CS 154 (Networks I)

WAN Technologies
What is WAN?

- Wide Area Network
- covers a relatively broad geographic area
- may consist of LANs
- often connected through public networks like telephone systems but may also use leased lines or satellites
What is WAN?

- may be privately owned or rented
  - but the term usually connotes the inclusion of public (shared user) networks
- MAN - intermediate form of network in terms of geography
- The Internet - largest WAN in existence
What is WAN?

- generally function at the lower three layers of the OSI reference model: physical, data link, network
Wide Area Networking Issues

- Trend towards distributed processing architectures to support applications and organizational needs.
- Expansion of wide area networking technologies and services available to meet those needs.
WAN Considerations

- **Nature of traffic**
  - stream generally works best with dedicated circuits
  - bursty better suited to packet-switching

- **Strategic and growth control** – limited with public networks

- **Reliability, Performance** – WAN has advantages over a public network like the Internet

- **Security** – not much more of a problem than with networks confined to one location

- **Higher cost** – generally more expensive compared to LAN for comparable speed; increases with distance

- **new disruptive technologies** – require enormous amounts of bandwidth, monitoring and management
WANs for Voice

- Requires very small and non-variable delays for natural conversation -- difficult to provide this with packet-switching
  - As a result, the preferred method for voice transmission is circuit-switching
  - Packet-switching has gained ground in recent years with improved “quality of service (QoS) features

- Most businesses use public telephone networks, but a few organizations have implemented private voice networks
WANs for Data

- Public packet-switched networks (X.25)
- Private packet-switched networks
- Leased lines between sites (non-switched)
- Public circuit-switched networks
- Private circuit-switched networks (interconnected digital PBXs)
- ISDN (integrated X.25 and traditional circuit-switching)
WANs – Voice/Data

- with today's separate infrastructures, two strategic directions toward the convergence of data, voice, and video are possible
Common Non-switched Offerings

- Analog lines (dedicated modems)
- Digital data lines (dedicated DSUs)
- T-1, T-3 leased lines
- Frame relay over dedicated lines
Common Switched Offerings

- Dial-up modems
- X.25 packet switching
- ISDN
- Frame relay
- ATM
### Signaling Technology

**DS/T-Carrier**

<table>
<thead>
<tr>
<th>Signal Level</th>
<th>Digital Bit Rate</th>
<th>Carrier System</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS0</td>
<td>64 Kbps</td>
<td>(none)</td>
</tr>
<tr>
<td>DS1</td>
<td>1.544 Mbps</td>
<td>T1</td>
</tr>
<tr>
<td>DS1C</td>
<td>3.152 Mbps</td>
<td>T1C</td>
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<td>DS2</td>
<td>6.312 Mbps</td>
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<td>DS3</td>
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<td>T3</td>
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<td>DS3C</td>
<td>89.472 Mbps</td>
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<td>DS4</td>
<td>274.176 Mbps</td>
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<td>DS4E</td>
<td>411.264 Mbps</td>
<td>T4E</td>
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<td>DS4C</td>
<td>560.160 Mbps</td>
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<td>DS4X</td>
<td>822.528 Mbps</td>
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<td>DS5</td>
<td>1.120 Gbps</td>
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<td>DS5X</td>
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<tr>
<td>DS5E</td>
<td>1.680 Gbps</td>
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### Signaling Technology

- **E-Carrier**

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<tr>
<td>E1</td>
<td>2.048 Mbps</td>
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<tr>
<td>E2</td>
<td>8.448 Mbps</td>
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<td>E3</td>
<td>34.368 Mbps</td>
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<td>E5</td>
<td>565.148 Mbps</td>
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### Signaling Technology

#### Optical Carrier

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<tr>
<td>STS1</td>
<td>51.84 Mbps</td>
<td>OC1</td>
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<tr>
<td>STS-3/SDH-1</td>
<td>155.52 Mbps</td>
<td>OC3</td>
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<td>STS-9/SDH-3</td>
<td>466.56 Mbps</td>
<td>OC9</td>
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<td>STS-12/SDH-4</td>
<td>622.08 Mbps</td>
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<td>STS-18/SDH-6</td>
<td>933.12 Mbps</td>
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<tr>
<td>STS-24/SDH-8</td>
<td>1.244 Gbps</td>
<td>OC24</td>
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<tr>
<td>STS-36/SDH-12</td>
<td>1.866 Gbps</td>
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<td>STS-48/SDH-16</td>
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<td>STS-96/SDH-32</td>
<td>4.976 Gbps</td>
<td>OC96</td>
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<td>STS-192/SDH-64</td>
<td>9.952 Gbps</td>
<td>OC192</td>
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<td>STS-256</td>
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<td>STS-768/SDH-256</td>
<td>39.813 Gbps</td>
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<tr>
<td>STS-3072/SDH-1024</td>
<td>159.252 Gbps</td>
<td>OC3072</td>
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### WAN Choices

#### Nonswitched (leased)

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<tr>
<th>Service</th>
<th>1 kbps</th>
<th>10 kbps</th>
<th>100 kbps</th>
<th>1 Mbps</th>
<th>10 Mbps</th>
<th>100 Mbps</th>
<th>1 Gbps</th>
<th>10 Gbps</th>
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<tr>
<td>Analog</td>
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<td>Digital Data</td>
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<td>T-1</td>
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<tr>
<td>Frame Relay</td>
<td>1.54</td>
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<td>44.736</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>T-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>44.736</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SONET</td>
<td></td>
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<td></td>
<td></td>
<td>51.84</td>
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<td>2.488</td>
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#### Switched (networked)

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<th>10 kbps</th>
<th>100 kbps</th>
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<th>10 Mbps</th>
<th>100 Mbps</th>
<th>1 Gbps</th>
<th>10 Gbps</th>
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<tbody>
<tr>
<td>Dial-up/modem</td>
<td>1.2</td>
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<tr>
<td>X.25 packet switching</td>
<td>2.4</td>
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<td>ISDN</td>
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<td>1.54</td>
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<td>ADSL</td>
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<td>9</td>
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<tr>
<td>Frame relay</td>
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<td>44.736</td>
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<tr>
<td>SMDS</td>
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<td>44.736</td>
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<td></td>
<td></td>
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<tr>
<td>ATM</td>
<td>25</td>
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<td></td>
<td>155</td>
<td></td>
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</table>

Transmission speed (log scale)
Integrated Network Access Using Dedicated Channels
Integrated Network Access Using Public Switched WAN
X.25

- set of protocols developed by the ITU-T or CCITT
- specifies how to connect and maintain computer devices over an internetwork
- defines layers 1, 2, and 3 in the OSI Reference Model
- hop-by-hop Layer 2 and Layer 3 flow and error control
- speed: about 64Kbps
X.25

- uses a store and forward method
  - drawback: causes about a half second delay in data reception when two way communications are used
- considerable overhead
- designed for links with high error rates
- allows computers on different public networks to communicate through an intermediary computer at the network layer level
Switched Multi-megabit Data Service (SMDS)

- uses fixed length cell switching
- runs at speeds of 1.533 to 45Mbps
- provides no error checking
- assumes devices at both ends provide error checking
Synchronous Optical Network (SONET)

- a physical layer standard
- defines voice, data, and video delivery methods over fiber optic media
- topology: mesh or ring
- uses multiplexing
- data rates are in terms of optical carrier (OC) levels
Synchronous Optical Network (SONET)

- also defines synchronous transport signals (STS) for copper media which use the same speed scale of OC levels
- ITU has incorporated SONET into their Synchronous Digital Hierarchy (SDH) recommendations
BISDN

- Broadband Integrated Services Digital Network
- Uses ATM Technologies over SONET-based transmission circuits
- Provides 155 - 622 Mbps and beyond
Frame Relay Characteristics

- Designed to eliminate excessive overhead of traditional packet switching
- Control signaling takes place on a separate logical connection (nodes don’t need state tables for each call)
- Multiplexing/switching take place at layer 2, eliminating a layer of processing
- No hop-by-hop flow/error control
Traditional Packet Switching
Frame Relay Operation

![Frame Relay Operation Diagram]

- **Add frame envelope**
- **Route**
- **Route**
- **Remove frame envelope**

**Layering:**
- **Physical layer**
- **Link layer**

**Network Elements:**
- **LAN**
- **Host**

**Routing:**
- Data flows through the network, with frames being added and removed at each node.
Frame Relay Congestion Control

- Minimize discards
- Maintain agreed QoS
  - Minimize variance in QoS
- Minimize probability of one end user monopoly
- Simple to implement
  - Little overhead on network or user
- Create minimal additional traffic
- Distribute resources fairly
- Limit spread of congestion
- Operate effectively regardless of traffic flow
- Minimum impact on other systems
Traffic Rate Management

- Must discard frames to cope with congestion
  - Arbitrarily, no regard for source
  - No reward for restraint so end systems transmit as fast as possible
  - Committed information rate (CIR)
    - Data in excess of this liable to discard
    - CIR should not exceed physical data rate

- Burst Size
Operation of CIR

- Committed Information Rate (CIR)
- Current rate
- Maximum Rate
- Transmit if possible
- Guaranteed transmission
- Discard all excess
- Access rate
Asynchronous Transfer Mode (ATM)

- Also known as cell relay
- Faster than X.25, more streamlined than frame relay
- Supports data rates several orders of magnitude greater than frame relay
- Data on logical connection is organized into fixed-size packets, called cells.
- No link-by-link error control or flow control
- Identified more with telephone lines
Virtual Channels & Virtual Paths

- Logical connections in ATM are virtual channels
  - analogous to a virtual circuit in X.25 or a frame relay logical connection
  - used for connections between two end users, user-network exchange (control signaling), and network-network exchange (network management and routing)

- A virtual path is a bundle of virtual channels that have the same endpoints.
ATM Connection Relationships
Advantages of Virtual Paths

- Simplified network architecture
- Increased network performance and reliability
- Reduced processing
- Short connection setup time
- Enhanced network services
Virtual-Path/Virtual-Channel Characteristics

- Quality of service
- Switched and semi-permanent virtual-channel connections
- Cell sequence integrity
- Traffic parameter negotiation and usage monitoring
ATM Service Categories

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

- **Non-real time**
  - Non-real time variable bit rate (nrt-VBR)
  - Available bit rate (ABR)
  - Unspecified bit rate (UBR)
ATM Bit Rate Services

![Diagram showing percentage of line capacity over time with different bit rate services: available bit rate and unspecified bit rate, variable bit rate, constant bit rate.](image)
Real Time Services

- Amount of delay
- Variation of delay (jitter)
CBR

- Fixed bit rate continuously available
- Data sent in a steady stream
- Analogous to leased line
- Tight upper bound on delay
- Uncompressed audio and video
  - Video conferencing
  - Interactive audio
  - A/V distribution and retrieval
rt-VBR

- Time sensitive application
  - Tightly constrained delay and delay variation
- rt-VBR applications transmit at a rate that varies with time
- e.g. compressed video
  - Produces varying sized image frames
  - Original (uncompressed) frame rate constant
  - So compressed data rate varies
- Can statistically multiplex connections
nrt-VBR

- May be able to characterize expected traffic flow
- Improve QoS in loss and delay
- End system specifies:
  - Peak cell rate
  - Sustainable or average rate
  - Measure of how bursty traffic is
- e.g. Airline reservations, banking transactions
UBR

- Does not guarantee any throughput levels
- May be additional capacity over and above that used by CBR and VBR traffic
  - Not all resources dedicated
  - Bursty nature of VBR
- For application that can tolerate some cell loss or variable delays
  - e.g. TCP based traffic, file transfers
- Cells forwarded on FIFO basis
- Best efforts service
ABR

- Application specifies peak cell rate (PCR) and minimum cell rate (MCR)
- allows data to be “bursting” at higher capacities when the network is free
- Resources allocated to give at least MCR
- Spare capacity shared among all ARB sources
- e.g. LAN interconnection
<table>
<thead>
<tr>
<th>Technology</th>
<th>Speed</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>1.544 Mbps</td>
<td>24 Multiplexed channels</td>
</tr>
<tr>
<td>T3</td>
<td>44.736 Mbps</td>
<td>672 Multiplexed channels</td>
</tr>
<tr>
<td>X.25</td>
<td>64 Kbps</td>
<td>Packet switching, error correction, store and forward, with round trip delay</td>
</tr>
<tr>
<td>SMDS</td>
<td>1.533 – 45 Mbps</td>
<td>Fixed cell length with no error checking</td>
</tr>
<tr>
<td>SONET</td>
<td>51.8 Mbps (OC-1)</td>
<td>OC2 is 2 x OC1, OC3 is 3 x OC1</td>
</tr>
<tr>
<td>BISDN</td>
<td>155 - 622 Mbps</td>
<td>Uses ATM Technologies over SONET-based transmission circuits</td>
</tr>
<tr>
<td>Frame Relay</td>
<td>56 Kbps – 1.544 Mbps</td>
<td>Varying length frames with permanent virtual circuit</td>
</tr>
<tr>
<td>ATM</td>
<td>155 - 622 Mbps</td>
<td>Fixed length packets; Works on SONET and T carrier lines; Uses virtual circuits</td>
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