Lecture 03
Chapter 11 – Asynchronous Transfer Mode

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Asynchronous Transfer Mode

One man had a vision of railways that would link all the mainline railroad termini. His name was Charles Pearson and, though born the son of an upholsterer, he became Solicitor to the city of London. There had previously been a plan for gaslit subway streets through which horse-drawn traffic could pass. This was rejected on the grounds that such sinister tunnels would become lurking places for thieves. Twenty years before his system was built, Pearson envisaged a line running through "a spacious archway," well-lit and well-ventilated.

His was a scheme for trains in a drain.

—King Solomon's Carpet,
Barbara Vine (Ruth Rendell)
Outline

- The Role of ATM
- Protocol Architecture
- ATM Logical Connections
- ATM Cells
- Transmission of ATM Cells
- ATM Service Categories
Learning Outcome

- Understand how the ATM protocol works
- Understand how ATM enables data transfer at high speeds
- Be aware of ATM services
The Role of ATM
The Role of Asynchronous Transfer Mode (ATM)

- ATM is a switching and multiplexing technology
- ATM uses fixed-length packets called cells
- connection-oriented (Virtual Circuits)
- performance of a circuit-switching network and the flexibility and efficiency of a packet-switching network
- supports data, voice, video
- ATM network makes reservations and preplans routes
- transmission based on priority and QoS
ATM

- ITU-T leading the development of standards
- ATM Forum ensures interoperability among private and public ATM implementations
- commonly used to implement WANs
- DSL uses ATM for multiplexing and switching
- used as a backbone in IP networks and Internet
ATM

- A streamlined packet transfer interface
- Similarities to packet switching and frame relay
  - Transfers data in discrete chunks
  - Supports multiple logical connections over a single physical interface
- ATM uses fixed sized packets called cells
- Minimal error and flow control capabilities
  - Reduces the overhead of processing ATM cells
  - Reduces the number of overhead bits required with each cell,
- ATM operate at high data rates
  - The data rates specified at the physical layer range from 25.6 Mbps to 622.08 Mbps.
  - Other data rates, both higher and lower, are possible.
Protocol Architecture
Protocol Architecture

**Physical Layer**
- Specifies how the signal is transmitted and encoded in a transmission medium.

**ATM Layer**
- Defines the how data is transmitted in fixed-size cells and how of logical connections are used.

**ATM Adaptation Layer (AAL)**
- (1) maps data of higher-layer into ATM cells to be transported over an ATM network,
- (2) collects data from ATM cells for delivery to higher layers.
Reference Model Planes

- **user plane**
  - provides for user information transfer

- **control plane**
  - performs call and connection control

- **management plane**
  - plane (global) management
  - whole system management and coordination between all the planes
  - layer management
  - resources and parameters in protocol entities
ATM Network Interfaces

- switches are interconnected by point-to-point ATM links called **interfaces**
  
  - **user-network** interface (UNI)
  - **network node** interface (NNI)

- interface specification includes:
  
  - definition of link types allowed
  - addressing formats
  - cell format
  - control signaling protocols
ATM

Figure 11.3 ATM Interfaces

B-ICI = broadband intercarrier interface
NNI = network node interface
UNI = user network interface
ATM Logical Connections
ATM Logical Connections

- **virtual channel connections (VCC)**
  - analogous to virtual circuit in X.25

- **basic unit of switching between two end users**
  - variable rate
  - full duplex flow
  - fixed-size cells

- **VCCs also used for**
  - user-network exchange (control signaling)
  - network-network exchange (network management and routing)
ATM Connection Establishment

- Signaling request
- Connection routed—set up path
- Connection accepted/rejected
- Data flow—along same path
- Connection tear-down
ATM Virtual Path Connection

- Virtual Path Connection (VPC)
  - bundle of VCCs with same end points
- Why VPC is needed?
  - reduce the control cost by grouping connections sharing the same path
  - the management of a small number of groups of connections (paths) is easier than the management of a large number of connections
Advantages of Virtual Paths

Virtual paths have several advantages:

- Simplified network architecture
- Increased network performance and reliability
- Reduced processing and short connection setup time
- Enhanced network services: user groups definition
### Virtual Path/Virtual Channel Terminology

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>Virtual Channel (VC)</td>
<td>A generic term used to describe unidirectional transport of ATM cells associated by a common unique identifier value.</td>
</tr>
<tr>
<td>Virtual Channel Link</td>
<td>A means of unidirectional transport of ATM cells between a point where a VCI value is assigned and the point where that value is translated or terminated.</td>
</tr>
<tr>
<td>Virtual Channel Identifier (VCI)</td>
<td>A unique numerical tag that identifies a particular VC link for a given VPC.</td>
</tr>
<tr>
<td>Virtual Channel Connection (VCC)</td>
<td>A concatenation of VC links that extends between two points where ATM service users access the ATM layer. VCCs are provided for the purpose of user-user, user-network, or network-network information transfer. Cell sequence integrity is preserved for cells belonging to the same VCC.</td>
</tr>
<tr>
<td>Virtual Path</td>
<td>A generic term used to describe unidirectional transport of ATM cells belonging to virtual channels that are associated by a common unique identifier value.</td>
</tr>
<tr>
<td>Virtual Path Link</td>
<td>A group of VC links, identified by a common value of VPI, between a point where a VPI value is assigned and the point where that value is translated or terminated.</td>
</tr>
<tr>
<td>Virtual Path Identifier (VPI)</td>
<td>Identifies a particular VP link.</td>
</tr>
<tr>
<td>Virtual Path Connection (VPC)</td>
<td>A concatenation of VP links that extends between the point where the VCI values are assigned and the point where those values are translated or removed, i.e., extending the length of a bundle of VC links that share the same VPI. VPCs are provided for the purpose of user-user, user-network, or network-network information transfer.</td>
</tr>
</tbody>
</table>
Call Establishment Using VPs

- Virtual path connection set-up process is decoupled from the process of setting up an individual virtual channel connection.

- The virtual path control mechanisms include:
  - calculating routes,
  - allocating capacity, and
  - storing connection state information.

- To set up a virtual channel, there must first be a virtual path connection to the required destination node with sufficient available capacity to support the virtual channel, with the appropriate QoS.

- A virtual channel is set up by storing the required state information (virtual channel/virtual path mapping).
Virtual Channel Connection Uses

- **between end users**
  - carry end-to-end user data
  - carry control signaling
  - VPC provides a global capacity to end users
    - VCC organization is done by users

- **between end user and network**
  - user to network control signaling
  - VPC used to aggregate traffic (to network or server)

- **between network entities**
  - network traffic management
  - routing
Virtual Channel Characteristics

**Quality-of-Service (QoS)**

- A user of a VCC is provided with a QoS (e.g. cell loss ratio and cell delay variation (jitter)).

**Switched and semi-permanent channel connections**

- **Switched VCC (SVC)** is an on-demand connection: requires a call control signaling for setup and termination.
- **(Semi) Permanent VCC (PVC)** is a connection of long duration: it is set up by configuration or network management action.

**Cell sequence integrity**

- The sequence of transmitted cells within a VCC is preserved.

**Traffic parameter negotiation and usage monitoring**

- Traffic parameters can be negotiated between user and network for each VCC (e.g. average rate, peak rate, burstiness, and peak duration).
- The network monitors cells in the VCC to ensure negotiated parameters are not violated.
Virtual Path Characteristics

- quality of service
- switched and semi-permanent channel connections
- cell sequence integrity
- traffic parameter negotiation and usage monitoring
- virtual channel identifier restriction within a VPC

• One or more virtual channel identifiers may not be available to the user of the VPC but may be reserved for network use. (e.g. VCCs used for network management)
Control Signaling in ATM
Control Signaling - VCC

- In ATM, a **Control Signaling** mechanism is needed for the establishment and release of VPCs and VCCs.
- Control signaling uses separate connections from those used for data.
- One or a combination of these methods can be used in any particular network:
  1. **semi-permanent VCC**: no need for control signaling
  2. **meta-signaling channel**: low data rate, permanent channel for exchanging control signaling information
     1. **user-to-network signaling virtual channel**: used to set up VCCs between user and network. VCC will be used to carry data
     2. **user-to-user signaling virtual channel**: used to set up VCCs between users. It must be setup within a pre-established PVC
Control Signaling - VPC

- methods for control signaling for VPCs:
  1. semi-permanent
  2. customer controlled: the customer uses a signaling VCC to request the VPC from the network
  3. network controlled: the network establishes a VPC for its own convenience. The path may be network-to-network, user-to-network, or user-to-user
ATM Signaling Protocols

UNI signaling

- used between end system and switch across UNI links
- UNI signaling in ATM defines the protocol by which switched VCCs (SVC) are established and released dynamically by the ATM devices in the network.

NNI signaling

- used between switches across NNI links
- includes both signaling and routing
ATM Cells
ATM Cells

- ATM use of fixed-size cells, consisting of a 5-octet header and a 48-octet information field.

- Advantages to the use of small, fixed-size cells.
  - the use of small cells may reduce queuing delay for a high-priority cell,
  - fixed-size cells can be switched more efficiently
  - it is easier to implement the switching mechanism in hardware
ATM Header Fields

- **generic flow control (GFC)**
  - used for control of cell flow only at the **user-network interface**
  - used to assist the customer in controlling the flow of traffic for different QoS (alleviate short-term overload condition).

- **virtual path identifier (VPI)**
  - used for routing: 8 bits in user interface and 12 bits in network interface.

- **virtual channel identifier (VCI)**
  - used for routing to and from the end users.

- **payload type (PT)**
  - Type of data in the information field (data) – see Table 11.2

- **cell loss priority (CLP)**
  - One bit that provides guidance to the network in congestion situation

- **header error control (HEC)**
  - used for both error control and synchronization
## Payload Type (PT) Field Coding

<table>
<thead>
<tr>
<th>PT Coding</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 0</td>
<td>User data cell, congestion not experienced, SDU-type = 0</td>
</tr>
<tr>
<td>0 0 1</td>
<td>User data cell, congestion not experienced, SDU-type = 1</td>
</tr>
<tr>
<td>0 1 0</td>
<td>User data cell, congestion experienced, SDU-type = 0</td>
</tr>
<tr>
<td>0 1 1</td>
<td>User data cell, congestion experienced, SDU-type = 1</td>
</tr>
<tr>
<td>1 0 0</td>
<td>OAM segment associated cell</td>
</tr>
<tr>
<td>1 0 1</td>
<td>OAM end-to-end associated cell</td>
</tr>
<tr>
<td>1 1 0</td>
<td>Resource management cell</td>
</tr>
<tr>
<td>1 1 1</td>
<td>Reserved for future function</td>
</tr>
</tbody>
</table>

SDU = Service Data Unit  
OAM = Operations, Administration, and Maintenance
ATM Cells

Generic Flow Control
Generic Flow Control (GFC)

- control traffic flow at user to network interface (UNI) to alleviate short term overload
- two sets of procedures are used (at the UNI)
  - uncontrolled transmission
  - controlled transmission
- every connection subject to flow control or not
- if subject to flow control:
  - may be one group (A) – default: one-queue model
  - may be two groups (A and B): two-queue model
- flow control is from subscriber to network
GFC - Single Group of Connections

1. If $\text{TRANSMIT}=1$ send uncontrolled cells any time. If $\text{TRANSMIT}=0$ no cells may be sent
2. If $\text{HALT}$ received, $\text{TRANSMIT}=0$ until $\text{NO_HALT}$
3. If $\text{TRANSMIT}=1$ & no uncontrolled cell to send:
   1. If $\text{GO_CNTR}>0$, TE may send controlled cell and decrement $\text{GO_CNTR}$
   2. If $\text{GO_CNTR}=0$, TE may not send controlled cells
4. TE sets $\text{GO_CNTR}$ to $\text{GO_VALUE}$ upon receiving $\text{SET}$ signal
Use of HALT

- to limit effective data rate on ATM
- should be cyclic
- to reduce data rate by half, HALT issued to be in effect 50% of time
- done on regular pattern over lifetime of connection
### Generic Flow Control (GFC) Field Coding

<table>
<thead>
<tr>
<th></th>
<th>Uncontrolled</th>
<th>Controlling → Controlled</th>
<th>Controlled → Controlling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1-Queue Model</td>
<td>2-Queue Model</td>
</tr>
<tr>
<td>First bit</td>
<td>0</td>
<td>HALT(1)/NO_HALT(0)</td>
<td>HALT(1)/NO_HALT(0)</td>
</tr>
<tr>
<td>Second bit</td>
<td>0</td>
<td>SET(1)/NULL(0)</td>
<td>SET(1)/NULL(0) for Group A</td>
</tr>
<tr>
<td>Third bit</td>
<td>0</td>
<td>0</td>
<td>SET(1)/NULL(0) for Group B</td>
</tr>
<tr>
<td>Fourth bit</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Two Queue Model

- uses two counters each with current and initial values:
  - GO_CNTR_A
  - GO_VALUE_A
  - GO_CNTR_B
  - GO_VALUE_B
ATM Cells

Header Error Control
Header Error Control

- Each ATM cell includes an 8-bit HEC field calculated based on the remaining 32 bits of the header.
  - The polynomial generating the code is $X^8 + X^2 + X + 1$.
- In the case of ATM, the input to the calculation is small (32 bits) as compared to 8 bits for the code.
  - allows the code to be used not only for error detection but also, in some cases, for actual error correction.
  - Reason: there is sufficient redundancy in the code to recover from certain error patterns.
Header Error Control

- **Correction Mode**
  - No error detected (no action)
  - Single-bit error detected (correction)

- **Detection Mode**
  - No error detected (no action)
  - Multibit error detected (cell discarded)
  - Error detected (cell discarded)
Effect of Error in Cell Header
Impact of Random Bit Errors on HEC Performance

![Graph showing the relationship between bit error probability and outcome probability. The graph indicates that as the bit error probability increases, the probability of discarded cells and the probability of valid cells with errored headers also increase.]
Transmission of ATM Cells
Transmission of ATM Cells

I.432 specifies several data rates:
- 622.08 Mbps
- 155.52 Mbps
- 51.84 Mbps
- 25.6 Mbps

Two choices of transmission structure:
- Cell based physical layer
- SDH based physical layer
Transmission of ATM Cells

Cell-based Physical Layer
Cell Based Physical Layer

- No framing is needed
- The interface structure consists of a continuous stream of 53-octet cells
- Synchronization is achieved on the basis of the HEC field in the cell header
  - cell delineation based on header error control field
Cell Delineation State Diagram

- **HUNT state**: a cell delineation algorithm is performed bit by bit to determine if the HEC coding law is observed (i.e., match between received HEC and calculated HEC). Once a match is achieved, it is assumed that one header has been found, and the method enters the PRESYNC state.

- **PRESYNC state**: a cell structure is now assumed. The cell delineation algorithm is performed cell by cell until the encoding law has been confirmed consecutively $d$ times.

- **SYNC state**: the HEC is used for error detection and correction. Cell delineation is assumed to be lost if the HEC coding law is recognized consecutively as incorrect $a$ times.
Impact of Random Bit Errors on Cell Delineation Performance

![Graph showing impact of random bit errors on cell delineation performance.](image)

- **Bit error probability ($\rho_e$)**
- **In-sync time $T_d(\alpha)$ in cell units**
- **For 155.52 Mbps**
- **Parameters: $\alpha = 5$, $\alpha = 7$, $\alpha = 9$**
- **Time intervals:**
  - 1 second
  - 1 minute
  - 1 day
  - 10 days
  - 100 days
  - 10 years
  - 100 years
  - 10^10 years
  - 10^20 years
Acquisition Time vs. Bit Error Rate
Transmission of ATM Cells

SDH-based Physical Layer
SDH Based Physical Layer

- it imposes structure on ATM stream (framing)
  - eg. for 155.52Mbps
  - use STM-1 (STS-3) frame
- can carry ATM and STM payloads
- specific connections can be circuit switched using SDH channel
- SDH multiplexing techniques can combine several ATM streams
STM-1 Payload for SDH-Based ATM Cell Transmission
Advantages of the SDH-based approach

- Ability to carry both ATM-based or STM-based (synchronous transfer mode) payloads,

- Some specific connections can be circuit switched using an SDH channel.
  - For example, a connection carrying constant-bit-rate video traffic can be mapped into its own exclusive payload envelope of the STM-1 signal, which can be circuit switched. This may be more efficient than ATM switching.

- Ability to combine several ATM streams to build interfaces with higher bit rates than those supported by the ATM layer at a particular site.
  - For example, four separate ATM streams, each with a bit rate of 155 Mbps (STM-1), can be combined to build a 622-Mbps (STM-4) interface.
  - This arrangement may be more cost effective than one using a single 622-Mbps ATM stream.
ATM Service Categories
ATM Service Categories

Real time - limit amount/variation of delay

- Constant bit rate (CBR)
- Real time variable bit rate (rt-VBR)

Non-real time - for bursty traffic

- Non-real time variable bit rate (nrt-VBR)
- Available bit rate (ABR)
- Unspecified bit rate (UBR)
- Guaranteed frame rate (GFR)
Constant Bit Rate (CBR)

- fixed data rate continuously available
- tight upper bound on delay
- uncompressed audio and video
  - video conferencing
  - interactive audio
  - A/V distribution and retrieval
Real-Time Variable Bit Rate (rt-VBR)

- for time sensitive applications
  - tightly constrained delay and delay variation
- rt-VBR applications transmit data at a rate that varies with time
- characterized as bursty
- allow more flexibility than CBR
Non-Real-Time Variable Bit Rate (nrt-VBR)

- used for data transfers with critical response time
  - airline reservations, banking transactions
- end system specifies:
  - a peak cell rate
  - a sustainable or average cell rate
  - measure of how bursty or clumped cells can be
Unspecified Bit Rate (UBR)

- may be additional capacity over and above that used by CBR and VBR traffic
  - not all resources dedicated to CBR/VBR traffic
  - unused cells due to bursty nature of VBR
- for application that can tolerate some cell loss or variable delays
  - eg. TCP based traffic
- cells forwarded on FIFO basis
- best effort service
- examples:
  - text/data/image transfer
  - telecommuting
Available Bit Rate (ABR)

- application specifies peak cell rate (PCR) and minimum cell rate (MCR)
- resources allocated to give at least MCR
- spare capacity shared among all ARB sources
  - eg. LAN interconnection
ATM Bit Rate Services

The diagram illustrates different bit rate services in ATM networks:

- **Available Bit Rate and Unspecified Bit Rate:** This service provides variable bandwidth, adapting to the traffic demand. The percentage of line capacity varies over time, reflecting the fluctuating demands.

- **Constant Bit Rate:** This service guarantees a fixed bit rate, ensuring stable bandwidth for applications requiring consistent data transmission. The line capacity is fully utilized, indicated by the 100% mark.

The diagram emphasizes the flexibility and adaptability of ATM networks in accommodating diverse traffic patterns with appropriate bit rate services.
Guaranteed Frame Rate (GFR)

- better service for frame based traffic
  - IP, Ethernet
- goal is to optimize traffic passing from LAN onto an ATM backbone network
  - large enterprise, carrier, Internet service providers
- allows user to reserve capacity for each GFR VC
Summary

- role of Asynchronous Transfer Mode (ATM)
- protocol architecture
- ATM logical connections
- virtual path/virtual channel
- ATM Cell format
- transmission of ATM cells
- ATM services