Chapter 9:
WAN Technology ad Protocols

Switching Networks

- **Switching nodes** - provide a switching facility that move data between nodes
- **Stations** – devices attached to the network
- **Nodes** – switching devices that provide communication
- **Communications network** – collection of nodes
- **Switched communication network** – data entering the network from a station are routed to the destination by being switched from node to node
Switching Networks

- Long distance transmission is typically done over a network of switched nodes
- Nodes not concerned with content of data
- End devices are stations
  - Computer, terminal, phone, etc.
- A collection of nodes and connections is a communications network
- Data is routed by being switched from node to node

Nodes

- Nodes may connect to other nodes only, or to stations and other nodes
- Node to node links usually multiplexed
- Network is usually partially connected
  - Some redundant connections are desirable for reliability
- Two different switching technologies
  - Circuit switching
  - Packet switching
Circuit Switching

- Dedicated communication path between two stations
- Three phases
  - Establish
  - Transfer
  - Disconnect
- Must have switching capacity and channel capacity to establish connection
- Must have intelligence to work out routing
Public Circuit Switched Network

Figure 9.3  Circuit Establishment
Circuit-Switching Technology

- Driven by applications that handle voice traffic
  - Key requirement is no transmission delay and no variation in delay
- Efficient for analog transmission of voice signals
- Inefficient for digital transmission
- Transparent
  - Once a circuit is established it appears as a direct connection; no special logic is needed

Telecom Components

- Subscriber
  - Devices attached to network
- Subscriber line
  - Local Loop
  - Subscriber loop
  - Connection to network
  - Few km up to few tens of km
- Exchange
  - Switching centers
  - End office - supports subscribers
- Trunks
  - Branches between exchanges
  - Multiplexed
Circuit Establishment

Circuit Switch Elements
Circuit-Switching Concepts

- Digital switch
  - Provides a transparent signal path
  - Must allow full-duplex transmission

- Network interface
  - Functions and hardware needed to connect digital devices

- Control unit
  - Establishes, maintains, and tears down the connection

Blocking or Non-blocking

- Blocking
  - A network is unable to connect stations because all paths are in use
  - A blocking network allows this
  - Used on voice systems
    - Short duration calls

- Non-blocking
  - Permits all stations to connect (in pairs) at once
  - Used for some data connections
Space Division Switching

- Developed for analog environment
- Separate physical paths
- Crossbar switch
  - Number of cross-points grows in $n^2$
  - Loss of cross-point prevents connection
  - Inefficient use of cross-points
    - All stations connected, only a few cross-points in use
    - Non-blocking
Multistage Switch

- Reduced number of cross-points
- More than one path through network
  — Increased reliability
- More complex control
- May be blocking

Three Stage Space Division Switch
Interconnection Networks

- Omega Network

![Diagram of Omega Network]

- Butterflies
  - Isomorphic to Omega (a composition of shuffle-exchange networks with programmable switches) and SW-Banyan switch
  - Closely related to hypercube and shuffle-exchange network
  - Number of nodes $N = (k + 1)2^k$
    - This means $k + 1$ rows (or ranks) consisting of $n = 2^k$ nodes each
  - Let node$(i,j)$ refer to the $j$-th node in the $i$-th row, where $i$ is in $[0,k]$
  - Then node$(i,j)$ in row $i>0$ is connected to two nodes in row $i-1$
    - node$(i-1,j)$ and node$(i-1,m)$ where $m$ is the integer found by inverting the $i$-th most significant bit in the binary representation of $j$.
  - Note that if node$(i,j)$ is connected to node$(i-1,m)$, then node$(i,m)$ is connected to node$(i-1,j)$.
  - Benes network is consisting of two butterflies back to back
Interconnection Networks

- Butterflies

row 0

row 1

row 2

row 3

Interconnection Networks

—Delta Switch Matrix

- non-blocking/blocking
- self routing

Hal96 fig.10.9
Interconnection Networks

Two extremes

Hal96 fig.10.8

Matrix switch

Routing addresses

Time Division Switching

- Modern digital systems use intelligent control of space & time division elements
- Use digital time division techniques to set up and maintain virtual circuits
- Partition low speed bit stream into pieces that share higher speed stream
- Individual pieces manipulated by control logic to flow from input to output
Figure 9.7 Time-Slot Interchange

(a) TSI Operation

(b) TSI Mechanism

Figure 9.8 A Time-Multiplexed Switch
**Traditional Circuit Switching**

(a) Traditional circuit switching

**Softswitch**

(b) Softswitch architecture
**Circuit Switching**

- Circuit switching designed for voice
  - Resources dedicated to a particular call
  - Much of the time a data connection is idle
  - Data rate is fixed
    - Both ends must operate at the same rate

**Packet Switching:**

- Packet switching was designed for data
- Data transmitted in small packets
  - Typically 1000 octets
  - Longer messages split into series of packets
  - Each packet contains a portion of user data plus some control info
- Control info
  - Routing (addressing) info
- Packets are received, stored briefly (buffered) and past on to the next node
  - Store and forward
Use of Packets

Advantages

- Line efficiency
  - Single node to node link can be shared by many packets over time
  - Packets queued and transmitted as fast as possible
- Data rate conversion
  - Each station connects to the local node at its own speed
  - Nodes buffer data if required to equalize rates
- Packets are accepted even when network is busy
  - Delivery may slow down
- Priorities can be used
Switching Techniques

- Station breaks long message into packets
- Packets sent one at a time to the network
- Packets can be handled in two ways:

  **Datagram**
  - Each packet is treated independently with no reference to previous packets

  **Virtual circuit**
  - A preplanned route is established before any packets are sent

**Datagram**

- Each packet treated independently
- Packets can take any practical route
- Packets may arrive out of order
- Packets may go missing
- Up to receiver to re-order packets and recover from missing packets
Virtual Circuit

- Preplanned route established before any packets sent
- Call request and call accept packets establish connection (handshake)
- Each packet contains a virtual circuit identifier instead of destination address
- No routing decisions required for each packet
- Clear request to drop circuit
- Not a dedicated path
Virtual Circuits vs. Datagram

- **Virtual circuits**
  - Network can provide sequencing and error control
  - Packets are forwarded more quickly
    - No routing decisions to make
  - Less reliable
    - Loss of a node looses all circuits through that node

- **Datagram**
  - No call setup phase
    - Better if few packets
  - More flexible
    - Routing can be used to avoid congested parts of the network
Packet Size

Circuit vs Packet Switching

- Performance
  - Propagation delay
  - Transmission time
  - Node delay
Figure 9.14 The Use of Virtual Circuits

(a) Circuit switching
(b) Virtual circuit packet switching
(c) Datagram packet switching

Figure 9.15 Event Timing for Circuit Switching and Packet Switching
<table>
<thead>
<tr>
<th>Circuit Switching</th>
<th>Datagram Packet Switching</th>
<th>Virtual Circuit Packet Switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dedicated transmission path</td>
<td>No dedicated path</td>
<td>No dedicated path</td>
</tr>
<tr>
<td>Continuous transmission of data</td>
<td>Transmission of packets</td>
<td>Transmission of packets</td>
</tr>
<tr>
<td>Fast enough for interactive</td>
<td>Fast enough for interactive</td>
<td>Fast enough for interactive</td>
</tr>
<tr>
<td>Messages are not stored</td>
<td>Packets may be stored until delivered</td>
<td>Packets stored until delivered</td>
</tr>
<tr>
<td>The path is established for entire conversation</td>
<td>Route established for each packet</td>
<td>Route established for entire conversation</td>
</tr>
<tr>
<td>Call setup delay; negligible transmission delay</td>
<td>Packet transmission delay</td>
<td>Call setup delay; packet transmission delay</td>
</tr>
<tr>
<td>Busy signal if called party busy</td>
<td>Sender may be notified if packet not delivered</td>
<td>Sender notified of connection denial</td>
</tr>
<tr>
<td>Overload may block call setup; no delay for established calls</td>
<td>Overload increases packet delay</td>
<td>Overload may block call setup; increases packet delay</td>
</tr>
<tr>
<td>Electromechanical or computerized switching nodes</td>
<td>Small switching nodes</td>
<td>Small switching nodes</td>
</tr>
<tr>
<td>User responsible for message loss protection</td>
<td>Network may be responsible for individual packets</td>
<td>Network may be responsible for packet sequences</td>
</tr>
<tr>
<td>Usually no speed or code conversion</td>
<td>Speed and code conversion</td>
<td>Speed and code conversion</td>
</tr>
<tr>
<td>Fixed bandwidth</td>
<td>Dynamic use of bandwidth</td>
<td>Dynamic use of bandwidth</td>
</tr>
<tr>
<td>No overhead bits after call setup</td>
<td>Overhead bits in each packet</td>
<td>Overhead bits in each packet</td>
</tr>
</tbody>
</table>

**Asynchronous Transfer Mode (ATM)**

- A switching and multiplexing technology that employs small, fixed-length packets called cells
- A fixed-size packet ensures function could be carried out efficiently, with little delay variation
- Small cell size supports delay-intolerant interactive voice service with a small packetization delay
- Designed to provide the performance of a circuit-switching network and the flexibility and efficiency of a packet-switching network
- Standardization effort was to provide a powerful set of tools for supporting a rich QoS capability and a powerful traffic management capability
**ATM**

- Commonly used by telecommunications providers to implement wide area networks
- Used by many DSL implementations
- Used as a backbone network technology in numerous IP networks
- Multiprotocol Label Switching (MPLS) has reduced the role for ATM

**Virtual Channel Connection (VCC)**

- Logical connection in ATM
- Analogous to a virtual circuit
- Basic unit of switching in an ATM network
- 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
- Also used for user-network exchange and network-network exchange
Figure 9.16 ATM Connection Relationships

Virtual Path Advantages

- Simplified network architecture
  - Network transport functions can be separated into those related to an individual logical connection and those related to a group of logical connections

- Increased network performance and reliability
  - The network deals with fewer, aggregated entities

- Reduced processing and short connection setup time
  - By reserving capacity on a virtual path connection, new virtual channel connections can be established by executing simple control functions at the endpoints of the virtual path connection

- Enhanced network services
  - The virtual path is used internal to the network but is also visible to the end user; the user may define closed user groups or closed networks of virtual channel bundles
Virtual Channel Characteristics

- ITU-T Recommendation I.150 lists the following characteristics of VCCs:
  
  Quality of service (QoS)
  - Specified by parameters such as cell loss ratio and cell delay variation
  
  Switched and semipermanent VCCs
  - A switched VCC is an on-demand connection which requires a call control signaling for setup and tearing down
  - A semipermanent VCC is one that is of long duration and 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 a user and the network for each VCC
  - The network monitors the input of cells to ensure that the negotiated parameters are not violated

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  Virtual channel identifier restriction within a VPC
  - One or more virtual channel identifiers, or numbers, may not be available to the user of the VPC but may be reserved for network use
Control Signaling

VCCs

- Semipermanent VCCs may be used for user-to-user exchange
  - No control signaling is required
- If there is no preestablished call control signaling channel, then one must be set up
  - Meta-signaling channel
- The meta-signaling channel can be used to set up a VCC between the user and the network for call control signaling
  - User-to-network signaling virtual channel
- The meta-signaling channel can also be used to set up a user-to-user signaling virtual channel
  - Such a channel must be set up within a preestablished VPC

VPCs

- Can be established on a semipermanent basis by prior agreement
  - No control signaling is required
- VPC establishment/release may be customer controlled
  - The customer uses a signaling VCC to request the VPC from the network
- VPC establishment/release may be 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

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Sequence 9

Figure 9.17 ATM Cell Format

(a) User-Network Interface

(b) Network-Network Interface
### Table 9.2

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

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

### Summary

- Switched communications networks
- Circuit-switching networks
- Circuit-switching concepts
  - Space division switching
  - Time-division switching
- Softswitch architecture
- Packet-switching principles
  - Switching technique
  - Packet size
  - External network interface
  - Comparison of circuit switching and packet switching
- Asynchronous transfer mode
  - ATM logical connections
  - ATM cells