Wide Area Networks (WANs)

Reference:
Chapters 10 and 11 -Stallings
Study Guide 12

Lecture 11 Revision

- Question - What is the major tradeoff in the design of a routing strategy for a circuit-switching network?

Lecture 11 Revision

- Question - What is the major tradeoff in the design of a routing strategy for a circuit-switching network?
- Answer - The tradeoff is between efficiency and resilience.

Lecture 11 Revision

- Question - What are the key requirements for a routing function for a packet-switching network?

Lecture 11 Revision

- Question - What are the key requirements for a routing function for a packet-switching network?
- Answer - Correctness, simplicity, robustness, stability, fairness, optimality, and efficiency.

Lecture 11 Revision

- Question - What are the advantages and disadvantages of adaptive routing?

Lecture 11 Revision

- Question - What are the advantages and disadvantages of adaptive routing?
- Answer - Advantages:(1) An adaptive routing strategy can improve performance, as seen by the network user. (2) An adaptive routing strategy can aid in congestion control. Because an adaptive routing strategy tends to balance loads, it can delay the onset of severe congestion. Disadvantages:(1) The routing decision is more complex; therefore, the processing burden on network nodes increases. (2) In most cases, adaptive strategies depend on status information that is collected at one place but used at another. There is a tradeoff here between the quality of the information and the amount of overhead. The more information that is exchanged, the more frequently it is exchanged, the better will be the routing decisions that each node makes. On the other hand, this information is itself a load on the constituent networks, causing performance degradation. (3) An adaptive strategy may react too quickly, causing congestion-producing oscillation, or too slowly, being irrelevant.

Learning Objectives

- understand the principles of packet switching and circuit switching in computer networks;
- describe Frequency-and Time Division Multiplexing (FDM and TDM) and ATM protocol architecture; and
- analyse ATM real-time and non-real-time services.

Switched Communications Networks

- For transmission of data beyond a local area, communication is typically achieved by transmitting data from source to destination through a network of intermediate switching nodes
- The switching nodes are not concerned with the content of the data. Rather, their purpose is to provide a switching facility that will move the data from node to node until they reach their destination

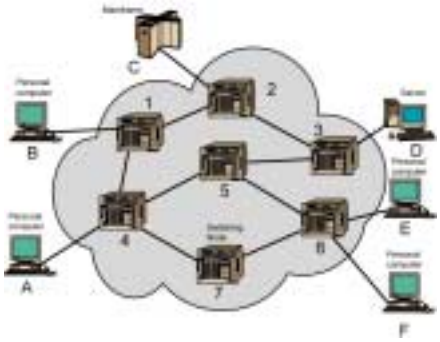
Switched Communications Networks Contd.

- The types of networks that are discussed in this lecture are referred to as switched communication networks. Data entering the network from a station are routed to the destination by being switched from node to node
- In switched communication networks, some nodes connect only to other nodes. Their sole task is the internal (to the network) switching of data

Switched Communications Networks Contd.

- Node-node links are usually multiplexed, using either frequency division multiplexing (FDM) or time division multiplexing (TDM)
- Usually, the network is not fully connected; that is , there is not a direct link between every possible pair of nodes
  - However, it is always desirable to have more than one possible path through the network for each pair of stations

Switched Communications Networks Contd.



Circuit Switching Networks

- Communication via circuit switching implies that there is a dedicated communication path between two stations
  - That path is a connected sequence of links between network nodes
  - On each physical link, a logical channel is dedicated to a connection
  - Communication via circuit switching involves 3 phases:
    - Circuit establishment
    - Data transfer
    - Circuit disconnect

Circuit Switching Networks Contd.

- In circuit switching, the switches must have intelligence to make resource allocations and to devise a route through the network
- Circuit switching can be rather inefficient
  - Channel capacity is dedicated for the duration of a connection, even if no data are being transferred
  - For a voice connection, utilisation may be rather high, but still does not approach 100%
  - For a terminal-to-computer connection, the capacity may be idle during most of the time of the connection

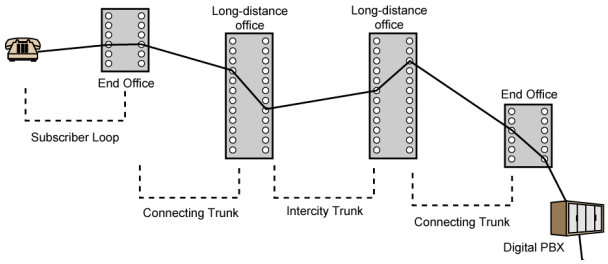
Circuit Switching Networks Contd.

  - In terms of performance, there is a delay prior to signal transfer for call establishment. However, once the circuit is established, the network is effectively transparent to the users
  - Information is transmitted at a fixed data rate with no delay other than the propagation delay through the transmission link
  - The delay at each node is negligible
- Circuit switching was developed to handle voice traffic but is now also used for data traffic

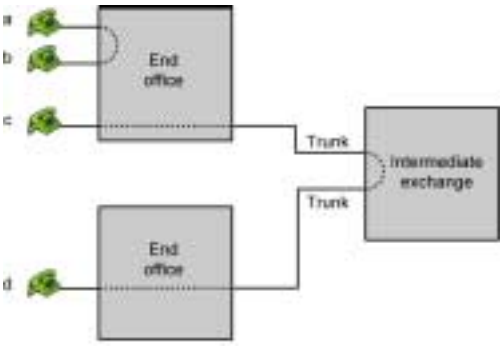
Circuit Switching Networks Contd.

  - The best-known example of a circuit-switching network is the public telephone network
  - Another well-known application of circuit switching is the private branch exchange (PBX), used to connect telephones within a building or office
  - Circuit-switching is also used in private networks

Circuit Switching Networks Contd.



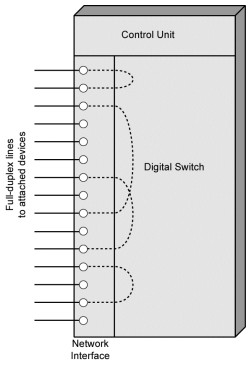
Circuit Switching Networks Contd.



Circuit-Switching Concepts

- A network built around a single circuit-switching node consists of a collection of stations attached to a central switching unit
  - The central switch establishes a dedicated path between any two devices that wish to communicate
- The heart of a modern system is digital switch

Circuit-Switching Concepts Contd.



Circuit-Switching Concepts Contd.

- An important characteristic of a circuit-switching device is whether it is blocking or nonblocking
- Blocking occurs when the network is unable to connect two stations because all possible paths between them are already in use
- A nonblocking network permits all stations to be connected (in pairs) at once and grant all possible connection requests as long as the called party is free
- When a network is supporting only voice traffic, a blocking configuration is generally acceptable, because it is expected that most phone calls are of short duration and that therefore only a fraction of the telephones will be engaged at any time

Circuit-Switching Concepts Contd.

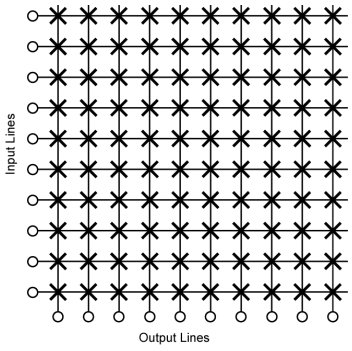
- However, when data processing devices are involved, these assumptions may be invalid. Hence, for a data applications, there is a requirement for a nonblocking or nearly nonblocking configuration

- One of the switching techniques internal to a single cir-switching node is space division switching
  - It was originally developed for the analog environment and has been carried over into the digital realm
  - As the name implies, a space division switch is one which the signal paths are physically separate from one another

Circuit-Switching Concepts Contd.

- Each connection requires the establishment of a physical path through the switch that is dedicated solely to transfer of signals between the two end points
- The basic building block of the switch is a metallic cross-point or semiconductor gate that can be enabled and disabled by a control unit
- The crossbar switch has a number of limitations:
  - The number of crosspoints grows with the square of the number of attached stations
    - This is costly for a large switch

Circuit-Switching Concepts Contd.



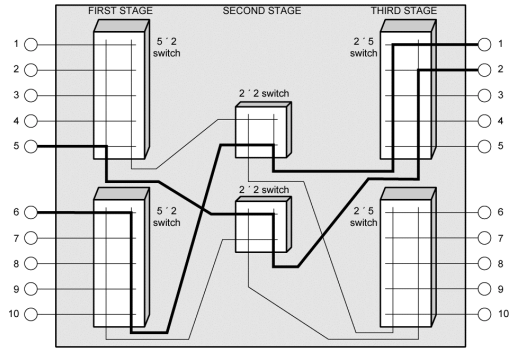
Circuit-Switching Concepts Contd.

- The loss of a crosspoint prevents connection between the two devices whose lines intersect at that crosspoint
- The crosspoints are inefficiently utilised;
  - even when all of the attached devices are active, only a small fraction of the crosspoints are engaged

– To overcome these limitations, multiple-stage switches are employed

- This type of arrangement has two advantages over a single-stage crossbar matrix:(1) There is more than one path through the network to connect two endpoints, increasing reliability, (2) The number of crosspoints is reduced; in the example, the total number of crosspoints for 10 stations is reduced from 100 to 48

Circuit-Switching Concepts Contd.



Circuit-Switching Concepts Contd.

- However, a multistage network requires a more complex control scheme
- Another consideration with a multistage space division switch is that it may be blocking
- With the advent of digitised voice and synchronous time division multiplexing techniques, both voice and data can be transmitted via digital signals

Circuit-Switching Concepts Contd.

– Instead of relatively dumb space division systems, modern digital systems rely on intelligent control of space – and time division systems

– Virtually all modern circuit switches use digital time division techniques for establishing and maintaining circuits

– Time division switching involves the partitioning of a lower-speed bit stream into pieces that share a higher-speed stream with other bit streams

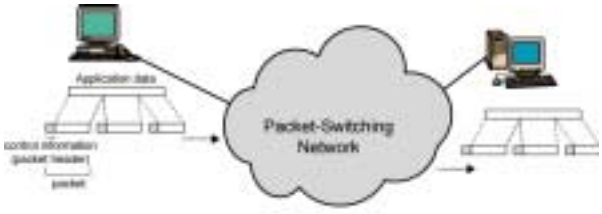
Packet-Switching Principals

- When circuit switching networks began to be used increasingly for data connections, two shortcomings became apparent:
  - In typical user/host data connection, much of the time the line is idle
    - Thus, with the data connections, a circuit-switching approach is inefficient
  - In a circuit-switching network, the connection provides for transmission at a constant data rate
    - Thus, each of the two devices that are connected must transmit and receive at the same data rate as the other. This limits the utility of the network in interconnecting a variety of host computers and workstations

Packet-Switching Principals

- In packet switching, data are transmitted in short packets
  - A typical upper bound on packet length is 1000 octets
- If a source has a longer message to send, the message is broken up into a series of packets
- Each packet contains a portion (or all for a short message) of the user's data plus some control information
- The control information, at a minimum, includes the information that the network requires to be able to route the packet through the network and deliver it to the intended destination

Packet-Switching Principals Contd.



Packet-Switching Principals Contd.

- The packet-switching approach has a number of advantages over circuit-switching:
  - Line efficiency is greater, because a single node-to-node link can be dynamically shared by many packets over time
    - The packets are queued up and transmitted as rapidly as possible over the link. By contrast, with circuit switching, time on a node-to-node link is preallocated using synchronous time division multiplexing

Packet-Switching Principals Contd.

- A packet-switching network can perform data-rate conversion
  - Two stations of different data rates can exchange packets because each connects to its node at its proper data rate
- When traffic becomes heavy on a circuit-switching network, some calls are blocked
  - On a packet-switching network, packets are still accepted, but delivery delay increases
- Priorities can be used
  - If a node has a number of packets queued for transmission, it can transmit the higher-priority packets first

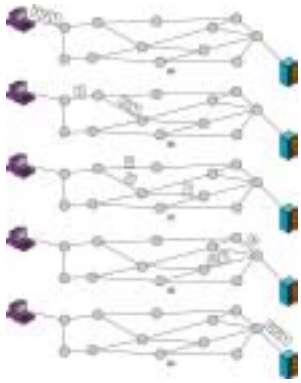
Packet-Switching Principals Contd.

- A network uses two approaches to handle a stream of packets as it attempts to route them through the network and deliver them to the intended destination
  - (1) Datagram
    - Each packet is treated independently, with no reference to packets that have gone before
    - Each node chooses the next node on a packet's path, taking into account information received from neighbouring nodes on traffic, line failures, and so on
    - So the packets, each with the same destination address, do not all follow the same route, and they may arrive out of sequence at the exit point

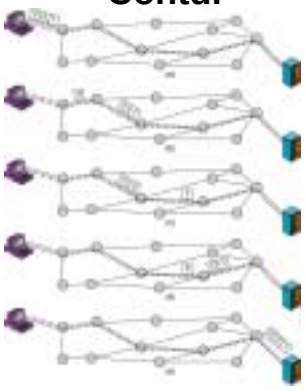
Packet-Switching Principals Contd.

- (2) Virtual circuits
  - A preplanned route is established before any packets are sent
  - Once the route is established, all the packets between a pair of communicating parties follow this same route through the network
  - Because the route is fixed for the duration of the logical connection, it is somewhat similar to a circuit in a circuit-switching network and is referred to as a virtual circuit
  - Each packet contains a virtual circuit identifier as well as data
  - At any time, each station can have more than one virtual circuit to any other station and can have virtual circuits to more than one station

Packet-Switching Principals Contd.



Packet-Switching Principals Contd.



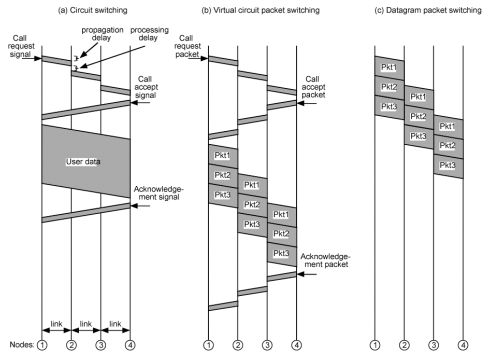
Comparison of Circuit Switching and Packet Switching

- When a comparison of performance between the two types is done, we are concerned with 3 types of delay:
  - Propagation delay: The time it takes a signal to propagate from one node to the next, this time is generally negligible
  - Transmission time:The time it takes for a transmitter to send out a block of data, eg. it takes 1s to transmit a 10,000-bit block of data onto a 10-kbps line
  - Node delay: The time it takes for a node to perform necessary processing as it switches data

Comparison of Circuit Switching and Packet Switching

- In circuit switching, once a connection is established, a constant data rate is provided to the connected stations
- In the case of packet switching, a variable delay is introduced and packets arrive in a choppy manner
- For packet switching, analog data must be converted to digital before transmission

Comparison of Circuit Switching and Packet Switching



Asynchronous Transfer Mode (ATM)

- ATM is the transmission technology that is the foundation of broadband ISDN (Integrated Services Digital Network)
- ATM is also finding widespread application beyond its use as part of ISDN
- ATM is, in essence, a packet switching technology, but is far more streamlined and efficient than traditional packet switching. It is designed to support very high data rates

Protocol Architecture

- ATM, also known as cell relay, takes advantage of the reliability and fidelity of modern digital facilities to provide faster packet switching than X.25
- Like packet switching and frame relay, ATM involves the transfer of data in discrete chunks
- Also like packet switching and frame relay, ATM allows multiple logical connections to be multiplexed over a single physical interface
- In ATM, the information on each logical connection is organised into fixed-size packets, called cells

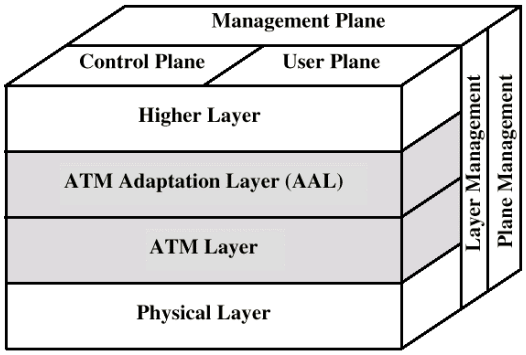
Protocol Architecture Contd.

- ATM is a streamlined protocol with minimal error- and flow control capabilities
  - This reduces the overhead of processing ATM cells and reduces the number of overhead bits required with each cell
- Use of fixed-size cells simplifies the processing required at each ATM node
  - This also supports the use of ATM at high data rates

Protocol Architecture Contd.

- Two layers of the protocol architecture relate to ATM functions
  - ATM layer
    - Common to all layers that provides packet transfer capabilities
    - Defines the transmission of data in fixed-size cells and defines the use of logical connections
  - ATM adaptation layer (AAL)
    - This layer is service dependent
    - Use of ATM creates the need for an adaptation layer to support information transfer protocols not based on ATM
      - The AAL maps higher-layer information into ATM cells to be transported over an ATM network

Protocol Architecture Contd.



Protocol Architecture Contd.

- The ATM protocol reference model involves 3 separate planes:
  - User plane
    - Provides for user information transfer, along with associated controls (e.g., flow control error control)
  - Control plane
    - Performs call control and connection control functions
  - Management plane
    - Performs management functions related to a system as a whole and coordination between all planes
    - Also includes layer management, which performs management functions relating to resources and parameters residing in its protocol entities

ATM Logical Connections

- Logical connections in ATM are referred to as virtual channel connections (VCCs)
- A VCC is the basic unit of switching in an ATM network
- A VCC is set up between two end users through the network and a variable-rate, full-duplex flow of fixed-size cells is exchanged over the connection
- VCCs are also used for user-network exchange (control signalling) and network-network exchange (network management and routing

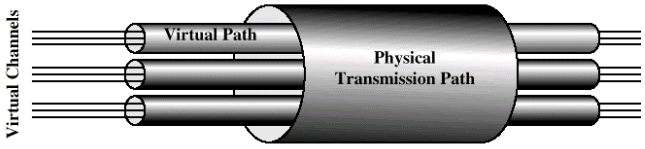
ATM Logical Connections Contd.

- For ATM, a second sublayer of processing has been introduced that deals with the concept of virtual path
  - A virtual path connection (VPC) is a bundle of VCCs that have the same endpoints. Thus, all of the cells flowing over all of the VCCs in a single VPC are switched together
- The virtual path concept was developed in response to a trend in high-speed networking
  - In that the control cost of the network is becoming an increasingly higher proportion of the overall network cost

ATM Logical Connections Contd.

- The virtual path technique helps contain the control cost by grouping connections sharing common paths through the network into a single unit
  - Network management actions can then be applied to a small number of groups of connections instead of a large number of individual connections
- The advantages of using virtual paths are:
  - Reduced processing and short connection setup time
  - Simplified network architecture
  - Increased network performance and reliability

ATM Logical Connections Contd.



ATM Logical Connections Contd.

- The process of setting up a virtual path connection is decoupled from the process of setting up an individual virtual channel connection:
  - To set up a virtual channel, there must first be a virtual path connection to the required destination node

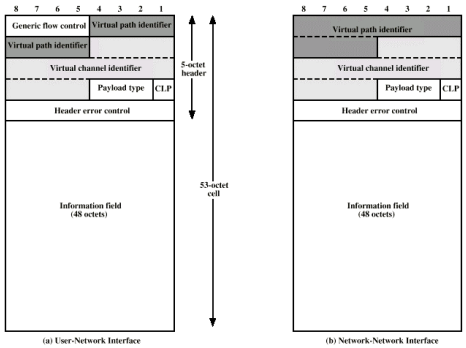
Control Signaling

- In ATM, a mechanism is needed for the establishment and release of VPCs and VCCs
- The exchange of information involved in this process is referred to as control signaling and take place on separate connections from those that are being managed

ATM Cells

- ATM makes use of fixed-size cells, consisting of a 5-octet header and a 48-octet information field
- There are several advantages to the use of small, fixed-size cells:
  - Reduce the queueing delay for a high-priority cell, because it waits less if it arrives slightly behind a lower-priority cell
  - It appears that fixed-size cells can be switched more efficiently. This is important for very high data rates of ATM
  - It is easier to implement the switching mechanism in hardware with fixed-size cells

ATM Cells Contd.



ATM Cells Contd.

- In the cell header format, generic flow control (GFC) field does no appear in the cell header internal to the network
  - It only appears at the user-network interface
  - Hence, it can be used for control of cell flow only at the local- user-network interface
  - The field could be used to assist the customer in controlling the flow of traffic for different qualities of service
  - In any case, GFC mechanism is used to alleviate short-term overload conditions in the network

ATM Cells Contd.

- The virtual path identifier (VPI) constitutes a routing field for the network
- The virtual channel identifier (VCI) is used for routing to and from the end user
- The payload type (PT) field indicates the type of information in the information field

ATM Cells Contd.

- The cell loss priority (CLP) bit is used to provide guidance to the network in the event of congestion
  - A value 0 indicates a cell of relatively higher priority, which should not be discarded unless no other alternative is available
  - A value of 1 indicates that this cell is subject to discard within the network
    - The user might employ this field so that extra cells (beyond the negotiated rate) may be inserted into the network, with a CLP of 1, and delivered to the destination if the network is not congested
- The header error control field is used for both error control and synchronisation

ATM Service Categories

- An ATM network is designed to be able to transfer many different types of traffic simultaneously
  - These include real-time flows such as voice, video, and bursty TCP flows
- Each such traffic is handled as a stream of 53-octet cells travelling through a virtual channel
  - However, the way in which each data flow is handled within the network depends on the characteristics of the traffic flow and the requirements of the application

ATM Service Categories Contd.

- The following service categories have been defined by ATM Forum:
  - Real-Time Services
    - The most important distinction among applications concerns the amount of delay and variability of delay (jitter) that the applications can tolerate
    - Real-time applications typically involve a flow of information to a user that is intended to reproduce that flow at a source
      - A user expects a flow of audio or video information to be presented in a continuous, smooth fashion
      - Applications that involve interaction between people have tight constraints on delay

ATM Service Categories Contd.

- Constant Bit Rate (CBR)
  - Used by applications that require a fixed data rate that is continuously available during the connection lifetime and a relatively tight upper bound on transfer delay
  - Commonly used for uncompressed audio and video information
  - CBR applications include:
    - » Videoconferencing
    - » Interactive audio (e.g., telephony)
    - » Audio/Video distribution (e.g., television)
    - » Audio/Video retrieval (e.g., video on demand)

ATM Service Categories Contd.

- Real_Time Variable Bit Rate (rt-VBR)
  - Intended for time sensitive applications
    - » That is, those requiring tightly constrained delay and delay variation
  - The main difference with CBR traffic is that rt-VBR applications transmit at a rate that varies with time
    - » Equivalently, an rt-VBR source can be characterised as somewhat bursty
  - The rt-VBR service allows the network more flexibility than CBR
    - » The network is able to statistically multiplex a number of connections over the same dedicated capacity and still provide the required service to each connection

ATM Service Categories Contd.

- Non-Real-Time Services
  - Intended for applications that have bursty traffic characteristics and do not have tight constraints on delay and delay variation
    - The network has greater flexibility in handling such flows and can make greater use of statistical multiplexing to increase network efficiency
  - Non-Real-Time Variable Bit Rate (nrt-VBR)
    - For some non-real-time applications, it is possible to characterise the expected traffic flow so that the network can provide substantially improved quality of service in the areas of delay and loss
    - With this service, the end system specifies a peak cell rate, a sustainable or average cell rate, and a measure of how bursty or clumped the cells may be

ATM Service Categories Contd.

- Unspecified Bit Rate (UBR)
  - At any given time, a certain amount of capacity of an ATM network is consumed in carrying CBR and the two types of VBR traffic
  - This service is suitable for applications that can tolerate variable delays and some cell losses, which is typically true of TCP-based traffic
  - With UBR, cells are forwarded on a FIFO basis using the capacity not consumed by other services
  - Additional capacity is available for one or both of the following reasons:
    - » Not all of the total resources have been committed to CBR and VBR traffic
    - » The bursty nature of VBR traffic means that at some times less than the committed capacity is being used

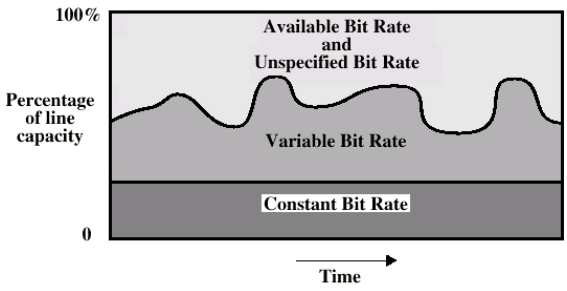
ATM Service Categories Contd.

- Available Bit Rate (ABR)
  - To improve the service provided to bursty sources that would otherwise use UBR, the ABR service has been defined
  - An application using ABR specifies a peak cell rate (PCR) that it will use and a minimum cell rate (MCR) that it requires
  - The network allocates resources so that all ABR applications receive at least their MCR capacity
  - The ABR mechanism uses explicit feedback to sources to assure that capacity is fairly allocated
  - Any capacity not used for ABR sources remains available for UBR traffic

ATM Service Categories Contd.

- Guaranteed Frame rate (GFR)
  - The most recent addition to ATM service categories
  - Designed specifically to support IP backbone subnetworks
  - GFR provides better service than UBR for frame-based traffic, including IP and Ethernet
  - The major goal of GFR is to optimise the handling of frame-based traffic that passes from a LAN through a router onto an ATM backbone network
  - Such ATM networks are increasingly being used in large enterprise, carrier, and Internet service provider networks to consolidate and extend IP services over the wide area

ATM Service Categories Contd.



ATM Adaptation Layer

- The use of ATM creates the need for an adaptation layer to support information transfer protocols not based on ATM
  - Two examples are PCM voice and the IP
    - PCM voice is an application that produces a stream of bits from a voice signal. To employ this application over ATM, it is necessary to assemble PCM bits into cells for transmission and to read them out on reception in such a way to produce a smooth constant flow of bits
    - When IP-based networks interconnect with ATM networks, a convenient way of integrating the two is to map IP packets into ATM cells

ATM Adaptation Layer Contd.

- ITU-T I.362 lists the following general examples of services produced by AAL:
  - Handling transmission errors
  - Segmentation and reassembly, to enable larger blocks of data to be carried in the information field of ATM
  - Handling of lost and misinserted cell conditions
  - Flow control and timing control

ATM Adaptation Layer Contd.

- In essence, the AAL layer provides the mechanisms for mapping a wide variety of applications onto the ATM layer
  - It provides protocols that are built on top of the traffic management capabilities of the ATM layer
  - Accordingly, the design of the AAL protocols must relate to the service categories discussed earlier

ATM Adaptation Layer Contd.

- The types of applications that AAL and ATM together can support include:
  - Circuit emulation
    - Refers to the support of synchronous TDM transmission structures over an ATM network
  - VBR voice and video
    - Real-time applications that are transmitted in compressed format
    - One effect of the compression is that a variable bit rate can support the application, which requires a continuous bit-stream delivery to the destination

ATM Adaptation Layer Contd.

- General data services
  - These include messaging and transaction services that do not require real-time support
- IP over ATM
  - Transmission of IP packets in ATM cells
- Multiprotocol encapsulation over ATM (MPOA)
  - Supports a variety of protocols other than IP (e.g., IPX, Apple Talk) over ATM
- LAN emulation (LANE)
  - Supports LAN-to-LAN traffic across ATM networks, with emulation of LAN broadcast capability

ATM Adaptation Layer Contd.

- AAL layer is organised in two logical sublayers:
  - Convergence sublayer (CS)
    - Provides the functions needed to support specific applications using AAL
    - Each AAL user attaches to AAL at a service access point (SAP), which is simply the address of the application
    - This sublayer is service dependant
  - Segmentation and reassembly sublayer (SAR)
    - Responsible for packaging information received from CS into cells for transmission and unpacking the information at the other end

ATM Adaptation Layer Contd.

- General protocol architecture for ATM and AAL typically encapsulate a higher-layer block of data into a single protocol data unit (PDU)
  - This PDU consists of the higher-layer data and possibly a header and trailer containing protocol information at the CS level
  - This CS PDU is then passed down to the SAR layer and segmented into a number of blocks

ATM Adaptation Layer Contd.