Asynchronous Transfer Mode (ATM)

- Background
- Physical and ATM Layers
- AALs
- Applications

ATM Quick Highlights

- The Telecom Industry’s thrust into multi-media data networking
- Comm unit is small, fixed-sized “cell” (53 bytes)
- Built to provide Quality-of-service
- Connection-oriented
- Designed to run over SONET/SDH

ATM History

- 1980: ISDN
- 1985: B-ISDN Study Group
  - ITU chooses ATM approach B-ISDN
- 1990: ATM Forum founded
- 1995: Anchorage Accord Stabilizes Specifications
- 2000:

The B-ISDN ATM Reference Model

- Plane Management
- Layer Management
- Data Transfer
- User and Control
- Packets
- Cells, VC's
- Physical Medium

Convergence Sublayer
Segmentation and Reassembly Sublayer
Transmission Convergence Sublayer (Framing)
Physical Medium Dependent Sublayer
Why?

- Why a small cell instead of a large packet?
  - Queue delays tend to grow as packet size grows. A small cell helps maintain streamlined flows.
  - No/little performance loss due to padding large fields
  - Small cells better for voice
  - No need for in-route fragmentation

Why?

- Why a fixed cell size instead of variable-size packets?
  - Switch architecture can be optimized to the fixed size, so switching can be done in hardware
  - Scalable parallel switch designs

Why?

- Why 53 bytes?
  - US wanted 64 payload bytes, Europe wanted 32
  - Compromised on 48
  - +5 header = 53

Why?

- Why start out with 9% Overhead?
  - Overhead isn’t everything...
  - Ethernet / SS10: 9 Mb/s BW, 900 μsec overhead
  - ATM Synoptics: 7.8 Mb/s BW, 1.250 μsec overhead.
  - NFS trace over 1 week: 95% mins < 200 bytes
ATM + and –

+ OoS
  + Multimedia Support
  + Hardware Switching -> High Speed
  + Connection-Oriented (-?)

- IP Support
  + LAN arena dominated by huge installed Ethernet base
  + Ethernet growing toward MAN, WAN
  + Connection-Oriented (+?)
  + Living up to the hype of the early 90’s

ATM Architecture

ATM

- Physical and ATM Layers
  - Background
  - Physical and ATM Layers
    - Cells, Formats, and Addressing
    - Virtual Circuits
    - Switches and Media
    - Interfaces
  - AALs
  - Applications

Cell Format

- Header
  + UNI Header
    - GFC
    - VPI
    - VCI
    - PTI
    - HEC
  + NNI Header
    - VPI
    - VCI
    - PTI
    - HEC

- Payload
**Header Error Control (HEC)**

HEC covers the header only, not the payload -- the goal is to ensure correct delivery.

- **First Four Cell Header Bytes**

\[ x^3 + x + 1 \]

- **Remainder**

\[ 01010101 \]

If \( P(\text{bit error}) = 10^{-9} \), then \( P(\text{Undetected header error}) = 10^{-90} \)

at OC-3, about 1 per 90,000 yrs

HEC also assists in synchronizing:
- Look at 53-byte sequences until you find one where the HEC field works correctly
- If this holds up for 0 sequences in a row, assume you’ve synched
- \( p(\text{bad synch}) = 2^{-30} \)

**UNI Header Fields**

- **GFC** - General Flow Control
  - Only used between host and network. Overwritten by first switch
- **VPI** - Virtual Path ID
- **VCI** - Virtual Circuit ID
- **PTI** - Payload type ID
- **CLP** - Cell Priority (ID’s cells for deletion when congestion experienced)
- **HEC** - Header Checksum (all 1-bit errors corrected, 90% of multi-bit errors detected)

**NNI Header Fields**

- **VPI** - Virtual Path ID
- **VCI** - Virtual Circuit ID
- **PTI** - Payload type ID
- **CLP** - Cell Priority (used to ID cells for deletion when congestion experienced)
- **HEC** - Header Checksum (all 1-bit errors corrected, 90% of multi-bit errors detected)

**PTI Field Codes**

- **000** - User Data Cell Type 0 - No congestion experienced
- **001** - User Data Cell Type 1 - No congestion experienced
- **010** - User Data Cell Type 0 - Congestion experienced
- **011** - User Data Cell Type 1 - Congestion experienced
- **100** - Maintenance info between adjacent switches
- **101** - Maintenance info between source and destination switches
- **110** - Resource management cell (for ABR congestion control)
- **111** - Reserved

**Explicit Forward Congestion Indicator (EFCI)**

Set by Congested switch

Used by AAL5 to denote end of message
ATM Addressing

E.164: Telephone Numbers - up to 15 digits
ATM End-System Addresses (AESAs) – 20-byte Addresses

<table>
<thead>
<tr>
<th>Address</th>
<th>US Code</th>
<th>Formal Indicator</th>
<th>Org. ID</th>
<th>Specified by Organization</th>
<th>Sub-address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Org. ID</td>
<td>840F</td>
<td>Specified by Organization</td>
<td>80</td>
<td>809134.0001</td>
<td>01</td>
</tr>
<tr>
<td>Example</td>
<td>Format</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Address Aggregation (Hierarchical Routing)

- 39.840F.80.809134.0001
- 39.840F.80.809134.0001.01
- 39.840F.80.809134.0001.0F
- 39.840F.80.809134.0001.0F.01
- 39.840F.80.809134.0001.0F.02

Example of Addressing:
- BigCorp, Inc.
- Plant 1
- Plant 15
- Bldg 2
- Bldg 1

Virtual Circuits

- Normally Unicast, but one-way Multicasting Supported
- Unidirectional, but a pair can be created with same ID – effectively full-duplex
- Customers can lease a VP, then allocate VC’s within it ("Permanent VP")
- Types of VC’s:
  - Standard VC ("PVC") – Static route
  - Soft VC – Route can be changed in event of failure
  - Signalled VC ("SVC") – Demand connection initiated by user
### VC Connection

<table>
<thead>
<tr>
<th>Message</th>
<th>Meaning (if from host)</th>
<th>Meaning (if from Network)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SETUP</td>
<td>Call request</td>
<td>Incoming call</td>
</tr>
<tr>
<td>CALL PROCEEDING</td>
<td>ACK Incoming call</td>
<td>ACK Call request</td>
</tr>
<tr>
<td>CONNECT</td>
<td>Incoming call accepted</td>
<td>Call request accepted</td>
</tr>
<tr>
<td>CONNECT ACK</td>
<td>ACK Call request accepted</td>
<td>ACK incoming call accepted</td>
</tr>
<tr>
<td>RELEASE</td>
<td>Terminate request</td>
<td>Terminate req from remote</td>
</tr>
<tr>
<td>RELEASE COMPLETE</td>
<td>ACK Terminate from remote</td>
<td>ACK terminate request</td>
</tr>
</tbody>
</table>

### Virtual Circuit Setup Process

- Source Host
- Switch 1
- Switch 2
- Destination Host

### ATM Broadcasting /Multicasting

- Cells to be Broadcast
- Destinations

### Operation Administration and Maintenance (OA&M)

- Supervision, Maintenance, Testing, Performance Measurement, Loopbacks
- Organized into levels according to Network Segment Type
### Preassigned VPI and VCI Numbers

<table>
<thead>
<tr>
<th>VPI</th>
<th>VCI</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Unassigned</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>Metasignaling</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>F4 Flow (segment)</td>
</tr>
<tr>
<td>0</td>
<td>4</td>
<td>F4 Flow (end-to-end)</td>
</tr>
<tr>
<td>0</td>
<td>5</td>
<td>Signaling</td>
</tr>
<tr>
<td>0</td>
<td>15</td>
<td>SMDS</td>
</tr>
<tr>
<td>0</td>
<td>16</td>
<td>Intermediate Layer Management Interface (ILMI)</td>
</tr>
</tbody>
</table>

### Switch Operation

#### Switching Table

<table>
<thead>
<tr>
<th>IN Port</th>
<th>OUT Port</th>
<th>Label Switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

### Transmission Media

- Baseline is SONET (B-ISDN)
- Short runs, Cat 5 TP OK
- All runs point-to-point
**SONET / SDH**

- **Bell:** Synchronous Optical Network (SONET)
- **CCITT:** Synchronous Digital Hierarchy (SDH)

- Only minor differences

**SONET Multiplexing**

- Synchronous, frame-oriented, TDM
- For basic SONET:
  - 6480 bits/125µsec = 51.84 Mbps total ("STS-1")
  - User data rate =~ 50Mbps

**SONET/SDH Data Rates**

<table>
<thead>
<tr>
<th>SONET</th>
<th>SDH</th>
<th>Data Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric</td>
<td>Optical</td>
<td>Gross</td>
</tr>
<tr>
<td>STS-1</td>
<td>OC-1</td>
<td>51.84</td>
</tr>
<tr>
<td>STS-3</td>
<td>OC-3</td>
<td>155.52</td>
</tr>
<tr>
<td>STS-9</td>
<td>OC-9</td>
<td>466.96</td>
</tr>
<tr>
<td>STS-12</td>
<td>OC-12</td>
<td>994.08</td>
</tr>
<tr>
<td>STS-18</td>
<td>OC-18</td>
<td>3288.32</td>
</tr>
<tr>
<td>STS-24</td>
<td>OC-24</td>
<td>7166.40</td>
</tr>
<tr>
<td>STS-36</td>
<td>OC-36</td>
<td>11886.24</td>
</tr>
<tr>
<td>STS-48</td>
<td>OC-48</td>
<td>24688.32</td>
</tr>
</tbody>
</table>

- "OC-n" means multiple users, muxed
- "OC-nI" means one user – slightly higher User B/W

**ATM over SONET**

- ATM designed to run over SONET OC-3c
- Basic: 155.52 Mbps gross rate
  - Usually quoted as 155 Mbps
- New generation runs at OC-12 (622 Mbps), OC-48 (2.4 Gbps)
ATM - Physical and ATM Layers

- Background
- Physical and ATM Layers
  - Cells, Formats, and Addressing
  - Virtual Circuits
  - Switches and Media
  - Interfaces
- AALs
- Applications

ATM Interfaces

- Broadband Inter-Carrier Interface (B-ICI)
  - Public Network-to-Network Interface
  - Based on Broadband ISDN User-Part (B-ISUP) messages

NNI

- Switch-to-switch interface protocol
- Two versions: Public and private (similar, more flexibility in private version)
- NNI Includes:
  - Routing protocol (Link-sate/OSPF)
  - Signaling protocol for link setup/teardown
**UNI**

- Protocol for interfacing with user equipment
- Follows ITU-T Q.2931 message format

**DXI**

- "Frames In, Cells Out"
- Provides Frame-Based Access to an ATM Network

**DXI Variants**

<table>
<thead>
<tr>
<th>Mode</th>
<th>AALs Supported</th>
<th>VCs Supported</th>
<th>Flag Header</th>
<th>Body</th>
<th>FCS</th>
<th>Flag</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>AAL5</td>
<td>1023</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>1b</td>
<td>AAL5,3/4</td>
<td>1023,1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>AAL3/4,5</td>
<td>16.6M</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**ATM**

- Background
- Physical and ATM Layers
- AALs
  - AAL Overview
  - AAL 1 and 2
  - AAL 3/4
  - AAL 5
- Applications
Why AAL?

An “impedance matcher” between ATM and higher-level protocols with variable-length cells

The Evolution Of the AAL’s

Original Service Classes

A Real-time Constant Bit Rate Connection-Oriented
B Real-time Variable Bit Rate Connection-Oriented
C Non-real-time Variable Bit Rate Connection-Oriented
D Non-real-time Variable Bit Rate Connectionless

AAL1
AAL2
AAL3
AAL3/4
AAL4
AAL5

Cell Formation

ATM

• Background
• Physical and ATM Layers
• AALs
  • AAL Overview
  • AAL 1 and 2
  • AAL 3/4
  • AAL 5
• Applications
**AAL 1**

- Designed to support Class A traffic (voice)
- Voice has good error tolerance -> No bit error control (CRC) needed
- Sequence numbers needed to ID missing cells

**AAL 1 Convergence Sublayer**

- Detects lost cells
- Detects mis-delivered ("misinserted") cells
- Smooths incoming traffic to minimize jitter
- Breaks bit stream into 47/46-byte segments for SAR sublayer
- Does not add headers or trailers

---

**AAL 1 SAR PDU (non-pointer type)**

- Adds sequence # with protection (checksum)
- Adds parity bit (even) over header

**AAL 1 SAR PDU (Pointer Type)**

- Pointer field gives offset to start of next message (0-92 bytes)
AAL 2
- Designed to support Variable Bit Rate ("Bandwidth on Demand")
- Provides for partial payloads to support low-rate data with low latency
- Error protection over full PDU
- Simple flag to indicate position in message

AAL 2 SAR PDU
- [Diagram]

ATM
- AAL Layer

ATM
- Background
- Physical and ATM Layers
- AALs
  - AAL Overview
  - AAL 1 and 2
  - AAL 3/4
  - AAL 5
- Applications

AAL 3/4
- Originally 2 separate AALs:
  - AAL3: Connection-oriented packet svcs (X.25)
  - AAL4: Connectionless svcs (IP)
- Eventually combined into a single type for all data service
- Data support overtaken by AAL5
AAL3/4 CS PDU

<table>
<thead>
<tr>
<th>bytes</th>
<th>1</th>
<th>1</th>
<th>2</th>
<th>1 to 65535</th>
<th>8 to 3</th>
<th>1</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Btag</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BA Size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Payload</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pad</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Etag</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **CPI**: Common Part Indicator - Message type, Units for BA Size and Length
- **Btag**: Identical sentinel bytes, Incremented for each new message
- **BA Size**: Estimated payload size (for buffer allocation)
- **Pad**: Bytes added to make Payload a multiple of 4 bytes
- **Length**: True payload size

AAL3/4 SAR PDU

<table>
<thead>
<tr>
<th>bytes</th>
<th>1</th>
<th>1</th>
<th>2</th>
<th>44 bytes</th>
<th>1</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cell Seq #</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muxing ID</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Payload Length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **ST**: Segment Type
  - Indicates if this cell is from the middle (00), end (01) or beginning (10) of this message or if this is a single-cell message (11)
- **Muxing ID**: ID of the session that this cell belongs to (the CS may be handling multiple sessions simultaneously)

ATM - AAL Layer

- **AAL5**
  - Pushed by computer industry as a lower-overhead data format
  - The idea: Instead of using some of the 48-byte cell payload for SAR info, steal a bit from the cell to denote end of message

<table>
<thead>
<tr>
<th>Efficiency:</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAL3/4: 4 bytes per message + 4 bytes per cell =&gt; 44 User Data Bytes / Cell</td>
</tr>
<tr>
<td>AAL5: 8 bytes per message =&gt; 48 User Data Bytes / Cell, 8% improvement</td>
</tr>
</tbody>
</table>

AAL Overview
- AAL 1 and 2
- AAL 3/4
- AAL 5

Applications

Chart © Glenn W Cox, 2001-2004
AAL5 CS PDU

- Payload
- Pad
- UU
- Length
- CRC

1 to 65535 bytes
0 to 47
1
1
2
4

- Pad: Inserted to make entire CS PDU a multiple of 48 bytes
- UU: "User-to-User" field. Available for use by higher levels.
- Length: Payload length, not counting padding

AAL5 SAR

- Simply breaks CS PDU into 48-byte chunks and passes them to ATM Layer.
- No overhead bytes added.

ATM - AAL Layer

ATM - Applications

- Background
- Physical and ATM Layers
- AALs
- Applications
  - QoS
  - LANE
  - IP over ATM, MPOA

ATM QoS

- A (The?) Major ATM selling point vs. Best-Effort
- The idea:
  - At VC setup, sender specifies level and quality of service required, also planned traffic profile.
  - While establishing VC, network attempts to allocate resources to meet requirements.
  - Requirements are agreed to or available capability is passed back to sender.
  - During transmission, network enforces traffic profile
**ATM Classes of Service**

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
<th>CCA-C Cell Rate</th>
<th>CTA-C Cell Transfer Delay</th>
<th>SCR-C Sustained Cell Rate</th>
<th>DCR-C Drop Cell Rate</th>
<th>PCR-C Peak Cell Rate</th>
<th>VBR-T Variable Bit Rate, Real-Time</th>
<th>VBR-NRT Variable Bit Rate, Non-Real-Time</th>
<th>ABR Available Bit Rate, File Transfer, Email</th>
<th>UBR Unspecified Bit Rate (e.g., TCP/IP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBR</td>
<td>Constant bit rate (e.g., Phone traffic)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>VBR-RT</td>
<td>Variable bit rate, Real-Time (e.g., Interactive Compressed Video)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>VBR-NRT</td>
<td>Variable bit rate, Non-Real-Time (e.g., Multimedia email)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>ABR</td>
<td>Available bit rate (e.g., File Transfer, Email)</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>UBR</td>
<td>Unspecified bit rate (e.g., TCP/IP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

**QoS Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCR - Peak Cell Rate</td>
<td>Max rate req'd</td>
</tr>
<tr>
<td>SCR - Sustained Cell Rate</td>
<td>Avg rate req'd</td>
</tr>
<tr>
<td>MCR - Minimum Cell Rate</td>
<td>Min acceptable rate (Used in ABR Service)</td>
</tr>
<tr>
<td>DCR - Cell Delay Variation Tolerance</td>
<td>Max acceptable jitter</td>
</tr>
<tr>
<td>SCR - Cell Loss Rate</td>
<td>Fraction of cells lost in rate</td>
</tr>
<tr>
<td>CTD - Cell Transfer Delay</td>
<td>Delivery time (mean and max)</td>
</tr>
<tr>
<td>SCR - Cell Delay Variation</td>
<td>Measured jitter</td>
</tr>
<tr>
<td>SCR - Cell Error Rate</td>
<td>Fraction with one or more errors</td>
</tr>
<tr>
<td>SECBR - Severely-Errored Cell Block Ratio</td>
<td>Fraction of &quot;M&quot;-cell blocks with &quot;N&quot; or more errored cells</td>
</tr>
<tr>
<td>DMR - Cell Misinsertion Rate</td>
<td>Fraction delivered to wrong destination</td>
</tr>
<tr>
<td>BT - Burst Tolerance</td>
<td>Max Burst that can be sent at Peak Rate</td>
</tr>
</tbody>
</table>

**Traffic Shaping**

Unregulated Cell Stream

```
| Target Mean | Max Burst |
```

*Leaky Bucket*

```
Max: Discard above Mean
Release at Regular Rate
```

Regulated Cell Stream

**Agenda**

- Background
- Physical and ATM Layers
- AALs
- Applications
  - QoS
  - LANE
  - IP over ATM, MPOA
**LANE – The Goal**

To Make Work Like

- Virtual Circuits
- No (easy) Broadcast
- Packet-Oriented (802)
- Broadcast as a Basic Function

**LANE Protocol Stack**

- Application
- ATM-LAN Bridge
- Media Access Control
- ATM
- Physical

**LANE -- Address Translation in the Virtual LAN**

The idea is to establish a VC to the host that a LAN packet would go to. We need a way to determine which host to set up the VC to.

In 802-series LAN, the ARP protocol is used to translate Network-Layer Address (e.g., IP) to MAC address. Network addresses are broadcast to all possible targets, the right one responds.

**Broadcast and Unknown Server (BUS)**

Provides Broadcast, Multicast Capability

Cells to be Broadcast

- LEC
- BUS
- LEC
ATM
- Background
- Physical and ATM Layers
- AALs
- Applications
  • QoS
  • LANE
  • IP over ATM, MPOA

Classical IP over ATM
• Could use LANE to implement ATM-IP interoperability, but may be too much overhead for large networks
• Defined by IETF (RFC 1577)
• The key is IP <-> ATM address resolution
  • ATM Address Resolution Protocol (ATMARP)
  • Inverse ATMARP (InATMARP)

IP over ATM
Connection Setup Process

MultiProtocol Over ATM (MPOA)
LANE supports a single legacy LAN format over ATM. MPOA extends this to multiple LAN types