WAN Technologies

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Relationships among different technologies

analog telephony
  Digital conversion
  digital telephony
    voice + data
      ISDN
        wideband
          B-ISDN
  leased analog
    Switching
      frame
        packet
          X.25
            core-edge
      TDM
        core-edge
          Frame Relay
            cells
        DQDB
          cells
            SMDS
              cells
        ATM
          cells
            IP
ISDN:
Integrated Service Digital Network

- TELEPHONE
- TERMINAL/TELEX
- COMPUTER
- FACSIMILE GROUP 4
- MULTISERVICE TERMINAL
- VIDEOTELEPHONE
ISDN

- Dati + voice + Videotelephony + FAX G4
- The user terminal becomes digital
  - 2B + D or base access
    - 2 data channels at 64 kbps
    - 1 signaling channel at 16 kbps
    - total 144 kbps up to user's premises
  - 30B + D or primary access
    - 30 data channels at 64 kbps
    - 1 signaling channel at 64 kbps
    - total 2 Mbps up to user's premises
ISDN

ISDN phone

Videoconference

Bus S

NT1

ISDN Exchange

PC with ISDN

Fax G.4

c/o UTENTE

c/o PTT
Private networks based on TDM

- TDM (Time Division Multiplexer)
  - divide the total bandwidth in sub-bands
- Each service can “see” only its assigned sub-band as a synchronous channel with fixed bit rate
- Routers and bridges can use a channel as equivalent of a physical link
- The bandwidth not actually used by a service (in a certain interval of time) cannot be used by other services and it is wasted
TDM technology

Switch

BANDWIDTH

Switch
PDH (Plesiochronous Digital Hierarchy) and SDH (Synchronous Digital Hierarchy)

**PDH hierarchies**
- **Europe**
  - **E1** 2.048 Mbps
  - **E3** 34.368 Mbps
  - **E4** 139.26 Mbps
- **USA**
  - **T1 - DS1** 1.544 Mbps
  - **T3 - DS3** 44.736 Mbps

**SDH hierarchies**
- **USA: SONET**
  - **OC-1c / STS-1c** 51.84 Mbps
- **Europe: SDH**
  - **STM-1** 155.52 Mbps
  - **STM-4** 622.08 Mbps
  - **STM-12** 2.4 Gbps

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Physical architecture

- **Section:** fiber optic between repeaters
- **Line:** sequence of sections between devices operating at line level
- **Path:** end-to-end connection
Protocol architecture

- **Photonic Layer**: fiber, laser
- **Section Layer**: frames, OAM (Operation Administration and Management)
- **Line Layer**: synchronization, multiplexing, switching, OAM
- **Path Layer**: end-to-end data transfer (bytes)
# Frame format

**STS-1**: 810 bytes transmitted in 125 µs $\rightarrow$ 51.84 Mbps

<table>
<thead>
<tr>
<th>A1</th>
<th>A2</th>
<th>C1</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>E1</td>
<td>F1</td>
</tr>
<tr>
<td>D1</td>
<td>D2</td>
<td>D3</td>
</tr>
<tr>
<td>H1</td>
<td>H2</td>
<td>H3</td>
</tr>
<tr>
<td>B2</td>
<td>K1</td>
<td>K2</td>
</tr>
<tr>
<td>D4</td>
<td>D5</td>
<td>D6</td>
</tr>
<tr>
<td>D7</td>
<td>D8</td>
<td>D9</td>
</tr>
<tr>
<td>D10</td>
<td>D11</td>
<td>D12</td>
</tr>
<tr>
<td>Z1</td>
<td>Z2</td>
<td>E2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>J1</th>
</tr>
</thead>
<tbody>
<tr>
<td>B3</td>
</tr>
<tr>
<td>C2</td>
</tr>
<tr>
<td>G1</td>
</tr>
<tr>
<td>D5</td>
</tr>
<tr>
<td>D8</td>
</tr>
<tr>
<td>D11</td>
</tr>
<tr>
<td>Z2</td>
</tr>
<tr>
<td>Z5</td>
</tr>
</tbody>
</table>

- **Section Overhead**: 9 octets
- **Line Overhead**: 3 octets
- **Path Overhead**: 87 octets

Synchronous Payload Environment (SPE) 87 octets
Frames

- In packet switching
  - Frame contains bytes of a single communication
  - Destination (source) identified in the header
  - Frames are transmitted asynchronously
    - Whenever there is data to transmit
    - Whenever link is free
  - Statistical multiplexing

- In circuit switching
  - Frame contains bytes of multiple communications
  - Destination (source) identified by the position
  - Frames are transmitted synchronously
    - Back-to-back
    - Independently of whether there is data to transmit
Packet-based multiplexing/switching

- If a source has no traffic, bandwidth is not wasted
  - Statistical multiplexing

  ![Diagram]

- The same network infrastructure can statistically accommodate more communications
  - Cost of communicating is lower
  - Service is not deterministic
Building packet switching on top of circuit switching

Use circuits through a circuit network to interconnect packet/frame switches/routers

<table>
<thead>
<tr>
<th>X.25</th>
<th>Frame Relay</th>
<th>SMDS</th>
<th>ATM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packet switching</td>
<td>Cell switching</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDH</td>
<td></td>
<td></td>
<td>SDH</td>
</tr>
</tbody>
</table>
Frame Relay
Frame Relay Network Architecture

Data Communication Equipment

DTE -> DCE

Frame Relay Network

DCE

Virtual Circuits

DCE

Data Terminal Equipment

DTE

DTE
Frame Relay standard

- Standard for DCE-DTE interfaces
  - Multiple logical connections through a single access link
  - Similarly to X.25
- Layer 2 only
  - Switches do not need to process 2 headers (layer 2 and layer 3) like in the previous X.25
  - X.25 does have a layer 3
Core-Edge Approach

- Error correction: re-transmission only at the network edge, not in the intermediate nodes (core)
- X.25 corrects errors at each hop
- Requires reliable links
- Takes advantage of fast links
- Small latency:
  - 2 ms per frame relay node
  - from 5 to 20 ms per X.25 node
Frame Relay applications

- Interconnection of Intermediate Systems (router, bridge, gateway) through WANs
  - All commercial devices offer FR interfaces
  - Physical layer is common (PDH)
  - Data-link layer is implemented in software

- It is possible to specify the bandwidth required by/provided to the customer

- Variable transit times
  - Problematic with voice/video transmission
CIR: Committed Information Rate

- $B_c$: committed burst size
  - Maximum burstiness
- $T_c = B_c / CIR$
  - Interval of time where CIR is applied
  - It is possible to transmit up to $B_c$ bit at wire speed del collegamento fisico in each time interval $T_c$
Asynchronous Transfer Mode (ATM)
Enabling Factors

Protocol Architecture

Core & Edge Cells

System innovations

Asynchronous interconnection services

ATM

Enabling technologies

Fibre ottiche

VLSI (CMOS)
General features

- Switching of small, fixed length units: cells
  - 53 bytes
- Fast links (with low bit error rate)
  - $\geq 150$ Mb/s
- Low latency
  - Good for data, voice and video
- Can be deployed in both LAN and WAN
- Selected for implementing the B-ISDN
General features

- Sophisticated signaling:
  - Multiparty or point-to-point connections
- Sophisticated mechanisms for flow control
  - Sliding window is not efficient on long, fat pipes
- Dynamic bandwidth allocation
  - Bandwidth management
- Fine granularity in bandwidth allocation
- Support for “bursty” traffic
- Adaptability for applications that are sensible to time or data loss

Nothing else?!?!!
Virtual channels

4 Mbps (3 party conference)
50 Mbps (Image transfer)
ATM Switch
Cell switching

Cell = 53 bytes
Statistical multiplexing
ATM technology

Switch
ATM

Switch
ATM

Switch

BANDA

Switch
ATM cell

Header

Payload

UNI Cell

User Data
(48 octets)

HEC

VCI

VPI

GFC

VCI

PT

CLP

VPI

VCI

1

2

3

4

5

6

53
Terminology

- GFC: General Flow Control
- VPI: Virtual Path Identifier
- VCI: Virtual Channel Identifier
- PT: Payload Type
- CLP: Congestion Loss Priority
- HEC: Header Error Control
ATM

- Cells are transmitted back-to-back, possibly inserting empty ones
- Each cell carries an identifier of the circuit
  - VCI/VPI: Virtual Channel/Path Identifier
- Error correction:
  - *Core-edge approach as in frame relay*
- Flow control more sophisticated than sliding windows, to take into account:
  - Different types of traffic
  - The “memory” of the channel
ATM node

Look-up port #2

<table>
<thead>
<tr>
<th>Port</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>D</td>
</tr>
<tr>
<td>1</td>
<td>C</td>
</tr>
</tbody>
</table>

VCI/VPI changes each time an ATM switch is traversed
Core-Edge Principle

- Nodes execute only essential functions (switching and multiplexing) at ATM level (1-2 OSI stack)
- Additional functionalities for the different services are implemented at the edge

```
User terminal
    ↓
          |         
          |         
          |         
          |         
          |         
          |         
          |         
          |         
          ↓
ATM switch
    ↓
          |         
          |         
          |         
          |         
          |         
          |         
          |         
          |         
          ↓
ATM (core)
    ↓
          |         
          |         
          |         
          |         
          |         
          |         
          |         
          |         
          ↓
PHY
    ↓
          |         
          |         
          |         
          |         
          |         
          |         
          |         
          |         
          ↓
ATM
    ↓
          |         
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          ↓
PHY
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          ↓
Edge
    ↓
          |         
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          |         
          |         
          |         
          ↓
Upper layer protocols
```

Error control (only for some services and upon request)
B-ISDN Reference Model

- Management Plane
- Control Plane
- User Plane
- Higher Layer Protocols
- ATM Adaptation Layer (AAL)
- ATM Layer
- Physical Layer
AAL 5 Segmentation and Reassembly

USER BITS

0 to 65,000 Bytes

PAD

Ctrl/Length

CRC

4Bytes

SEGMENTATION

REASSEMBLY

L3-PDU

PAD

Ctrl/Length

CRC

0-47

4

4Bytes

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Copyright: see page 2
Example of an ATM network

Private NNI

Private ATM Network

Public ATM Network

Bridge / Router

Private UNI

Public UNI

Public NNI

Copyright: see page 2
ATM LAN Emulation

ATM Workstation

SWITCH ATM

BUS

LES

Access device

Server

Access device
ATM LAN Emulation

Access devices operate as bridges
IP over ATM: Classical model

- H1 needs to communicate with H2
  - Initially, H1 learns the A address
  - H1 sends an ARP-Request to A with H2-IP
  - A sends an ARP-Response with the address H2-ATM
  - H1 requests to the ATM network the connection with H2
IP over ATM: classical model

- H1 needs to communicate with H3
  - H1 sends an ARP-Request to A with R-IP
  - A sends an ARP-Response with the address R-ATM
  - H1 requests to the ATM net a connection with R and it sends the packet for H3
  - R sends an ARP-Request to B with H3-IP
  - B sends an ARP-Resp. with the address H3-ATM
  - R requests to the ATM net a connection with H3
IP over ATM: Next Hop Resolution Protocol

- H1 needs to communicate with H3
  - H1 sends an NHRP-Request to A with H3-IP
  - A forwards it to B
  - B sends an NHRP-Response to A, A forwards it to H1, con H3-ATM