Part III: Overview of Technologies, ATM, and IP

- **Overview of Networking Technologies**
  - Developments
  - High-speed Characteristics
  - Switching Techniques
- **ATM (Asynchronous Transfer Mode)**
  - Principles of Cell Switching
  - ATM Connection Management
  - ATM Layer and Adaptation Layer
- **IP (Internet Protocol)**
  - Key Elements
  - Protocol Stack

Networks

- Networks provide an **infrastructure** for:
  - Interconnecting machines or services (connectivity),
  - Making available scarce resources (resource sharing),
  - Equalizing traffic volumes (load balancing), and
  - Providing alternative fallbacks (reliability).

- Structuring networks according to **dimensions**:
  - Expansion (LAN, MAN, WAN),
  - Topology (star, ring, bus, meshed),
  - Performance (low-speed, high-speed, real-time),
  - Administration (public, private), and
  - Task (internet or physical net, intranet or virtual net).
Inventions in Telecommunications

- Oscillating needle telegraph experiments
- Early telegraphy (Morse code dots and dashes)
- Printing telegraph systems
- Baudot multiplex telegraph (6 machines on one line)
- First telephone channels constructed
- First carrier telephony
- Carrier telephony carries 12 voice channels on wire
- 60 voice channels over coaxial cable
- 1800 voice channels over cable and microwave
- 3600 voice channels over cable (T3) and microwave
- 600 voice channels over cable and microwave
- 108000 voice channels over cable and microwave
- Multimode optical fiber 16 Gbit/s
- Monomode optical fiber 565 Mbit/s
- Monomode optical fiber 140 Mbit/s
- Monomode optical fiber 45 Mbit/s
- Multimode optical fiber 2.5 Gbit/s
- Multimode optical fiber 1 Gbit/s
- Multimode optical fiber 400 Mbit/s
- Monomode optical fiber 10 Gbit/s
- Monomode optical fiber 1000 Mbit/s
- Monomode optical fiber 10 Gbit/s
- Multimode optical fiber 100 Mbit/s
- Multimode optical fiber 10 Gbit/s
- Monomode optical fiber 1000 Mbit/s
- Monomode optical fiber 1 Tbit/s
- Monomode optical fiber 10 Tbit/s
- Monomode optical fiber 100 Tbit/s
- Monomode optical fiber 1 Pbit/s
- Monomode optical fiber 1 Ebit/s
- Monomode optical fiber 1 Zbit/s

Transmission Media

- Fiber optical media:
  - Low error rates, long distances, low attenuation.
Last Mile Problem:
- Connection between the home and the backbone is serious.
- Requires a huge capital investment.
- Fiber ignores the last mile problem.

Evolution of Bandwidth

<table>
<thead>
<tr>
<th>Time [year]</th>
<th>LAN</th>
<th>WAN</th>
<th>POTS</th>
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<tr>
<td>1975</td>
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<td>1980</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>LAN</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

High Speed Networks – Overview (1)

- High Speed Local Area Networks (LAN):
  - Fast Ethernet: 100 Mbit/s
  - Gigabit Ethernet: 1.0 Gbit/s
  - HIPPI: 800 Mbit/s
  - Fiber Channel: 100, 200, 400, or 800 Mbit/s
  - High Speed Token Ring: 100 Mbit/s (1 Gbit/s)

- High Speed Metropolitan Area Networks (MAN):
  - FDDI: 100 Mbit/s
  - FDDI-II: 100 Mbit/s (incl. isochronous channels)
  - DQDB: 34 Mbit/s, 155 Mbit/s, or 622 Mbit/s

- High Speed Wide Area Networks (WAN):
  - ATM-based B-ISDN: e.g., 2, 34, 155, 622, or 2,400 Mbit/s
High Speed Networks – Overview (2)

- Carrier support (physical layer):
  - Plesiochronous Digital Hierarchy (PDH):
    - e.g., DS-0: 0.064 Mbit/s (= 1 voice channel)
    - T-1 (USA): 1.544 Mbit/s (= 24 voice channels) (also called DS-1)
    - E-1 (Europe): 2.048 Mbit/s
    - E-3 (Europe): 34.368 Mbit/s
    - T-3 (USA): 44.736 Mbit/s (also called DS-3)
  - Synchronous Digital Hierarchy (SDH) or Synchronous Optical Network (SONET):
    - e.g., STS/OC-1: 51.84 MBit/s
    - STS/OC-3: 155.52 MBit/s (= STM-1)

High Speed Networks – Overview (3)

- Carrier support (physical layer) continued:
  - Wavelength Division Multiplexing (WDM)

- Access technologies:
  - Cable TV
  - Frame Relay (FR)
  - xDSL (Digital Subscriber Line)
  - Satellite networks and wireless local loop

- Service technologies:
  - Switched Multimegabit Data Service (SMDS)
Network Dimensions

Transmission rate [Mbit/s]

- HSTR, Fast Ethernet, xDSL
- Local Area Network ≈ 1995
- Metropolitan Area Network ≈ 1995
- Token Ring Ethernet
- Ethernet
- FDDI, DQDB, CRMA
- X.25, N-ISDN
- STM, SDN
- ATM LAN

Distance [km]

10⁻³ 10⁻² 10⁻¹ 10⁰ 10¹ 10² 10³ 10⁴

ATM: Asynchronous Transfer Mode
HDLC: High Data Link Control
IP: Internet Protocol
PPP: Point-to-Point Protocol
WDM: Wavelength Division Multiplexing
Characteristics of High Speed Networks

- Low bit error rate (fiber optical media),
- Higher packet error rate (buffer overflow),
- Existing Jitter (different buffer lengths),
- Small transmission units (cells),
- Many connections (context data),
- High bandwidth (fiber optical media), and
- Extreme bandwidth-delay product.

Protocols have to deal with these issues to alleviate influences of delayed, corrupted, or lost data.

File Transfer Example

- File size: 1 Mbyte
- Link: San Diego – Boston
- Signal delay: 25 ms

- 64 kbit/s channel:
  - 64 kbit/s * 25 ms = 1,600 bit
  - 0.02 % of file on link

- 2 Mbit/s channel:
  - 2 Mbit/s * 25 ms = 50,000 bit
  - 0.6 % of file on link

- 1 Gbit/s channel:
  - 1 Gbit/s * 25 ms = 25,000,000 bit
  - 8 ms for transmission, 17 ms idle

Bits are smaller – not faster!
Effects on Data in Transit

- **Signal delay** is dominating the transmission delay.
  - This grows worse for high transmission rates.
- **Buffer overflows** dominate occurring errors.
  - The effect grows worse for fast and real-time traffic.
- **Error recovery** has to be a trade-off between a waste of bandwidth or extending delays.
  - Bandwidth is much cheaper than tolerating high delays.
  - Multimedia applications normally don’t like delays.

A huge amount of data is in transit within high speed and long distance networks

\[
P_C = B \times D_{signal}
\]

\(B\): Bandwidth, \(D_{signal}\): Signal delay.

Switching Techniques – Overview

- **Switching Techniques:**
  - Based on circuits, cells, frames, or packets.

  - **Circuit Switching (STM)**: Fixed Behavior of Bandwidth
  - **Fast Circuit Switching**: Variable Behavior of Bandwidth
  - **Packet Switching**: Intricacy
  - **Fast Packet Switching**: Intricacy
  - **Frame Switching**: Intricacy
  - **Frame Relay**: Intricacy

- Circuit switching suffers from fixed bandwidth constraints for bursty traffic.
- Packet switching allows for variable bandwidth.
Circuit Switching

- Circuit information are stored during establishment times in a translation table.
  - Delay is determined by the propagation delay and the processing in switches.
  - Bounded to 450µs by ITU-T.
  - Bit error rates are caused by single bit errors (switching malfunction) or bursts (loss of synchronization).

- Inflexible, e.g., G.703 PCM.
  - Fixed bandwidth.

<table>
<thead>
<tr>
<th>Incoming Link</th>
<th>Time Slot</th>
<th>Outgoing Link</th>
<th>Time Slot</th>
</tr>
</thead>
<tbody>
<tr>
<td>$l_1$</td>
<td>1</td>
<td>$o_3$</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>$o_2$</td>
<td>2</td>
</tr>
<tr>
<td>...</td>
<td>m</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>$l_2$</td>
<td>1</td>
<td>$o_1$</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>$o_2$</td>
<td>2</td>
</tr>
<tr>
<td>...</td>
<td>m</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>$l_m$</td>
<td>1</td>
<td>$o_1$</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>$o_2$</td>
<td>m</td>
</tr>
<tr>
<td>...</td>
<td>m</td>
<td>...</td>
<td>1</td>
</tr>
</tbody>
</table>

Packet Switching

- Based on user data that are encapsulated in packets.
- Concept is based on technology available in the 60s:
  - Erroneous links:
    - Link-based error control in complex protocols.
  - Low bandwidth links:
    - High delays (due to retransmissions) and low speed (due to protocol processing)
    - Lacking support of real-time and multimedia traffic
  - Software-based protocol implementations:
    - Variable sized packets require a complex buffering.

- X.25 is the oldest example of packet switching nets.
Frame Relay (1)

- Frame Relay supports connection-oriented services.
- **Subscriber Network Interface** (SNI) defined between customer (router) and PTO equipment.
  - Support of pure data, not particularly voice etc.
  - Multiplexes flows of data being divided in data blocks.
  - Flows are carried in virtual channels which may exceed their bandwidth as other channels are idle.
  - Frame Relay may carry X.25 packets/frames.
- **Performance**:
  - Different implementation approaches exist, however, 2 Mbit/s access speeds are common.
  - Insufficient guarantees on bandwidth and delay variation.

Frame Relay (2)

- **Physical and data link layer** specifications available.
- The data link layer is based on LAPD (ISDN):
  - Data link services: addressing (DLCI, local significance).
  - Error control is left out as an end-to-end function.
  - Core LAPD frame:
    - Byte 1: Flag, Address
    - Byte 2: Payload, FCS
    - Byte 3: Flag
    - Byte 4: DLCI, C/R, EA
    - Byte 5: DLCI, FECN, BECN, DE, EA
    - Bit 6: Data Link Connection Identifier
    - C/R: not used
    - EA: Extended Address
    - FECN: Forward Error Congestion Notification
    - BECN: Backward Error Congestion Notification
    - DE: Discard Eligibility
Frame Relay (3)

Frame Relay DLCI assignments:
- 0: Reserved for Call Control Signaling
- 1-15: Reserved
- 16-1007: Assigned to Permanent Virtual Circuits (PVC)
- 1008-1022: Reserved
- 1023: Local Management Interface

A simple sample Frame Relay network:

User A

16, 145, 1007: DLCI

User B

User C

Permanen Virtual Circuits

Comparison

Comparison of important functional differences:

<table>
<thead>
<tr>
<th>Feature</th>
<th>X.25</th>
<th>Frame Switching</th>
<th>Frame Relay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connection-oriented</td>
<td>☑</td>
<td>☑ or ☑</td>
<td>☑</td>
</tr>
<tr>
<td>Connectionless</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
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<tr>
<td>Frame Boundaries</td>
<td>☑</td>
<td>☑</td>
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<tr>
<td>Bit Stuffing</td>
<td>☑</td>
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<tr>
<td>CRC</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
</tr>
<tr>
<td>Error-Control ARQ</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
</tr>
<tr>
<td>Flow-Control</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
</tr>
<tr>
<td>Multiplexing of log. Channels</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
</tr>
</tbody>
</table>

Light weight

Technology

Heavy weight

CRC: Cyclic Redundancy Check
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Cell-based Switching

- Integration of a variety of services:
  - Bursts are smoothened.
  - Isochronous data are delivered according to their jitter.
  - Data may be multiplexed statistically, if the overall bandwidth is sufficient.
- Efficiency: statistical multiplexing gain.

- Delay problems occur in case of sending packets of different length. Extremely long blocking can be avoided, if cells of fixed-size are used. If the overall cell length is too big, a similar problem appears.
Handling Cells – Segmentation/Reassembly

- To sent packets over cell-based networks, packets have to be segmented and reassembled again.

- The segmentation and reassembly (SAR) functionality is placed right above the cell level.

Structure of an ATM-based B-ISDN Network

- ATM: Asynchronous Transfer Mode
- MM: Multimedia
- NNI: Network Node Interface
- UNI: User Network Interface
B-ISDN Reference Model – I.321

- Modeling communication systems is done in a logically hierarchical structure, *e.g.*, ISO/OSI BRM.
- Relation between OSI and B-ISDN/ATM undefined.
- The plane approach has been used within B-ISDN.

![B-ISDN Reference Model Diagram](image)

ATM Connections (1)

- Connections, links, ATM equipment, and identifiers:

```
```

VC: Virtual Channel, VP: Virtual Path, L: Link, I: Identifier, C: Connection
ATM Connections (2)

- **Hierarchical connection concept** includes:
  - **Virtual Connections** are identified by two identifiers, which are significant only locally per link in the virtual connection.
    - Error-control is done end-to-end only, if required.
    - High quality links and a good call acceptance control.
    - Flow-control is not provided.
    - High bandwidth delay product.
  - **Virtual Channel (VC)** is a uni-directional channel, identified by the Virtual Channel Identifier (VCI).
    - Dynamically allocatable connections.
  - **Virtual Path (VP)** contains a group of VCs, identified by the Virtual Path Identifier (VPI).
    - Statically allocatable connections.

ATM Connections (3)

- Simultaneous support of many thousands of VCs requires the ATM cell to carry the VCI field.
- Supporting many semi-permanent connections between endpoints, carrying many grouped VPs requires the ATM cell to carry the VPI field.

![Diagram of ATM connections with VPI and VCI identifiers]
ATM Switching (1)

- Two types of switching may be performed.
  - VP switching (ATM Cross-connect):
    - Switching between VPs,
    - No evaluation and change of VCIs,
    - Change of VPIs, and
    - Variable number of VCs per VP possible.
  - VC/VP switching (ATM Switch):
    - Switching in close cooperation between VCs and VPs,
    - Evaluation of VCI and VPI in an intermediate system,
    - Change of VCI and VPI if necessary, and
    - Incoming VCs of one VP may be distributed between many outgoing VPs.

ATM Switching (2)

- Use of VPI in a B-ISDN network (cross-connect).
ATM Switching (3)

- Use of VPI-VCI in a B-ISDN network (ATM switch).

<table>
<thead>
<tr>
<th>VPI-VCI_{in}</th>
<th>VPI-VCI_{out}</th>
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<tbody>
<tr>
<td>7.1</td>
<td>5.1</td>
</tr>
<tr>
<td>7.2</td>
<td>7.3</td>
</tr>
<tr>
<td>7.3</td>
<td>7.4</td>
</tr>
<tr>
<td>9.3</td>
<td>5.3</td>
</tr>
</tbody>
</table>

VPI-VCI = VCI = 1, 2, 3

ATM Switching Diagram:

- ATM
- PHY
- B-ISDN Network

- VPI = 7
- VCI = 1, 2, 3

ATM Layer – UNI Cell Format

- **GFC**: Generic Flow-Control used at the service interface.
- **PT**: Payload Type defines contents of a cell:
  - User data congested,
  - User data non-congested,
  - Operation And Maintenance (OAM) cells, and
  - Resource management cells.
- **CLP**: Cell Loss Priority to identify low/high priority cells.
- **HEC**: Header Error Control.

ATM Layer Cell Format:

<table>
<thead>
<tr>
<th>Byte</th>
<th>Header</th>
<th>Payload</th>
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<tbody>
<tr>
<td>1</td>
<td>GFC</td>
<td>VPI</td>
</tr>
<tr>
<td>2</td>
<td>VCI</td>
<td>PT</td>
</tr>
<tr>
<td>3</td>
<td>CLP</td>
<td></td>
</tr>
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<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
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</tbody>
</table>

UNI: User-Network Interface
ATM Layer – NNI Cell Format

- **VPI**: Virtual Path Identifier comprises of 12 bit length.
- **PT**: Payload Type defines contents of a cell:
  - User data congested,
  - User data non-congested,
  - Operation And Maintenance (OAM) cells, and
  - Resource management cells.
- **CLP**: Cell Loss Priority to identify low/high priority cells.
- **HEC**: Header Error Control.

<table>
<thead>
<tr>
<th>Byte</th>
<th>VPI</th>
<th>VCI</th>
<th>PT</th>
<th>CLP</th>
<th>HEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>5</td>
<td></td>
<td></td>
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</table>

Structure of the AAL

- **AAL** includes sublayers:
  - Segmentation and Reassembly (SAR) between packets/cells.
  - Convergence sublayer (CS) for service-dependent adaptation:
    - Common Part Convergence Sublayer (CPCS) and
    - Service Specific Convergence Sublayer (SSCS).
  - Layers may be empty.
AAL Comparison

<table>
<thead>
<tr>
<th>Criteria</th>
<th>AAL 1</th>
<th>AAL 2</th>
<th>AAL 3/4</th>
<th>AAL 5</th>
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<tbody>
<tr>
<td>AAL Service Class</td>
<td>A</td>
<td>B</td>
<td>C/D</td>
<td>C/D</td>
</tr>
<tr>
<td>Message Delimiter</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>no</td>
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<tr>
<td>Advanced Buffer Allocation</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Multiplexing</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>CS Padding</td>
<td>0</td>
<td>0/46 Byte</td>
<td>4 Byte</td>
<td>0/47 Byte</td>
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<td>0</td>
<td>2 Byte</td>
<td>8 Byte</td>
<td>8 Byte</td>
</tr>
<tr>
<td>CS Checksum</td>
<td>no</td>
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<td>no</td>
<td>32 bit</td>
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<tr>
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<td>3 Byte</td>
<td>4 Byte</td>
<td>48 Byte</td>
</tr>
<tr>
<td>SAR Protocol Overhead</td>
<td>no</td>
<td>no</td>
<td>10 bit</td>
<td>no</td>
</tr>
<tr>
<td>SAR Checksum</td>
<td>46/47 Byte</td>
<td>1/47 Byte</td>
<td>44 Byte</td>
<td>0</td>
</tr>
</tbody>
</table>

PTI: Payload Type Information

ATM Functions per Layer – Summary

<table>
<thead>
<tr>
<th>Layer</th>
<th>Subl.</th>
<th>Function</th>
</tr>
</thead>
</table>
| AAL   | CS    | Handles transmission errors  
|       |       | Handles lost and misinserted cell conditions  
|       |       | Handles timing between source and destination  
|       |       | Handles cell delay variation |
| SAR   |     | Segments higher-layer information into 48 Byte fields  
|       |     | Reassembles cell payload in higher layer information |
| ATM   |     | Multiplexes cells from different ATM channels  
|       |     | Generates cell header (first four bytes)  
|       |     | Performs payload type discrimination  
|       |     | Performs traffic shaping and flow control  
|       |     | Routes and switches cells as needed  
|       |     | Indicates cell loss priority and selects cells for discarding |
| PHY   | TC    | HEC header sequence generation and verification  
|       |       | Cell delineation  
|       |       | Transmission frame generation and recovery |
|       | PM    | Bit timing |
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IP Technology

- Key elements of the technology used in the Internet:
  - Packet switching, using datagrams
  - No connection-dependent state information in the network
  - Distributed management
  - Many physical subnetwork technologies
  - One network protocol
  - Two transport protocols
  - Infrastructure for hundreds of different distributed applications
  - Scalability: to accommodate exponential growth
IP Protocol Stack

- **Application layer**: HTTP, FTP, DNS
- **Transport layer**: TCP, UDP
- **Internet layer**: IP, Routing
- **Phys. Network layer**: Ethernet, ATM, DECnet

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**Internet Protocol (IP)**

- **IPv4 shows addressing problems**:
  - Nearly exhausted Class B addresses. Classless Inter-domain Routing (CIDR) provides short-term solution only.
  - Routing tables grow extremely fast.
  - IP unicast address space will run out due to rapidly, *e.g.*, increasing Internet hosts and low-end Internet devices.

- **Next Generation Internet, IPv6, delivers solutions**:
  - Extended addressing: 128 bit addresses.
  - Address hierarchy levels (hierarchy: subscriber, subnet, ...)
  - Anycast addresses to reach the “nearest” node of a group (in terms of the routing metric).
  - Simplified IP header, including a flow label.
Internet Network Model

ISP: Internet Service Provider
SOHO: Small Office and Home

Large Enterprise
Regional ISP B
International ISP “Backbone”

Example – Backbone ISP: UUNET

http://www.caida.org/Tools/Mapnet/Backbones/
Example – Regional ISP: Switch

http://www.switch.ch

Switch – UUNET Interconnection

http://www.switch.ch
Co-location Model

- Extensions broaden the model by other services:
  - More than a pure routing and traffic exchange role.
  - Content provider supported, e.g., with high volumes, selection of non-local transit providers.
  - E.g., Multicast, Web, DNS, policy-based route services.

Services Integrated Internet

<table>
<thead>
<tr>
<th></th>
<th>Best-effort</th>
<th>IntServ</th>
<th>DiffServ</th>
</tr>
</thead>
<tbody>
<tr>
<td>QoS Guarantees</td>
<td>no</td>
<td>per data stream</td>
<td>aggregated</td>
</tr>
<tr>
<td>Zone</td>
<td>entire</td>
<td>per session</td>
<td>log-term (static)</td>
</tr>
<tr>
<td>Information</td>
<td>none</td>
<td>end-to-end data stream</td>
<td>domain-oriented</td>
</tr>
<tr>
<td>Protocol</td>
<td>none</td>
<td>per data stream, in router</td>
<td>(none, in BB, in edge router)</td>
</tr>
<tr>
<td>Status</td>
<td>operational</td>
<td>signaling (RSVP)</td>
<td>bit fields (BB, COPS)</td>
</tr>
</tbody>
</table>

IntServ: Integrated Services, DiffServ: Differentiated Services, QoS: Quality-of-Service
IntServ Implementation

- Integrated Services Architecture (IntServ) supports best-effort and guaranteed services.
- Traffic control functions:
  - Admission control,
  - Packet classifier, and
  - Packet scheduler.
  - Optional: Policy control (COPS).
- Protocol support:
  - Resource reservation, E.g., RSVP (Resource Reservation Protocol).
- Host and router require similar functionality.

The DiffServ Approach

- Requirements for Differentiated Services proposals:
  - Aggregated bandwidth allocation without the need of per-session signaling and complex router state,
  - Aggregated QoS guarantees with edge-complexity,
  - Long-term service contracts within a single domain,
  - Integrated and simplified accounting,
  - Better traffic isolation for performance predictability, and
  - Better services for users willing to pay more.

- A set of new proposals for DiffServ:
  - Expedited Forwarding (EF) and
  - Assured Forwarding (AF).
References (1)

References (2)


