<thead>
<tr>
<th>Message</th>
<th>Significance</th>
<th>Direction</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESUME</td>
<td>local</td>
<td>u n</td>
<td>Requests resumption of previously suspended call</td>
</tr>
<tr>
<td>RESUME REJECT</td>
<td>local</td>
<td>n u</td>
<td>Indicates failure to resume suspended call</td>
</tr>
<tr>
<td>SUSPEND</td>
<td>local</td>
<td>u n</td>
<td>Requests suspension of a call</td>
</tr>
<tr>
<td>SUSPEND REJECT</td>
<td>local</td>
<td>n u</td>
<td>Indicates failure of requested call suspension</td>
</tr>
<tr>
<td>ACKNOWLEDGE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUSPEND ACKNOWLEDGE</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Call clearing messages

<table>
<thead>
<tr>
<th>Message</th>
<th>Significance</th>
<th>Direction</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>DISCONNECT</td>
<td>global</td>
<td>both</td>
<td>Sent by user to request connection clearing; sent by network to indicate connection clearing</td>
</tr>
<tr>
<td>RELEASE</td>
<td>local</td>
<td>both</td>
<td>Indicates intent to release channel and call reference</td>
</tr>
<tr>
<td>RELEASE</td>
<td>local</td>
<td>both</td>
<td>Indicates release of channel and call reference</td>
</tr>
<tr>
<td>COMPLETE</td>
<td>local</td>
<td>both</td>
<td>Provides additional information</td>
</tr>
<tr>
<td>INFORMATION</td>
<td>local</td>
<td>both</td>
<td>Indicates information pertaining to a call</td>
</tr>
<tr>
<td>NOTIFY</td>
<td>access</td>
<td>both</td>
<td>Sent in response to a STATUS INQUIRY or at any time to report an error</td>
</tr>
<tr>
<td>STATUS INQUIRY</td>
<td>local</td>
<td>both</td>
<td>Solicits STATUS message</td>
</tr>
</tbody>
</table>
Digital Signal Encoding Format in ISDN

NRZ-L

Bipolar-AMI

Pseudo-ternary

0 1 0 0 1 1 0 0 0 1 1
### Physical connector in ISDN

#### Contact Assignments for Plugs and Jacks of ISDN

<table>
<thead>
<tr>
<th>Contact Number</th>
<th>TE</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Power Source 3</td>
<td>Power Sink 3</td>
</tr>
<tr>
<td>b</td>
<td>Power Source 3</td>
<td>Power Sink 3</td>
</tr>
<tr>
<td>c</td>
<td>Transmit</td>
<td>Receive</td>
</tr>
<tr>
<td>d</td>
<td>Received</td>
<td>Transmit</td>
</tr>
<tr>
<td>e</td>
<td>Received</td>
<td>Transmit</td>
</tr>
<tr>
<td>f</td>
<td>Transmit</td>
<td>Received</td>
</tr>
<tr>
<td>g</td>
<td>Power Sink 2</td>
<td>Power Source 2</td>
</tr>
<tr>
<td>h</td>
<td>Power Sink 2</td>
<td>Power Source 2</td>
</tr>
</tbody>
</table>
The U interface

Fixed by local administration

- 4 wire interface
  no echo cancellation procedures, simple line termination

- 2 wire interface
  Ping-Pong operation, no echo cancellation, only one
  cable pair, simple termination, limited lengths, extra
  processing for comm. direction handling

- 2 wire interface
  full duplex operation, echo cancellation, only one cable
  pair, no limitation on length, extensive processing for echo
  cancellation
U interface circuit

TX Data → Line Encoding → Echo Canceller

RX Data → Decision Feedback Equalisation → + → AD → Hybrid → DSL
ANSI U interface frame and superframe structure

<table>
<thead>
<tr>
<th></th>
<th>ISW</th>
<th>2B + D</th>
<th>2B + D</th>
<th>2B + D</th>
<th>2B + D</th>
<th>2B + D</th>
<th>M1 to M6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
</tr>
<tr>
<td>3</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
</tr>
<tr>
<td>4</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
</tr>
<tr>
<td>5</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
</tr>
<tr>
<td>6</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
</tr>
<tr>
<td>7</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
</tr>
<tr>
<td>8</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
</tr>
</tbody>
</table>

SW = Sync Word = +3+3-3-3+3-3+3+3+3
ISW= Inverted SW=-3-3+3+3+3-3+3-3-3
2B+D = |B1 |B2 |D | (|8|8|2) M1 to M6 over head bits
Data are encoded as 00 = -3, 01= -1, 11=+1, 10 = +3
TEI and SAPI assignment

User

Customer premises

Language

SI: Signalling information
PD: Packet data

Network

ET/NT2 Connection endpoint suffix

SAPI = 0
SAPI = 16

UTI = 3, 8, 127

TEI = 5
TEI = 3, 8, 127

TEI = 127
TEI = 5

Data link layer

Layer 3

TEI = 3, 8, 127

TEI = 5
TEI = 127

B 1 B 1
B 1 B 1

0 16 0 16
Asymmetric Digital Subscriber Line

ADSL spectrum sharing
Asymmetric Digital Subscriber Line (ADSL) basics

- A new MODEM technology

- Converts existing twisted-pair telephone lines into access paths for multimedia and high speed data communications.

- ADSL transmits more than 6 Mbps (optionally up to 8 Mbps) to a subscriber, and as much as 640 kbps (optionally up to 1 Mbps) more in both directions.

- Such rates expand existing access capacity by a factor of 50 or more without new cabling.

- ADSL can transform the existing public information network (limited to voice, text and low resolution graphics) to a powerful, ubiquitous system capable of bringing multimedia, including full motion video, to everyone's home now.
ADSL basics (contd 1)

➤ ADSL will play a crucial role over the next ten or more years for delivering information in video and multimedia formats.

➤ New broadband cabling will take decades to reach all prospective subscribers.

➤ Success of these new services will depend upon reaching as many subscribers as possible during the first few years.

➤ By bringing movies, television, video catalogs, remote CD-ROMs, corporate LANs, and the Internet into homes and small businesses, ADSL will make these markets viable, and profitable, for telephone companies and application suppliers alike.
ADSL basics (contd 2)

Three information channels

- a high speed downstream channel
  - Speed ranges from 1.5 to 6.1 Mbps

- a medium speed duplex channel
  - Speed range from 16 to 640 kbps

- a POTS (Plain Old Telephone Service) or an ISDN channel.
  - The POTS/ISDN channel is split off from the digital modem by filters, thus guaranteeing uninterrupted POTS/ISDN, even if ADSL fails.

Each channel can be submultiplexed to form multiple, lower rate channels, depending on the system.
Consistent with North American and European digital hierarchies.
## ADSL reach

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>Distance</th>
<th>Wire Size</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 or 2 Mbps</td>
<td>18,000 ft</td>
<td>0.5 mm</td>
<td>5.5 km</td>
</tr>
<tr>
<td>1.5 or 2 Mbps</td>
<td>15,000 ft</td>
<td>0.4 mm</td>
<td>4.6 km</td>
</tr>
<tr>
<td>6.1 Mbps</td>
<td>12,000 ft</td>
<td>0.5 mm</td>
<td>3.7 km</td>
</tr>
<tr>
<td>6.1 Mbps</td>
<td>9,000 ft</td>
<td>0.4 mm</td>
<td>2.7 km</td>
</tr>
</tbody>
</table>
# Communication Systems

<table>
<thead>
<tr>
<th>POINT-TO-POINT</th>
<th>BROADCAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>➤ ONE SOURCE</td>
<td>ONE SOURCE</td>
</tr>
<tr>
<td>➤ ONE SINK</td>
<td>MANY SINKS</td>
</tr>
<tr>
<td>FOR INFORMATION</td>
<td>FOR INFORMATION</td>
</tr>
<tr>
<td>➤ FEED BACK</td>
<td>SINKS</td>
</tr>
<tr>
<td>FROM SINKS, IN</td>
<td></td>
</tr>
<tr>
<td>FACT TWO WAY COMM.</td>
<td>PRIVACY PROHIBITED</td>
</tr>
<tr>
<td>➤ PRIVACY NEEDED</td>
<td>NO SUCH REQUIREMENT</td>
</tr>
<tr>
<td>EAVES DROPPING TO</td>
<td>PUBLIC INFO TRANSFER</td>
</tr>
<tr>
<td>BE AVOIDED</td>
<td></td>
</tr>
<tr>
<td>➤ PRIVATE DATA, INFO</td>
<td></td>
</tr>
<tr>
<td>EXCHANGE</td>
<td></td>
</tr>
<tr>
<td>➤ REQUIRES ESTABLISHMENT</td>
<td>NO</td>
</tr>
<tr>
<td>OF PATH BETWEEN</td>
<td></td>
</tr>
<tr>
<td>PARTIES</td>
<td></td>
</tr>
<tr>
<td>➤ THIS PATH ESTABLISHMENT</td>
<td>NO SWITCHING</td>
</tr>
<tr>
<td>IS CALLED &quot;SWITCHING&quot;</td>
<td></td>
</tr>
<tr>
<td>➤ REQUIRES &quot;SIGNALLING&quot;</td>
<td>NO</td>
</tr>
</tbody>
</table>
History of Switching

- Manual - through operator: 1880 onwards
- Step-by-Step - Strowger: ~1897
- First "big" strowger exchange: 1919
- # 1 Cross bar: 1938
- # 5 Cross bar: 1948
- # 3 Cross bar: 1974
- ESS I: 1965
- ESS II: 1970
- ESS III: 1976
- ESS ZB: 1976
- ESS IA: 1980 onwards

PAX: Private automatic exchange useful for local connections only

PABX: Private automatic branch Exchange useful for local and trunk connections
Types of Switching Systems

- **Circuit Switches**
  - Mainly for interactive communication
  - Voice, Video, etc.

- **Non-Circuit Switches**
  - For example: X25 service

Mainly for non-interactive communication
- Data terminals
- Computer communication
Switching system topology

EPABX

Primary

Secondary

Local Exchange
1000's of lines

Trunks
10 to 15% of sub lines
Signals in Switching Systems

Switching system objective: To interconnect two circuits for information exchange

Information: Voice, Data, FAX, Still Video, moving video, etc.

<table>
<thead>
<tr>
<th>Type of signal</th>
<th>Bandwidth</th>
<th>Data rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice</td>
<td>4 KHz</td>
<td>64 Kbps</td>
</tr>
<tr>
<td>Data</td>
<td></td>
<td>300 bps to several mbps</td>
</tr>
<tr>
<td>Still video</td>
<td>1 to 4 MHz</td>
<td></td>
</tr>
<tr>
<td>Moving video</td>
<td>4 to 10 MHz</td>
<td>1 to 30 Mbps</td>
</tr>
<tr>
<td>FAX</td>
<td>30 to 150 Mbps</td>
<td></td>
</tr>
<tr>
<td>150 Mbps</td>
<td></td>
<td>9.6 Kbps</td>
</tr>
</tbody>
</table>
Tasks of a Switch

1. SWITCHING: ESTABLISHING CONNECTIONS BETWEEN SUBSCRIBERS

2. SIGNALLING
   - CHANNEL ASSOCIATED - COMMUNICATION
   - CHANNEL (ZW) USED FOR SIGNALLING
      - FEED TONES
      - REMOVE TONES
      - DTMF, PULSE DIALLING
   - FLASH DETECTION
   - TONE OVER CONVERSATION...
   - LINE SIGNALLING - SIGNALS TRANSMITTED BETWEEN EQUIPMENT THAT TERMINATE & CONTINUOUSLY MONITOR TRAFFIC
   - CIRCUIT
      - OFF-HK, ON-HK ETC. ARE EXAMPLES
   - SELECTION SIGNALLING - ROUTING INFO
      - DIGITS, C-O-S INFO ETC.
   - COMMON CHANNEL SIGNALLING
     - SEPARATE CHANNEL FOR SIGNALS

3. MANAGEMENT
   - METERING, DIAGNOSTICS, CLASS OF SERVICE
Call processing in a Switch

CALLING  SWITCH  CALLED

OFF-HOOK (ORIGINATE)  IDENTITY SUBSCRIBER
DIAL TONE  ALLOCATE COMMON RESOURCES
DIAL DIGITS  DIGIT COLLECT ANALYSE
RING BACK TONE  PATH SET UP
CONVERSE  DISCONNECT TONES
ON-HOOK (FORWARD CLEAR)  DISCONNECT RETURN RESOURCES
RINGING CURRENT
OFF-HOOK
CONVERSE
DISCONNECT CALL
Switching System Architectures

SPACE DIVISION
- establish connection through galvanic connections
- once established, contact remains till disconnection
- dedicated paths
- expansion requires additional "paths"
- The actual switch is called a "CROSS POINT"

TIME DIVISION
- establish connections through data exchange in a memory
- contact between two parties at specific "time-slot"
- dedicated time-slot
- Expansion requires additional "time-slots"
- The actual switch is called a "SPEECH MEMORY"
Switching System Operations

- Path establishment - using extensive signalling
- Information interchange - using error free communication
- Facilities - offering extensive facilities to subscribers
- Tariff computation - using extensive signalling
- Tearing down the path after information exchange is complete - using signalling
- Billing - using computation facilities
- Maintenance - using computation facilities and a few added equipment
- Performance measurement - using computation facilities and a few added equipment
Electronic Stored Program Control Switches

- COMMON CONTROL
- CONTROL through' COMPUTER HW + SW
- BOTH TIME DIVISION & SPACE DIVISION POSSIBLE

SPACE DIVISION SWITCHING

- USING REED CONTACTS FOR CROSS POINTS
- USING SOLID STATE (JFETS/MOS FETs) FOR CROSS POINTS
- USING THYRISTORS/TRIACS FOR CROSS POINTS
Analogue Switch Features

- Low cost for small switches (say up to 64 subscribers)
- Low distortion due to direct speech switching
- Introducing tones very easy
- Cost vs service trade-off possible
- Fairly good bandwidth
- Blocking switch, particularly for large number of subscribers
- Cost increases with number of switches
- Expansion is difficult
- Handling data difficult
- Lower reliability due to switches
A generic N by N switch

N input lines

N output lines
Space division switch

First stage  Second stage  Third stage

Three-stage space-division switch
### Number of cross points for a non-blocking switch

<table>
<thead>
<tr>
<th>Lines</th>
<th>Single-Stage</th>
<th>Three stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>128</td>
<td>7,680</td>
<td>16,384</td>
</tr>
<tr>
<td>512</td>
<td>63,488</td>
<td>262,144</td>
</tr>
<tr>
<td>2,048</td>
<td>516,096</td>
<td>4.2 x 10^6</td>
</tr>
<tr>
<td>8,192</td>
<td>4.2 x 10^6</td>
<td>6.7 x 10^7</td>
</tr>
<tr>
<td>32,768</td>
<td>3.3 x 10^7</td>
<td>1 x 10^9</td>
</tr>
<tr>
<td>131,072</td>
<td>2.6 x 10^8</td>
<td>1.7 x 10^10</td>
</tr>
</tbody>
</table>
SPC Digital Switch Block schematic

- **SUB**: Sub Line Terminate
- **SWITCH MATRIX**: Switch Matrix
- **ANALOG TRUNK TERMINATE**: Analog Trunk Terminate
- **ANALOG TRUNKS**: Analog Trunks
- **SUB LINE CONTROL**: Sub Line Control
- **TERMINALS CONSOLES**: Terminals Consoles

The diagram illustrates the flow and connections between these components in a digital switch block.
Time slot interchange

* One Frame delay
Implementation of a digital TSI switch

PCM INPUT BUS

CONTROL MEMORY

PCM output bus

INFORMATION MEMORY

CONTROL
A Simple Time-Division Switch

A Simple Folded Time-Division Switch

TDM Bus switch
Time-space-time Switch

TML

1

5

38

TML

2

14

38

20

20

output

1

output

2

output

n

TML

k

TML

n
Space-time-space switch
Overview

• Copper Access
• Bandwidth Requirements
• Distance vs. Rate
• ADSL
• Modulation Techniques
• Competing Technologies
Copper Access Technologies // Voice

• Voice Grade Modems
  ● V.22 // V.32 // V.34
    ● 1,200 to 28,800 bps (33,600 bps)
  ● Full Duplex
  ● Data communications
  ● 56kbps modems are not full duplex (asymmetric much like ADSL)
Copper Access Technologies // Voice (V-series)

- V.19
- V.20
- V.21
- V.22bis
- V.23
- V.24ter
- V.26
- V.27ter
- V.27bis
- V.29
- V.32
- V.32bis
- V.33
- V.34
Copper Access Technologies // DSL (ISDN)

• Digital Subscriber Line
  ● DSL (ISDN BRI)
    ● 160 kbps (two 64 kbps (B) + one 16 kbps (D) + 16 kbps operation and maintenance channel [OMC])
  ● Full Duplex
  ● ISDN, voice and data communications
Copper Access Technologies // HDSL and SDSL

- High Data Rate and Single Line (Symmetric)
  - HDSL and SDSL
    - 1.544 Mbps // 2.048 Mbps
    - Full Duplex
    - T1/E1, telco feeders, WAN
    - SDSL (single twisted pair)
Copper Access Technologies // ADSL and RADSL

• Asymmetric Digital Subscriber Line (Rate Adaptive)
  ● ADSL // RADSL
    ● 1.5 Mbps to 9 Mbps (downstream)
    ● 16 kbps to 1.5 Mbps (upstream)
    ● Internet access, video on demand, remote LAN access, multimedia
    ● RADSL = adapt speeds based on conditions and distances
## Bandwidth Requirements

<table>
<thead>
<tr>
<th>Application Type</th>
<th>File Size</th>
<th>Modem 128kbps</th>
<th>ISDN 384kbps</th>
<th>DSL 768kbps</th>
<th>DSL 1.544Mbps</th>
<th>DSL 6.144 Mbps</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-mail</td>
<td>30k</td>
<td>8.3 s</td>
<td>1.9 s</td>
<td>0.63 s</td>
<td>0.31 s</td>
<td>0.16 s</td>
</tr>
<tr>
<td>Digitized Photo</td>
<td>125k</td>
<td>34.7 s</td>
<td>7.8 s</td>
<td>2.6 s</td>
<td>1.3 s</td>
<td>0.6 s</td>
</tr>
<tr>
<td>Documents</td>
<td>250k</td>
<td>69.4 s</td>
<td>15.6 s</td>
<td>5.2 s</td>
<td>2.6 s</td>
<td>1.3 s</td>
</tr>
<tr>
<td>Video Conferencing</td>
<td>384k</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>X-Ray</td>
<td>5M</td>
<td>23.1 m</td>
<td>5.2 m</td>
<td>1.7 m</td>
<td>52.1 s</td>
<td>25.9 s</td>
</tr>
<tr>
<td>Bulk File Transfer</td>
<td>20M</td>
<td>1.5 h</td>
<td>20.0 m</td>
<td>6.9 m</td>
<td>3.5 m</td>
<td>1.7 m</td>
</tr>
</tbody>
</table>
### Distance vs. Rate (downstream)

#### ADSL (24g wire)
- 1.544 Mbps @ 18,000 ft
- 2.048 Mbps @ 16,000 ft
- 6.312 Mbps @ 12,000 ft
- 8.448 Mbps @ 9,000 ft

#### VDSL (24g wire)
- 12.96 Mbps @ 4,500 ft
- 25.82 Mbps @ 3,000 ft
- 51.84 Mbps @ 1,000 ft

Distance is from Central Office or RT (repeater terminal) unit
• Asymmetric data streams
  • **Most** applications fit this model
    • video on demand
    • home shopping
    • Internet access
    • remote LAN access
Asymmetric Digital Subscriber Line (ADSL) basics

➤ A new MODEM technology

➤ Converts existing twisted-pair telephone lines into access paths for multimedia and high speed data communications.

➤ ADSL transmits more than 6 Mbps (optionally up to 8 Mbps) to a subscriber, and as much as 640 kbps (optionally up to 1 Mbps) more in both directions.

➤ Such rates expand existing access capacity by a factor of 50 or more without new cabling.

➤ ADSL can transform the existing public information network (limited to voice, text and low resolution graphics) to a powerful, ubiquitous system capable of bringing multimedia, including full motion video, to everyone's home now.
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- ADSL will play a crucial role over the next ten or more years for delivering information in video and multimedia formats.

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ADSL basics (contd 2)

Three information channels

- a high speed downstream channel
  - Speed ranges from 1.5 to 6.1 Mbps

- a medium speed duplex channel
  - Speed range from 16 to 640 kbps

- a POTS (Plain Old Telephone Service) or an ISDN channel.
  - The POTS/ISDN channel is split off from the digital modem by filters, thus guaranteeing uninterrupted POTS/ISDN, even if ADSL fails.

Each channel can be submultiplexed to form multiple, lower rate channels, depending on the system.
Consistent with North American and European digital hierarchies
ADSL in operation

Existing copper line

Broadband Network

Narrowband Network (PSTN)

DSLAM

POTS splitter

up

16kbps to 1.5 Mbps

down

1.5 to 6 Mbps

Existing

POTS splitter

1.5 to 6 Mbps

down

1.5 to 6 Mbps

up

16kbps to 1.5 Mbps
## ADSL reach

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>Distance</th>
<th>Wire Size</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 or 2 Mbps</td>
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<td>5.5 km</td>
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<td>0.4 mm</td>
<td>2.7 km</td>
</tr>
</tbody>
</table>
ADSL spectrum sharing
**ADSL (spectrum)**

**Frequency Spectrum**

*T1/T3 circuits, Bridge Taps, load coils are disturbers when in the same or adjacent binder as ADSL twisted pair.*

---

**Upstream**
- Data spectrum

**Downstream**
- Data spectrum

---

**POTS**

**Frequency Bands:**
- 4Khz
- 20Khz
- 1.1 Mhz

---

SmartVideoconferencing™

Jamadagni H S

DC/V1/2004
Modulation Techniques (ADSL)

- Discrete Multitone modulation (DMT)
  - multicarrier sub-channels (256 downstream, 32 upstream) [4 Khz]
  - inferior quality, traffic reassigned to different channel
    - 6 Mbps downstream
    - 640 kbps upstream
Modulation Techniques (ADSL)

- **Carrierless Amplitude/Phase modulation (CAP)**
  - proprietary, mature technology
  - single carrier system similar to V.34
  - automatic bit rate adjustments for line impairments
    - 1.5 Mbps downstream
    - 64 kbps upstream
Competing Technologies

Cable Modems
- 18,000 ft limit (head-end)
- Most cable operators need to upgrade their networks to support bi-directional service
- 128 kbps up to 30 Mbps (shared bandwidth, up to 200 users on a loop)
- Security
- Reliability in question
Competing Technologies

- **Digital Satellite transmission**
  - Still need upstream data provider (usually handled through modem or ISDN)
  - up to 30 Mbps downstream
  - Also used for push-technology
## Q. 931 Message format

<table>
<thead>
<tr>
<th>Protocol discriminator</th>
<th>Length</th>
<th>Call reference value</th>
<th>Message type</th>
<th>Other information elements if required</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 0 0 0 0</td>
<td></td>
<td>F</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other information element identifier</th>
<th>Contents of information element</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Info. element identifier</th>
<th>Contents of info. element</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Info. element identifier</th>
<th>Contents of info. element</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Information element identifier</th>
<th>Contents of information element</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
# Bearer capability information element identifier

<table>
<thead>
<tr>
<th></th>
<th>Length of bearer capability contents</th>
<th>Length of bearer capability contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1 X X X X X X X X X X</td>
<td>Codinbg std., info. transfer capability</td>
</tr>
<tr>
<td>4a</td>
<td>X X X X X X X X X X X</td>
<td>Transfer mode, transfer rate</td>
</tr>
<tr>
<td>4b</td>
<td>X X X X X X X X X X</td>
<td>Rate multiplier</td>
</tr>
<tr>
<td>5a</td>
<td>0/1 X X X X X X X X</td>
<td>Layer 1 identity, user info. layer 1</td>
</tr>
<tr>
<td>5c</td>
<td>X X X X X X X X X</td>
<td>Layer 2 identity, user info. layer 2</td>
</tr>
<tr>
<td>5d</td>
<td>X X X X X X X X X</td>
<td>Layer 3 identity, user info. layer 3</td>
</tr>
<tr>
<td>5e</td>
<td>X X X X X X X X X</td>
<td>Layer 3 identity, user info. layer 3</td>
</tr>
</tbody>
</table>
Procedure for a circuit-switched call

Data Flow

off hk Set up

Ring back

Call proceeding

RB stop

connect

Set up

Alerting

Connect

Data Flow

S1 ST1 ET1 ET2 ST2 S2
Modelling of basic and supplementary services
Layer 3
Functions

Routing
Network connection establishment
Connection release
Multiplexing
Congestion control
Addressing
Layer 2 Functions

Traffic over D channel (control Info and data over D) Q 921

Q921 services

- Convey user Info between layers entities using D channel
- Support multiple terminals at user-NW installation
- Multiple layer 3 entity: support two types of transfer
- Unacknowledged transfer (unnumbered frames)
- Acknowledged transfer (like X 25) HDLC
**Function of other layers**

*layer 4*: error detection / recovery  
flow control  
layer 4 connection, release, muxing  

*Layer 5*:  
session connection  
management  
session - transport management  

*layer 6*: encryption / decryption  
compression / expansion  

*Layer 7*: application related functions
Protocol reference model I
320

1. Protocol reference model I320

- Circuit - switched connection under common channel signalling
- Packet - switched comm over B/D/H
- Signalling between users and network based facilities (data base fores.)
- End - to - end signalling for users
- Combinations for multimedia comm.

2. Types of Info flow

1. User Info: digitised voice, data between users. Transmitted transparently through ISDN or processed (encrypted for e.g.)

2. Control Info : acted upon this Info switching a connection / clearing change service characteristics
Basic Call Control

- interact with layer 2 (LAPD) to transmit / receive messages
- generate and interpret layer 3 messages
- admin of times and logical entities (call reference) used in control
- admin of resources (like B ch1)
- check to provide proper service consistent with user requirements
- routing / relaying
- network connection control
- error detection (sequences)
- error recovery
- sequencing layer 3 information
Layer 1 Functions

- Encoding of digital data for transmission across the interface
- Full-duplex transmission of B channel data
- Full-duplex transmission of D channel data.
- Multiplexing of channels to form basic or primary access transmission structure.
- Activation and deactivation of physical circuit.
- Power feeding from network termination to the terminal.
- Terminal identification.
- Faulty terminal isolation.
- D channel contention access
Q931 message types

Circuit - mode connection control functions needed for circuit-switched B channel calls

Packed - mode connection control functions needed for circuit-switched connections to ISDN packet-switched node.

User - user signalling messages with global call reference functions are 4 types

- call establishment set up a call on B chl.
- call information user-NW Info transfer after set-up
- call clearing
- miscellaneous
Messages

Signaling exchanged between user - network, network - network.

Protocol discriminator (0001000) for Q931 call reference
Message type: length (1 for BRI, 2 for PRI)
Call reference: call reference value (assigned by TE local significance)
Flag: 0: originator, 1: remote end
Call reference length = 0, Supplementary services Q932
CRF = 0, global CRF
**Q931 messages for circuit mode connections**

Call Establishment Messages

<table>
<thead>
<tr>
<th>Message</th>
<th>Significance</th>
<th>Direction</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALERTING</td>
<td>global</td>
<td>both</td>
<td>Indicates that user alerting has begun</td>
</tr>
<tr>
<td>CALL PROCEEDING</td>
<td>local</td>
<td>both</td>
<td>Indicates that call establishment has been initiated</td>
</tr>
<tr>
<td>CONNECT</td>
<td>global</td>
<td>both</td>
<td>Indicates call acceptance by called TE</td>
</tr>
<tr>
<td>ACKNOWLEDGE</td>
<td>local</td>
<td>both</td>
<td>Indicates that user has been awarded the call</td>
</tr>
<tr>
<td>PROGRESS</td>
<td>global</td>
<td>both</td>
<td>Reports progress of a call</td>
</tr>
<tr>
<td>SETUP</td>
<td>global</td>
<td>both</td>
<td>Initiates call establishment</td>
</tr>
<tr>
<td>SETUP</td>
<td>local</td>
<td>both</td>
<td>Indicates that call establishment has been initiated but requests</td>
</tr>
<tr>
<td>ACKNOWLEDGE</td>
<td>local</td>
<td>both</td>
<td>more information</td>
</tr>
</tbody>
</table>
#### Call information phase messages

<table>
<thead>
<tr>
<th>Message</th>
<th>Significance</th>
<th>Direction</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESUME</td>
<td>local</td>
<td>u n</td>
<td>Requests resumption of previously suspended call</td>
</tr>
<tr>
<td>RESUME</td>
<td>local</td>
<td>n u</td>
<td>Indicates requested call has been reestablished</td>
</tr>
<tr>
<td>ACKNOWLEDGE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RESUME REJECT</td>
<td>local</td>
<td>n u</td>
<td>Indicates failure to resume suspended call</td>
</tr>
<tr>
<td>SUSPEND</td>
<td>local</td>
<td>u n</td>
<td>Requests suspension of a call</td>
</tr>
<tr>
<td>SUSPEND</td>
<td>local</td>
<td>n u</td>
<td>Indicates call has been suspended</td>
</tr>
<tr>
<td>ACKNOWLEDGE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUSPEND REJECT</td>
<td>local</td>
<td>n u</td>
<td>Indicates failure of requested call suspension</td>
</tr>
</tbody>
</table>
## Call clearing messages

<table>
<thead>
<tr>
<th>Message</th>
<th>Significance</th>
<th>Direction</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>DISCONNECT</td>
<td>global</td>
<td>both</td>
<td>Sent by user to request connection clearing; sent by network to indicate connection clearing</td>
</tr>
<tr>
<td>RELEASE</td>
<td>local</td>
<td>both</td>
<td>Indicates intent to release channel and call reference</td>
</tr>
<tr>
<td>RELEASE</td>
<td>local</td>
<td>both</td>
<td>Indicates release of channel and call reference</td>
</tr>
<tr>
<td>COMPLETE</td>
<td>local</td>
<td>both</td>
<td>Provides additional information</td>
</tr>
<tr>
<td>INFORMATION</td>
<td>local</td>
<td>both</td>
<td>Indicates information pertaining to a call</td>
</tr>
<tr>
<td>NOTIFY</td>
<td>local</td>
<td>both</td>
<td>Sent in response to a STATUS INQUIRY or at any time to report an error</td>
</tr>
<tr>
<td>STATUS</td>
<td>local</td>
<td>both</td>
<td>Solicits STATUS message</td>
</tr>
<tr>
<td>INQUIRY</td>
<td>local</td>
<td>both</td>
<td></td>
</tr>
</tbody>
</table>
Frame format in ISDN layer 2

(a) Frame format

<table>
<thead>
<tr>
<th>FLAG</th>
<th>ADDRESS</th>
<th>CONTROL</th>
<th>INFORMATION</th>
<th>FCS</th>
<th>FLAG</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 bits</td>
<td>16</td>
<td>8 or 16</td>
<td>Variable</td>
<td>16</td>
<td>8</td>
</tr>
</tbody>
</table>

0  C/R  SAPI  1  TEI

C/R is Command/response
SAPI is Service access point identifier
TEI is Terminal endpoint identifier
**LAPD format**

<table>
<thead>
<tr>
<th></th>
<th>N(S)</th>
<th>P/F</th>
<th>N(R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Information transfer

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>P/F</th>
<th>N(R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Supervisory

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>P/F</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Unnumbered

N(S) = Transmitter send sequence number  
N(R) = Transmitter receive sequence number  
S = Supervisory function bit  
M = Modifier function bit  
P/F = Poll/final bit
# LAPD commands and responses

<table>
<thead>
<tr>
<th>Name</th>
<th>Control Field</th>
<th>C/R</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Information format</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I (Information)</td>
<td>0-N(S)--P-N(R)-- C</td>
<td>C/R</td>
<td>Exchange user data</td>
</tr>
<tr>
<td><strong>Supervisory Format</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RR (Receive Ready)</td>
<td>10000000*-N(R)-- C/R</td>
<td>C/R</td>
<td>Positive ack; ready to receive I-frame</td>
</tr>
<tr>
<td>RNR (Receive Not Ready)</td>
<td>10100000*-N(R)-- C/R</td>
<td>C/R</td>
<td>Positive ack; not ready to receive</td>
</tr>
<tr>
<td>REJ (Reject)</td>
<td>10010000*-N(R)-- C/R</td>
<td>C/R</td>
<td>Negative ack; go back N</td>
</tr>
</tbody>
</table>
## Unnumbered format

<table>
<thead>
<tr>
<th>Action</th>
<th>Code</th>
<th>Mode</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SABME (Set Asynchronous Balanced Mode)</td>
<td>1111P110</td>
<td>C</td>
<td>Request logical connection</td>
</tr>
<tr>
<td>DM (Disconnected Mode)</td>
<td>1111F000</td>
<td>R</td>
<td>Unable to establish or maintain logical connection</td>
</tr>
<tr>
<td>UI (unnumbered Information)</td>
<td>1100P000</td>
<td>C</td>
<td>Used for unacknowledged information transfer service</td>
</tr>
<tr>
<td>DISC (Disconnect)</td>
<td>1100P010</td>
<td>C</td>
<td>Terminate logical connection</td>
</tr>
<tr>
<td>UA (Unnumbered Acknowledgement)</td>
<td>1100F110</td>
<td>R</td>
<td>Acknowledge SABME or DISC</td>
</tr>
<tr>
<td>FRMR (Frame Reject)</td>
<td>1110F001</td>
<td>R</td>
<td>Reports receipt of unacceptible frame</td>
</tr>
<tr>
<td>XID (Exchange ID-identification)</td>
<td>1111*101</td>
<td>C/R</td>
<td>Exchange identification information</td>
</tr>
</tbody>
</table>
### SAPI and TEI assignments

#### (a) SAPI Assignments

<table>
<thead>
<tr>
<th>SAPI Value</th>
<th>Related Protocol or Management Entity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Call-control procedures</td>
</tr>
<tr>
<td>16</td>
<td>packet communication conforming to X.25 level 3</td>
</tr>
<tr>
<td>32-61</td>
<td>Frame relay communication</td>
</tr>
<tr>
<td>63</td>
<td>Layer 2 management procedures</td>
</tr>
<tr>
<td>All others</td>
<td>Reserved for future standardisation</td>
</tr>
</tbody>
</table>

#### (b) TEI Assignments

<table>
<thead>
<tr>
<th>TEI Value</th>
<th>User Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-63</td>
<td>Nonautomatic TEI assignment user equipment</td>
</tr>
<tr>
<td>64-126</td>
<td>Automatic TEI assignment user equipment</td>
</tr>
<tr>
<td>127</td>
<td>Used during automatic TEI assignment</td>
</tr>
</tbody>
</table>
**TEI and SAPI assignment**

- **Customer premises**
  - **PD**: Packet data
  - **SI**: Signalling information
  - TEI = 5
  - SAPI = 0

- **Network**
  - **SI**: Signalling information
  - **PD**: Packet data
  - TEI = 3, 8, 127
  - SAPI = 16

- **Layer 3**
  - TEI (2)
  - TEI (1)
  - SI
  - PD

- **Data link layer**
  - TEI = 127
  - SAPI = 16
Digital Signal Encoding Format in ISDN

- NRZ-L
- Bipolar-AMI
- Pseudo-ternary
### Physical connector in ISDN

Contact Assignments for Plugs and Jacks of ISDN

<table>
<thead>
<tr>
<th>Contact Number</th>
<th>TE</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Power Source 3</td>
<td>Power Sink 3</td>
</tr>
<tr>
<td>b</td>
<td>Power Source 3</td>
<td>Power Sink 3</td>
</tr>
<tr>
<td>c</td>
<td>Transmit</td>
<td>Receive</td>
</tr>
<tr>
<td>d</td>
<td>Received</td>
<td>Transmit</td>
</tr>
<tr>
<td>e</td>
<td>Received</td>
<td>Transmit</td>
</tr>
<tr>
<td>f</td>
<td>Transmit</td>
<td>Received</td>
</tr>
<tr>
<td>g</td>
<td>Power Sink 2</td>
<td>Power Source 2</td>
</tr>
<tr>
<td>h</td>
<td>Power Sink 2</td>
<td>Power Source 2</td>
</tr>
</tbody>
</table>
The U interface

Fixed by local administration

- 4 wire interface
  - no echo cancellation procedures, simple line termination

- 2 wire interface
  - Ping-Pong operation, no echo cancellation, only one cable pair,
    simple termination, limited lengths, extra processing for comm.
    direction handling

- 2 wire interface
  - full duplex operation, echo cancellation, only one cable pair, no
    limitation on length, extensive processing for echo cancellation
**U interface circuit**

 TX Data → Line Encoding → Hybrid

 RX Data → Decision Feedback Equalisation → Echo Canceller → AD

 TX Data + RX Data → AD

 DSL
### ANSI U interface frame and superframe structure

<p>| | | | | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ISW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
\text{SW} = \text{Sync Word} = +3+3-3-3+3-3+3+3+3+3
\]

\[
\text{ISW} = \text{Inverted SW} = -3-3+3+3+3-3+3-3-3
\]

\[
2B+D = |B_1\ |
B_2\ |
D\ |
(|8|8|2) M1 to M6 over head bits
\]

Data are encoded as

\[
00 = -3, \ 01 = -1, \ 11 = +1, \ 10 = +3
\]