Wide Area Networks (WANs)

- Communication service requirements vary with:
  - Each specific application
  - Different application users
  - Over time with changing economics, technology and politics

- The network must satisfy the service requirements of its applications and users.
NETWORK SERVICE REQUIREMENTS

Examples:
- Performance (Throughput, Delay)
- Data (Integrity, Block Size)
- Flow (Sequence, Control, Guarantees, Uniformity)
- Connectivity (Addressing, Establishment)
- Reliability and Availability (Failure Modes)
- Maintainability (Failure Isolation, Removal)
- User Interface (Circuit, Transaction, Burstyness, Rate)
- Information Mode (Analog, Digital)
ANALOG NETWORK

Make Digital Data Look Like Voice
EVOLUTION OF SWITCHING

From:

To:
The following types of networks are in common use:

- **Switched Communication Network**
  - Circuit Switched Network
  - Message Switched Network
  - Packet Switched Network

- **Broadcast Communication Network**
  - Packet Radio Network
  - Satellite Network
  - Local Network
To pass data between the users, it must be sent over the channel, through the switches (if any), and between the interfaces.
SWITCHING

- Transferring data from an incoming channel to an outgoing channel through a switching entity; a SHARED channel is a distributed switch.

- Switching can be based on:
  - PHYSICAL CHANNEL ADDRESS - CIRCUIT SWITCHING
  - DATA ITEM ADDRESS - PACKET SWITCHING

- ROUTING builds a path through switch entities between end points.
CIRCUIT SWITCHING

- Dedicated path between two stations

- Requires 3 phases:
  1. End to End Circuit Establishment
  2. Data Transfer
     - Digital or analog data
     - Digital or analog signal
     - Usually full duplex
  3. Circuit Disconnect
GENERIC SWITCHING NETWORK

- Communication Network Node
- Network Station
CIRCUIT SWITCHING EXAMPLE

CHANNEL PATH IS **RESERVED - DEDICATED FOR THE DURATION OF THE CONNECTION.**

Station A wishes to connect to Station E.

- A sends request to Node 4.
- Node 4 decides route to Station E and chooses Node 5 over 1 & 7; Allocates a free channel using TDM or FDM.
- Node 5 goes through similar procedure in choosing Node 6.
- Node 6 connects to Station E.
Path formed from DEDICATED channels (subchannels) and switching elements
Path RESERVED for duration of connection.
Path has fixed bandwidth and delay; UNUSED BANDWIDTH CANNOT BE SHARED WITH OTHER USERS.
Efficient for constant traffic. Requires a path setup.
Usually stream-oriented interface as in real telephone circuit switching, but can be block-oriented from one byte to many bytes per block.
Error checking/correction usually done on an end-to-end basis.
MESSAGE SWITCHING EXAMPLE

- **M** = one message
- **NO** dedicated path.
- Each message contains a destination ADDRESS.
- Message travels from node to node.
- ENTIRE message is RECEIVED and STORED before it is forwarded to the next node.

Each message is received, stored and then forwarded.

<table>
<thead>
<tr>
<th>Message</th>
<th>Address E</th>
</tr>
</thead>
</table>

Copyright 1998, Professor John T. Gorgone
FUNCTIONS PERFORMED BY A MESSAGE - SWITCHING COMPUTER

1. The systems accepts messages from distant terminals. The terminals are often teleprinters, paper tape readers, and special input keyboards. The system may also accept messages from other computers.

2. On receipt of a message, it analyzes the message's header to determine the destination or destinations to which the message must be sent.

3. The system may analyze the header for a priority indication. This will tell the program that certain messages are urgent. They must jump any queues of messages and be sent to their destination immediately.
FUNCTIONS  (Continued)

4. It may analyze the header for an indication that some processing of the message is necessary; for example, statistical information from the message may be gathered by the system.

5. The system detects any errors in transmission of the incoming message and requests a retransmission of faulty messages. The retransmission may be automatic.
6. It detects format errors in incoming messages as much as possible. Types of format errors that may be picked up include the following:
   a. Address invalid: the address to which the message is to be sent is not included in the computer's directory.
   b. Excessive addresses: there are more than the given maximum number of addresses allowed.
   c. Incorrect format: an invalid character appears in the message in an incorrect location.
   d. A priority indicator is invalid.
   e. Originator code error: the address of the originator is not included in the computer's list.
   f. Incorrect character counts.
FUNCTIONS (Continued)

7. The system stores all the messages arriving and protects them from possible subsequent damage.

8. It takes messages from the store and transmits them to the desired addresses; or message may be sent to many different addresses. In doing this, it does not destroy the message held in the store. The store is thus a queuing area for messages received and messages waiting to be sent, as well as a file where messages are retained.

9. The system redirects messages from the store and sends them to the terminals requesting them. It may, for example, be asked to resend a message with a specified serial number or to send all messages from a given serial number.
FUNCTIONS  (Continued)

10. Systems in use store messages in this manner for several hours, or on some systems, several days. Any message in the store is immediately accessible for this period of time.

11. The system may also maintain a permanent log of messages received. This will probably be done on a relatively inexpensive medium, such as magnetic tape and not on a random access file.

12. If messages are sent to a destination at which the terminal is temporarily inoperative, the system intercepts these messages. It may automatically reroute them to alternative terminals that are operative. On the other hand, it may store them until the inoperative terminal is working again.
3. It may intercept messages for other reasons. For example, the system may be programmed to send a message to the location of an important person, although he may be moving from one place to another. The person in question indicates his current location to the computer, and the computer diverts messages for him to the location. The system may handle messages on a priority basis. There may be one urgent priority level so that these messages are sent before any others. Some systems have more than one level of priority, level 1 being transmitted before level 2 which is transmitted before level three and so on. The system may notify the operator in the event that any priority queue becomes too great. A simple system may have no priority scheme: messages being handled on a first-in, first-out basis.
14. The system maintains an awareness of the status of lines and terminals. It is programmed to detect faulty operation on terminals where possible, to make a log of excessive noise on lines, and to notify its operator when a line goes out. The system maintains a record of any faults it detects.

15. On a well planned system, the messages should be given serial numbers by the operator sending them. The computer checks the serial numbers and places new serial numbers on the outgoing messages. When serial numbers are used, the system can be designed to avoid the loss of any message. This is especially important in the event of a computer failure or a switchover in a duplex system.
FUNCTIONS (Continued)

16. At given intervals, perhaps once an hour, the system may send a message to each terminal, quoting the serial number of the last message it received from that terminal. The terminal's operator then knows that the switching system is still on the air.

17. The system may conduct a statistical analysis of the traffic that it is handling.

18. It may be programmed to bill the users for the messages sent. It may, for example, make a small charge per character sent from each terminal and bill the terminal location appropriately.
FUNCTIONS (Continued)

19. It produces periodic reports of its operation for its operator. These may include reports on the status of all facilities, error statistics, reports giving the number of messages in each queue, message counts, and so on.
MESSAGE vs. PACKET SWITCHING

M = Message of 270 characters at 2400 BPS.

Total transmission time = 2.7 seconds (Plus switching delays)
MESSAGE vs. PACKET SWITCHING

- \( m \) = message of 270 characters.
- One message is segmented into three packets (P1, P2, P3)

\[
\begin{array}{cccc}
\text{P3} & \text{P2} & \text{P1} \\
\text{1} & \text{2} & \text{3} \\
\end{array}
\]

\( m \) is a message of 270 characters.

- \( 1 - 300 \text{ Mili} \)
- \( 300 - 600 \text{ Mili} \)
- \( 600 - 900 \text{ Mili} \)
- \( 900 - 1200 \text{ Mili} \)
- \( 1200 - 1500 \text{ Mili} \)
- \( 1500 - \) 

Total transmission time = 1.5 seconds (Plus switching delays)

P1 = "Packet" of message \( m \). 2400 bps

Copyright 1998, Professor John T. Gorgone
PUBLIC PACKET SWITCHING NETWORK

- Efficient shared usage of facilities
- Costs based on data volumes
- Increased availability

DTE - Data Terminal Equipment
PDN - Public Data Network
PACKET SWITCHING

- Path formed from shared channels (Subchannels) and switching elements.
- Large messages are segmented and transmitted in small pieces (Packets).
- No fixed internal circuits, packets are routed independently through the network.
- Channels are shared - bandwidth dynamically allocated on demand.
- Total network bandwidth is divided among users based on channel and switch scheduling algorithm.
- High component utilization for bursty traffic.
A routine decision is made on each packet.
- Each packet may take a different route.
- May arrive out of sequence.
- Destination station must resequence.
- Each packet is treated independently.
A routine decision is made on each packet.
- Each packet may take a different route.
- May arrive out of sequence.
- Destination station must resequence.
- Each packet is treated independently.
A "Fixed" route is set up between the two stations before the data transfer.

The path is **NOT** reserved or dedicated.

A packet is still stored and forwarded at each node.

However, the routing decision is made for the first packet only, all other packets follow the same route.
VIRTUAL CIRCUIT CONCEPT:

Logical Connections Between DTEs.

Public Data Network
Internal Virtual Circuit - a route for packets between stations is defined and labeled. All packets for that Virtual Circuit follow the same route and arrive in sequence.
A logical connection is set up between two stations.
Packets are labeled with a virtual circuit number and a sequence number.
Internal Datagram - Each packet is treated independently by the network. Packets are labeled with a destination address and may arrive at the destination node out of sequence.
EXTERNAL DATAGRAMS

*.# (Destination Address, Sequence Number)

- Each packet is transmitted independently.
- Packets are labeled with a destination address and may arrive out of sequence.
PACKET vs. CIRCUIT SWITCHING

Packet Switching

- Economical by sharing channels, but overhead in the process.
- Created "Virtual Circuits" that appear as "Circuits" - sequence flow at user interface, but not fixed bandwidth or delay due to demand sharing.
- Can have high path reliability via adaptive routing and "User Level" error checking/correction.
- May not be fair to all users, may be hard to control under heavy load.
PACKET vs. CIRCUIT SWITCHING

- Circuit Switching
  - Dedicated channels, wasted bandwidth for very bursty users.
  - Low overhead, fixed bandwidth and delay pathway once setup is complete.
  - Path reliability a function of "User Level" mechanisms.
  - Can be block or stream oriented, connectivity via setup function.
  - User flow performance is independent of each other.
## Comparison of Communication Switching Techniques

<table>
<thead>
<tr>
<th>Circuit Switching</th>
<th>Message 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>
<td>No dedicated path</td>
</tr>
<tr>
<td>Continuous transmission of data</td>
<td>Transmission of messages</td>
<td>Transmission of packets</td>
<td>Transmission of packets</td>
</tr>
<tr>
<td>Fast enough for interactive</td>
<td>Too slow for interactive</td>
<td>Fast enough for interactive</td>
<td>Fast enough for interactive</td>
</tr>
<tr>
<td>Messages are not stored</td>
<td>Messages are filed for later retrieval</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 message</td>
<td>Route established for each packet</td>
<td>Route established for entire conversation</td>
</tr>
<tr>
<td>Cell setup delay</td>
<td>Message transmission delay</td>
<td>Packet transmission delay</td>
<td>Cell setup delay Packet transmission delay</td>
</tr>
<tr>
<td>Busy signal if called party busy</td>
<td>No busy signal</td>
<td>Sender may be notified if packet not delivered</td>
<td>Sender notified of connection denial</td>
</tr>
</tbody>
</table>
## Comparison of Communication Switching Techniques

<table>
<thead>
<tr>
<th>Circuit Switching</th>
<th>Message Switching</th>
<th>Datagram Packet Switching</th>
<th>Virtual-Circuit Packet Switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overload may block cell setup; no delay for established calls</td>
<td>Overload increases message delay</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>Messages switch center with filing facility</td>
<td>Small switching nodes</td>
<td>Small switching nodes</td>
</tr>
<tr>
<td>User responsible for message loss protection</td>
<td>Network responsible for messages</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>
<td>Speed and code conversion</td>
</tr>
<tr>
<td>Fixed bandwidth transmission</td>
<td>Dynamic use of 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 message</td>
<td>Overhead in each packet</td>
<td>Overhead bits in each packet</td>
</tr>
</tbody>
</table>
Event Timing for Various Communication switching Techniques

a. Circuit Switching  
- Call Request Signal
- Call Accept Signal
- Acknowledgment Signal

b. Message Switching  
- Call Request Packet
- Call Accept Packet
- Acknowledgment Packet

c. Virtual Circuit Packet Switching  
- Call Request Packet
- Call Accept Packet
- Acknowledgment Packet

d. Datagram Packet Switching  
- Call Request Packet
- Call Accept Packet
- Acknowledgment Packet
EXAMPLE PACKET SWITCHED NETWORK
## CENTRAL ROUTING DIRECTORY

<table>
<thead>
<tr>
<th>From Node</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>-</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>2</td>
<td>-</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>-</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>-</td>
</tr>
</tbody>
</table>

From Node 1 to Node 6:

- Route: From Node 1 to Node 6
- Path: 1 → #1 → #4 → #5 → #6
### CENTRAL ROUTING DIRECTORY

<table>
<thead>
<tr>
<th>Node 1 Directory</th>
<th>Destination</th>
<th>Next Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Node 2 Directory</th>
<th>Destination</th>
<th>Next Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Node 3 Directory</th>
<th>Destination</th>
<th>Next Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Node 4 Directory</th>
<th>Destination</th>
<th>Next Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Node 5 Directory</th>
<th>Destination</th>
<th>Next Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Node 6 Directory</th>
<th>Destination</th>
<th>Next Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
Figure 7.1 Comparison of Multiprocessor Systems, LANs, MANs, and WANs
# ASYNCHRONOUS ACCESS CONTROL TECHNIQUES

<table>
<thead>
<tr>
<th></th>
<th>CENTRALIZED</th>
<th>DISTRIBUTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round-Robin</td>
<td>Polling</td>
<td>Token Bus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Token Ring</td>
</tr>
<tr>
<td>Reservation</td>
<td>Centralized Reservation</td>
<td>Distributed Reservation</td>
</tr>
<tr>
<td>Contention</td>
<td>-----</td>
<td>ALOHA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSMA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSMA/CD</td>
</tr>
</tbody>
</table>
APPLICABILITY OF ACCESS CONTROL TECHNIQUES

Pocket Radio
ALOHA
CSMA

Satellite
ALOHA
Centralized Reservation
Distributed Reservation

Local Networks
CSMA/CD
Token Bus
Token Ring
Polling
BROADCAST COMMUNICATION NETWORKS

1. Packet Terrestrial Radio

2. Satellite Network

Sender

Satellite Relay

Receivers
3. Bus Local Network

4. Ring Local Network
Alternate Routing

• Possible routes to be used between two end offices are predefined.

• Originating switch responsible for selecting the appropriate route for each call.

• Each switch given a set of preplanned routes for each destination, in order of preference.

• Routing sequence reflects an analysis based on historical traffic patterns.

• Designed to optimize use of network resources.
Adaptive Routing

• Designed to enable switches to react to changing traffic patterns on the network.
• Due to exchange of information between switches, schemes require greater management overhead.
• Higher potential for effectively optimizing use of network resources as compared to alternative routing.
Public Telecommunications Network

- Regional or national networks.
- Generic architectural components
  - **Subscribers**: Devices that attach to the network.
  - **Local Loop**: Link between the subscriber and the network, also known as subscriber loop.
  - **Exchanges**: Switching centers in the network. A switching center directly supporting subscribers is known as end office.
  - **Trunks**: Branches between exchanges. Trunks carry multiple voice frequency circuits using either FDM or synchronous TDM.
Wide-Area Networks for Data

- **Public packet-switching networks**: User, typically leases a line from the user’s computing equipment to the nearest packet-switching node. Interface to such a network is X.25.
- **Private packet-switching networks**: User owns or leases the packet switching nodes. Leased lines, typically 56-or 64-kbps digital lines, interconnect the nodes.
- **Public circuit-switching networks**: Dial-up telephone lines employed for data communications using modems or switched digital services.
- **Private circuit-switching networks**: Interconnected set of digital PBX’s, using leased 56-kbps lines or T-1 lines. Network can carry both data and voice.
- **Private leased lines**: Dedicated lines involving no switching.
- **ISDN**: Both X.25 packet switching and traditional circuit switching offered in an integrated service.
What is a MAN?

- Metropolitan Area Network
- Provides network services within a metropolitan area of usually < 50 kilometers
- Used for inter-LAN connectivity
- Allows multiple locations (offices) to share data within a metropolitan area
Metropolitan-Area Networks (MANs)

• Middle ground between LANs and WANs.
• Satisfy high-capacity needs for customers in a metropolitan area.
• Provide required capacity at lower cost and greater efficiency as compared to equivalent services provided by local telephone companies.
• Designs use LAN technology, extended over a larger area or WAN technology, restricted to a metropolitan area.