Digital Communication Systems

H. S. Jamadagni, CEDT, IISc, Bangalore
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

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

-B  +B  Frequency

Spectrum of the properly sampled base band

Spectrum of the under sampled base band
Speech signal digitisation

Input signal

PAM samples

Output signal

Pulse train

LPF

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 errors
Quantisation error in PCM

Quantised output signal

Input signal

Decorder output

Input amplitude

Quantisation error as a function of amplitude

Jamadagni H S DC/V1/2004
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

<table>
<thead>
<tr>
<th>number of bits / sample</th>
<th>SNR (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

A/A_{max} (dB)
Non-linear AD conversion

Uniform Quantisation

Compressed sample values

Input sample values
Compression law - $\mu$ law
Compression law - A law

![Diagram of compression law with input and output scales showing a linear relationship between normalised input and output. The graph illustrates the decrease in output as input increases, with specific values marked on the x-axis and corresponding output values on the y-axis.]
Non linear AD conversion laws used in PCM for speech

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

\( \mu \text{ law} \)

\[ L_A(x) = \text{sgn}(x) \frac{1 + |x|}{\sqrt{|x|}} \]

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

- Speech signal
- Band limiting filter
- Differentiator
- A/D
- Sampler quantizer encoder
- Encoded difference samples
- D/A
- Accumulator
- Previous input estimate
- Encoded difference samples

- +
- -

Σ
DPCM implementation
Delta modulation

Input

LPF

+  +

Σ

-  -

"1"

Decoder

Integrator

Pulse generator

Output

LPF
Slope overload distortion in Delta modulation

Slope over load

Granular noise
Low Data Rate Modulation

CVSD (Continuous Variable Slope Delta Modulation)

Sample clock

Receive clock

Encoder

Decoder

Step size control

All 1s

All 0s

Jamadagni H S DC/V1/2004
Conceptual view of ISDN

- Telephone
- Data terminal
- PBX
- Alarm
- Local area network
- Customer ISDN interface
- "Digital pipe"
- Subscriber loop and ISDN channel structures
- "Digital pipes"
- 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

Integrated
Digital Network

Subscriber loop to ISDN channel
structures: Basic = 64 kbps + 64
kbps + 16 kbps

Primary = multiplexed 64 kbps
channels

Network-based
processing
services
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></td>
<td>Bit error rate</td>
</tr>
</tbody>
</table>

Connection performance
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
  - adapt 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 TR TR TR

TE TE
NT1 star

\[ \leq 1 \text{ km} \]
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></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>S</th>
<th>M</th>
<th>P/F</th>
<th>N(R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>SS0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Supervisory

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>M</th>
<th>P/F</th>
<th>M</th>
<th>M</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></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></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></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></td>
<td>Positive ack; not ready to receive</td>
</tr>
<tr>
<td>REJ (Reject)</td>
<td>10010000*-N(R)-- C/R</td>
<td></td>
<td>Negative ack; go back N</td>
</tr>
<tr>
<td>Command</td>
<td>Code</td>
<td>Mode</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>------</td>
<td>------</td>
<td>-------------</td>
</tr>
<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 unacceptable 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 value  (assigned by TE for 0/9 NT for calls)
(call reference)  (local significance)  flag: 0: originator, 1: remote end

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

<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></td>
<td></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>
## 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 ACKNOWLEDGE</td>
<td>local</td>
<td>n u</td>
<td>Indicates requested call has been re-established</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 ACKNOWLEDGE</td>
<td>local</td>
<td>n u</td>
<td>Indicates call has been suspended</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>COMPLETE</td>
<td>local</td>
<td>both</td>
<td>Indicates release of channel and call reference</td>
</tr>
<tr>
<td>INFORMATION</td>
<td>local</td>
<td>both</td>
<td>Provides additional information</td>
</tr>
<tr>
<td>NOTIFY</td>
<td>access</td>
<td>both</td>
<td>Indicates information pertaining to a call</td>
</tr>
<tr>
<td>STATUS INQUIRY</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>
</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

Σ

AD

Hybrid

DSL
## ANSI U interface frame and superframe structure

<table>
<thead>
<tr>
<th>18</th>
<th>18</th>
<th>18</th>
<th>18</th>
<th>18</th>
<th>6 total 240 bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ISW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
</tr>
<tr>
<td>2</td>
<td>SW</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>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>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>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>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>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>M1 to M6</td>
</tr>
</tbody>
</table>

**SW** = Sync Word = +3+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**
  - **Data link layer**
    - **PD**
    - **S**
  - **Layer 3**
    - **TE(1)**
  - **SI: Signalling information**
    - TEI = 127
    - TEI = 5
  - **PD: Packet data**

### Network

- **Network layer**
  - **S**
  - **PD**
  - **ET/NT2**
    - **Connection endpoint suffix**
    - **SAPI = 0**
    - **SAPI = 16**
  - **SAP identifier**
  - **TEI = 3, 8, 127**
  - **B B1 B2 1 2 3 2 1 B 1**
  - **Customer premises**
    - **PD**
    - **S**

---

**Terms:**
- **TEI:** Terminal Endpoint Identifier
- **SAPI:** Service Access Point Identifier
Asymetric Digital Subscriber Line

ADSL spectrum sharing

![Diagram showing FDM and Echo Cancellation in upstream and downstream frequency bands.](image-url)
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

POINT-TO-POINT

- ONE SOURCE
- ONE SINK
- FOR INFORMATION
- FEED BACK
- FROM SINKS, IN FACT TWO WAY COMM.
- PRIVACY NEEDED
- EAVES DROPPING TO BE AVOIDED
- PRIVATE DATA, INFO EXCHANGE
- REQUIRES ESTABLISHMENT OF PATH BETWEEN PARTIES
- THIS PATH ESTABLISHMENT IS CALLED "SWITCHING"
- REQUIRES "SIGNALLING"

BROADCAST

- ONE SOURCE
- MANY SINKS
- FOR INFORMATION
- SINKS
- PRIVACY PROHIBITED
- NO SUCH REQUIREMENT
- PUBLIC INFO TRANSFER
- NO
- NO SWITCHING
- NO
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

- **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

Trunks 10 to 15% of sub lines

Local Exchange 1000's of lines

Primary

Secondary
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></td>
<td>30 to 150 Mbps</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

- OFF-HOOK (ORIGINATE)
- DIAL TONE
- DIAL DIGITS
- RING BACK TONE
- CONVERSE

SWITCH

- IDENTITY SUBSCRIBER
- ALLOCATE COMMON RESOURCES
- DIGIT COLLECT ANALYSE
- PATH SET UP
- DISCONNECT TONES
- DISCONNECT RETURN RESOURCES

CALLED

- RINGING CURRENT
- OFF-HOOK
- CONVERSE
- DISCONNECT CALL

Jamadagni H S
DC/V1/2004
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
Space division switch

Three-stage space-division switch

First stage       Second stage       Third stage
### 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
- SUB LINE CONTROL
- SWITCH MATRIX
- ANALOG TRUNK TERMINATE
- ANALOG TRUNKS
- SWITCH CONTROL SYSTEM
- TERMINALS CONSOLES
Time slot interchange

* One Frame delay
Implementation of a digital TSI switch
TDM Bus switch

A Simple Time-Division Switch

A Simple Folded Time-Division Switch

n inlets

n outlets

n I O Pairs
Time-space-time Switch

![Diagram of a Time-space-time Switch](image)

TML

1

\[ \begin{array}{c}
5 \\
38 \\
2 \\
5 \\
\end{array} \]

output 1

TML

2

\[ \begin{array}{c}
20 \\
14 \\
2 \\
38 \\
20 \\
\end{array} \]

output 2

TML

n

\[ \begin{array}{c}
k \\
\end{array} \]

output 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)

SmartVideoconferencing™

Jamadagni H S

DC/V1/2004
Copper Access Technologies // Voice (V-series)

PSTN
V.19
V.20

Leased Lines
V.21

V.22bis
V.23

V.22bis
V.26

V.26ter
V.26

V.27ter
V.27

V.27bis
V.29

V.32

V.32bis

V.33

V.34

<300  600  1200  2400  4800  9600  14.4K  28.8K
• 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 6.144Mbps</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.
AdSL

- 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.
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 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

POTS splitter

1.5 to 6 Mbps

16kbps to 1.5 Mbps

Smart Videoconferencing™

Jamadagni H S

DC/V1/2004
### 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>
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.*

---

**POTS**

4Khz 20Khz

Upstream Data spectrum

Downstream Data spectrum

1.1 Mhz
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>0 0 0 0</th>
<th>Call reference value</th>
<th>Message type</th>
<th>Other information elements if required</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Info. element identifier</td>
<td>Contents of info. element</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Info. element identifier</td>
<td>Contents of info. element</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Information element identifier</td>
<td>Contents of information element</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Bearer capability information element identifier

<table>
<thead>
<tr>
<th>Field</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 0 0 0 0 0 1 0 0</td>
<td>Bearer capability info.element identifier</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Length of bearer capability contents</td>
</tr>
<tr>
<td>3</td>
<td>1 X X X X X X X X X</td>
<td>Coding std., info. transfer capability</td>
</tr>
<tr>
<td>4a</td>
<td>X X X X X X X X X X</td>
<td>Transfer mode, transfer rate</td>
</tr>
<tr>
<td>4b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>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</td>
<td>Layer 1 identity, user info. layer 1</td>
</tr>
<tr>
<td>5b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5e</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1 X X X X X X X X X</td>
<td>Layer 2 identity, user info. layer 2</td>
</tr>
<tr>
<td>7</td>
<td>1 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 hkSet up

Ringing

Set up

Alerting

Connect

RB stop

connect

Call proceeding

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>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></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</td>
</tr>
<tr>
<td>ACKNOWLEDGE</td>
<td></td>
<td></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>Indicates release of channel and call reference</td>
</tr>
<tr>
<td>INFORMATION</td>
<td>local</td>
<td>both</td>
<td>Provides additional information</td>
</tr>
<tr>
<td>NOTIFY</td>
<td>local</td>
<td>both</td>
<td>Indicates information pertaining to a call</td>
</tr>
<tr>
<td>STATUS</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>

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**

| 1  | 0   | S0  | 0   | 0   | P/F | N(R) |

**Supervisory**

| 1  | 1   | M   | M   | P/F | M   | M   | M   |

**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>Exchange user data</td>
<td></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>Positive ack; ready to receive I-frame</td>
<td></td>
</tr>
<tr>
<td>RNR (Receive Not Ready)</td>
<td>10100000*-N(R)-- C/R</td>
<td>Positive ack; not ready to receive</td>
<td></td>
</tr>
<tr>
<td>REJ (Reject)</td>
<td>10010000*-N(R)-- C/R</td>
<td>Negative ack; go back N</td>
<td></td>
</tr>
</tbody>
</table>
# Unnumbered format

<table>
<thead>
<tr>
<th>Code</th>
<th>Numeric Code</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SABME</td>
<td>1111P110</td>
<td>C</td>
<td>Request logical connection</td>
</tr>
<tr>
<td>DM</td>
<td>1111F000</td>
<td>R</td>
<td>Unable to establish or maintain logical connection</td>
</tr>
<tr>
<td>UI</td>
<td>1100P000</td>
<td>C</td>
<td>Used for unacknowledged information transfer service</td>
</tr>
<tr>
<td>DISC</td>
<td>1100P010</td>
<td>C</td>
<td>Terminate logical connection</td>
</tr>
<tr>
<td>UA</td>
<td>1100F110</td>
<td>R</td>
<td>Acknowledge SABME or DISC</td>
</tr>
<tr>
<td>FRMR</td>
<td>1110F001</td>
<td>R</td>
<td>Reports receipt of unacceptable frame</td>
</tr>
<tr>
<td>XID</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**

![Diagram showing TEI and SAPI assignment]

- **User**
  - **Customer premises**
  - **PD** (Packet data)
  - **SI** (Signalling information)
  - **Layer 3**
  - **B1**: 2
  - **B1**: 1

- **Network**
  - **ET/NT2**
  - **Connection endpoint suffix**
  - **SI**
  - **PD**
  - **B**
  - **B**
  - **SAPI identifier**
  - **SI**
  - **TEI**
  - **TEI = 127**
  - **TEI = 5**
  - **TEI = 5**
  - **TEI = 8, 127**

**Legend**
- **SI**: Signalling information
- **PD**: Packet data
- **TEI**: TEI (Transport Endpoint Identifier)
- **SAPI**: SAP identifier
- **B**: bytes

**Assignments**
- **SAPI = 0**
- **SAPI = 16**

**Notes**
- TEI = 3, 8, 127
Digital Signal Encoding Format in ISDN

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>0</th>
<th>0</th>
<th>1</th>
<th>1</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>1</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>NRZ-L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bipolar-AMI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudo-ternary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# 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 → Hybrid → DSL

RX Data → AD → Decision Feedback Equalisation → Σ → Hybrid
### ANSI U interface frame and superframe structure

<table>
<thead>
<tr>
<th></th>
<th>18</th>
<th>18</th>
<th>18</th>
<th>18</th>
<th>6</th>
<th>total 240 bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ISW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>SW</td>
<td>2B + D</td>
<td>2B + D</td>
<td>2B + D</td>
<td>M1 to M6</td>
<td></td>
</tr>
</tbody>
</table>

SW = Sync Word = +3+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