High Speed LANs

- Range of technologies
  - Fast and Gigabit Ethernet
  - Fibre Channel
  - High Speed Wireless LANs
Why High Speed LANs?

- Office LANs used to provide basic connectivity
  - Connecting PCs and terminals to mainframes and midrange systems that ran corporate applications
  - Providing workgroup connectivity at departmental level
  - Traffic patterns were light
    - Emphasis on file transfer and electronic mail
- Speed and power of PCs has risen
  - Graphics-intensive applications and GUIs
- MIS organizations recognize LANs as essential
  - Began with client/server computing
    - Now dominant architecture in business environment
    - Intranetworks
    - Frequent transfer of large volumes of data

Applications Requiring High Speed LANs

- Centralized server farms
  - User needs to draw huge amounts of data from multiple centralized servers
  - E.g. Color publishing
    - Servers contain tens of gigabytes of image data
    - Downloaded to imaging workstations
- Power workgroups
- Small number of cooperating users
  - Draw massive data files across network
  - E.g. Software development group testing new software version or computer-aided design (CAD) running simulations
- High-speed local backbone
  - Processing demand grows
  - LANs proliferate at site
  - High-speed interconnection is necessary
Ethernet (CSMA/CD)

- Carriers Sense Multiple Access with Collision Detection
- Developed by Xerox – original Ethernet
- IEEE 802.3

IEEE802.3
Medium Access Control

- Random Access
  - Stations access medium randomly
- Contention
  - Stations content for time on medium
ALOHA

- Packet Radio
- When station has frame, it sends
- Station listens (for max round trip time) plus small increment
- If ACK, fine. If not, retransmit
- If no ACK after repeated transmissions, give up
- Frame check sequence (as in HDLC)
- If frame OK and address matches receiver, send ACK
- Frame may be damaged by noise or by another station transmitting at the same time (collision)
- Any overlap of frames causes collision
- Max utilization 18%

Slotted ALOHA

- Time in uniform slots equal to frame transmission time
- Need central clock (or other sync mechanism)
- Transmission begins at slot boundary
- Frames either miss or overlap totally
- Max utilization 37%
**CSMA**

- Propagation time is much less than transmission time
- All stations know that a transmission has started almost immediately
- First listen for clear medium (carrier sense)
- If medium idle, transmit
- If two stations start at the same instant, collision

- Wait reasonable time (round trip plus ACK contention)
- If no ACK then retransmit
- Max utilization depends on propagation time (medium length) and frame length
  — Longer frame and shorter propagation gives better utilization

---

**CSMA Persistence and Backoff**

- **Nonpersistent:**
  - Transmit if idle
  - If busy, wait random time and repeat process
  - If collision, back off

- **1-Persistent:**
  - Transmit as soon as channel goes idle
  - If collision, back off

- **P-Persistent:**
  - Transmit as soon as channel goes idle with probability P
  - Otherwise, delay one time slot and repeat process
  - If collision, back off
**Nonpersistent CSMA**

- Nonpersistent CSMA rules:
  1. if medium idle, transmit
  2. if medium busy, wait amount of time drawn from probability distribution (retransmission delay) & retry
- random delays reduces probability of collisions
- capacity is wasted because medium will remain idle following end of transmission
- nonpersistent stations are deferential

**1-persistent CSMA**

- To avoid idle channel time that non-persistent protocol used
- Station wishing to transmit listens and obeys following:
  1. If medium idle, transmit; otherwise, go to step 2
  2. If medium busy, listen until idle; then transmit immediately
- 1-persistent stations are selfish
- If two or more stations are waiting, collision guaranteed
  — Gets sorted out after collision
P-persistent CSMA

• Compromise that attempts to reduce collisions
  — Like nonpersistent
• And reduce idle time
  — Like 1-persistent
• Rules:
  1. If medium idle, transmit with probability \( p \), and delay one time unit with probability \( 1 - p \)
     • Time unit typically maximum propagation delay
  2. If medium busy, listen until idle and repeat step 1
  3. If transmission is delayed one time unit, repeat step 1
• What is an effective value of \( p \)?

Value of \( p \)?

• Avoid instability under heavy load
• If \( n \) stations waiting to send then \( np \) stations will start transmitting
• If \( np > 1 \) on average there will be a collision
  — Repeated attempts to transmit almost guaranteeing more collisions
  — Retries compete with new transmissions
  — Eventually, all stations trying to send
    • Continuous collisions; zero throughput
• So \( np < 1 \) for expected peaks of \( n \)
  — If heavy load expected, \( p \) small
  — However, as \( p \) made smaller, stations wait longer
    • At low loads, this gives very long delays
CSMA/CD

- With CSMA, collision occupies medium for duration of transmission
- Stations listen whilst transmitting

1. If medium idle, transmit, otherwise, step 2
2. If busy, listen for idle, then transmit
3. If collision detected, jam then cease transmission
4. After jam, wait random time then start from step 1
Which Persistence Algorithm?

- IEEE 802.3 uses 1-persistent
- Both nonpersistent and p-persistent have performance problems
- 1-persistent ($p = 1$) seems more unstable than p-persistent
  - Greed of the stations
  - But wasted time due to collisions is short (if frames long relative to propagation delay
  - With random backoff, unlikely to collide on next tries
  - IEEE 802.3 and Ethernet use binary exponential backoff

Binary Exponential Backoff

- Attempt to transmit repeatedly if repeated collisions
- First 10 attempts, mean value of random delay doubled
- Value then remains same for 6 further attempts
- After 16 unsuccessful attempts, station gives up and reports error
- As congestion increases, stations back off by larger amounts to reduce the probability of collision.
- 1-persistent algorithm with binary exponential backoff efficient over wide range of loads
  - Low loads, 1-persistence guarantees station can seize channel once idle
  - High loads, at least as stable as other techniques
- Backoff algorithm gives last-in, first-out effect
- Stations with few collisions transmit first
Collision Detection

- On baseband bus, collision produces much higher signal voltage than signal
- Collision detected if cable signal greater than single station signal
- Signal attenuated over distance
- Special collision presence signal

IEEE 802.3 Frame Format

<table>
<thead>
<tr>
<th>7 octets</th>
<th>1</th>
<th>6</th>
<th>6</th>
<th>2</th>
<th>3</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preamble</td>
<td>SFD</td>
<td>DA</td>
<td>SA</td>
<td>Length</td>
<td>LLC Data</td>
<td>Pad</td>
<td>FCS</td>
</tr>
</tbody>
</table>

SFD = Start of frame delimiter
DA = Destination address
SA = Source address
FCS = Frame check sequence
100Mbps Fast Ethernet

- Use IEEE 802.3 MAC protocol and frame format
- 100BASE-X use physical medium specifications from FDDI
  - Two physical links between nodes
    - Transmission and reception
  - 100BASE-TX uses STP or Cat. 5 UTP
    - May require new cable
  - 100BASE-FX uses optical fiber
  - 100BASE-T4 can use Cat. 3, voice-grade UTP
    - Uses four twisted-pair lines between nodes
    - Data transmission uses three pairs in one direction at a time
- Star-wire topology
  - Similar to 10BASE-T

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100Mbps (Fast Ethernet)

**Table 16.3 IEEE 802.3 100BASE-T Physical Layer Medium Alternatives**

<table>
<thead>
<tr>
<th></th>
<th>100BASE-TX</th>
<th>100BASE-FX</th>
<th>100BASE-T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission</td>
<td>2 pair, STP</td>
<td>2 pair, Category 5 UTP</td>
<td>2 optical fibers</td>
</tr>
<tr>
<td>medium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signaling</td>
<td>MLT-3</td>
<td>MLT-3</td>
<td>4B5B, NRZI</td>
</tr>
<tr>
<td>technique</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data rate</td>
<td>100 Mbps</td>
<td>100 Mbps</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>Maximum</td>
<td>100 m</td>
<td>100 m</td>
<td>100 m</td>
</tr>
<tr>
<td>segment length</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network span</td>
<td>200 m</td>
<td>200 m</td>
<td>400 m</td>
</tr>
</tbody>
</table>
100BASE-X Data Rate and Encoding

- Unidirectional data rate 100 Mbps over single link
  - Single twisted pair, single optical fiber
- Encoding scheme same as FDDI
  - 4B/5B-NRZI
  - Modified for each option

100BASE-X Media

- Two physical medium specifications
- 100BASE-TX
  - Two pairs of twisted-pair cable
  - One pair for transmission and one for reception
  - STP and Category 5 UTP allowed
  - The MTL-3 signaling scheme is used
- 100BASE-FX
  - Two optical fiber cables
  - One for transmission and one for reception
  - Intensity modulation used to convert 4B/5B-NRZI code group stream into optical signals
  - 1 represented by pulse of light
  - 0 by either absence of pulse or very low intensity pulse
**100BASE-T4**

- 100-Mbps over lower-quality Cat 3 UTP
  - Taking advantage of large installed base
  - Cat 5 optional
  - Does not transmit continuous signal between packets
  - Useful in battery-powered applications
- Can not get 100 Mbps on single twisted pair
  - Data stream split into three separate streams
    - Each with an effective data rate of 33.33 Mbps
  - Four twisted pairs used
  - Data transmitted and received using three pairs
  - Two pairs configured for bidirectional transmission
- NRZ encoding not used
  - Would require signaling rate of 33 Mbps on each pair
  - Does not provide synchronization
  - Ternary signaling scheme (8B6T)

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**100BASE-T Options**

- **100BASE-T**
  - **100BASE-X**
    - **100BASE-TX**
      - 2 Category 5 UTP
    - **100BASE-FX**
      - 2 Optical Fiber
    - **100BASE-T4**
      - 4 Category 3 or Category 5 UTP
Full Duplex Operation

- Traditional Ethernet half duplex
  - Either transmit or receive but not both simultaneously
- With full-duplex, station can transmit and receive simultaneously
- 100-Mbps Ethernet in full-duplex mode, theoretical transfer rate 200 Mbps
- Attached stations must have full-duplex adapter cards
- Must use switching hub
  - Each station constitutes separate collision domain
  - In fact, no collisions
  - CSMA/CD algorithm no longer needed
  - 802.3 MAC frame format used
  - Attached stations can continue CSMA/CD

Mixed Configurations

- Fast Ethernet supports mixture of existing 10-Mbps LANs and newer 100-Mbps LANs
- E.g. 100-Mbps backbone LAN to support 10-Mbps hubs
  - Stations attach to 10-Mbps hubs using 10BASE-T
  - Hubs connected to switching hubs using 100BASE-T
    - Support 10-Mbps and 100-Mbps
    - High-capacity workstations and servers attach directly to 10/100 switches
    - Switches connected to 100-Mbps hubs using 100-Mbps links
    - 100-Mbps hubs provide building backbone
      - Connected to router providing connection to WAN
Gigabit Ethernet - Differences

- Carrier extension
- At least 4096 bit-times long
  - (for 10/100 Mbps minimum is 512)
- Frame bursting
  - allow multiple frames to be transmitted consecutively, i.e. “together”
**Gigabit Ethernet – Physical**

- 1000Base-SX
  - Short wavelength, multimode fiber
- 1000Base-LX
  - Long wavelength, Multi or single mode fiber
- 1000Base-CX
  - Copper jumpers <25m, shielded twisted pair
- 1000Base-T
  - 4 pairs, cat 5 UTP

---

**Gbit Ethernet Medium Options (log scale)**

<table>
<thead>
<tr>
<th>Medium Type</th>
<th>Distance Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000BASE-LX</td>
<td>10-μm single-mode fiber, 50-μm multimode fiber, 62.5-μm multimode fiber</td>
</tr>
<tr>
<td>1000BASE-SX</td>
<td>50-μm multimode fiber, 62.5-μm multimode fiber</td>
</tr>
<tr>
<td>1000BASE-T</td>
<td>Category 5 UTP</td>
</tr>
<tr>
<td>1000BASE-CX</td>
<td>Shielded cable</td>
</tr>
</tbody>
</table>

Maximum distance range: 25 m to 5000 m
10Gbps Ethernet - Uses

- High-speed, local backbone interconnection between large-capacity switches
- Server farm, Campus wide connectivity
- Enables Internet service providers (ISPs) and network service providers (NSPs) to create very high-speed links at very low cost
- Allows construction of (MANs) and WANs
  — Connect geographically dispersed LANs between campuses or points of presence (PoPs)
- Ethernet competes with ATM and other WAN technologies
- 10-Gbps Ethernet provides substantial value over ATM

10Gbps Ethernet - Advantages

- No expensive, bandwidth-consuming conversion between Ethernet packets and ATM cells
  — Network is Ethernet, end to end
- IP and Ethernet together offer QoS and traffic policing capabilities approach those provided by ATM
- Variety of standard optical interfaces (wavelengths and link distances) specified for 10 Gb Ethernet
  — Optimizing operation and cost for LAN, MAN, or WAN
10Gbps Ethernet - Advantages

- Maximum link distances cover 300 m to 40 km
- Full-duplex mode only
- 10GBASE-S (short):
  - 850 nm on multimode fiber
  - Up to 300 m
- 10GBASE-L (long)
  - 1310 nm on single-mode fiber
  - Up to 10 km
- 10GBASE-E (extended)
  - 1550 nm on single-mode fiber
  - Up to 40 km
- 10GBASE-LX4:
  - 1310 nm on single-mode or multimode fiber
  - Up to 10 km
  - Wavelength-division multiplexing (WDM) bit stream across four light waves

10Gbps Ethernet Distance Options (log scale)
Token Ring (802.5)

- One should at least know the basic issues

Token Ring (802.5)

- Developed from IBM's commercial token ring
- Because of IBM's presence, token ring has gained broad acceptance
- Never achieved popularity of Ethernet
- Currently, there is still large installed base of token ring products
  — Market share likely to decline
Ring Operation

- Each repeater connects to two others via unidirectional transmission links
- Single closed path
- Data transferred bit by bit from one repeater to the next
- Repeater regenerates and retransmits each bit
- Repeater performs data insertion, data reception, data removal
- Repeater acts as attachment point
- Packet removed by transmitter after one trip round ring

Listen State Functions

- Scan passing bit stream for patterns
  - Address of attached station
  - Token permission to transmit
- Copy incoming bit and send to attached station
  - Whilst forwarding each bit
- Modify bit as it passes
  - e.g. to indicate a packet has been copied (ACK)
Transmit State Functions

- Station has data
- Repeater has permission
- May receive incoming bits
  - If ring bit length shorter than packet
    - Pass back to station for checking (ACK)
  - May be more than one packet on ring
    - Buffer for retransmission later

Bypass State

- Signals propagate past repeater with no delay (other than propagation delay)
- Partial solution to reliability problem (see later)
- Improved performance
802.5 MAC Protocol

- Small frame (token) circulates when idle
- Station waits for token
- Changes one bit in token to make it SOF for data frame
- Append rest of data frame
- Frame makes round trip and is absorbed by transmitting station
- Station then inserts new token when transmission has finished and leading edge of returning frame arrives
- Under light loads, some inefficiency
- Under heavy loads, round robin
**Dedicated Token Ring**

- Central hub
- Acts as switch
- Full duplex point to point link
- Concentrator acts as frame level repeater
- No token passing
### 802.5 Physical Layer

<table>
<thead>
<tr>
<th>Date rate</th>
<th>4</th>
<th>16</th>
<th>100</th>
<th>100</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>transmission medium</td>
<td>UTP or STP or fiber</td>
<td>UTP or STP or fiber</td>
<td>UTP or STP</td>
<td>Fiber</td>
<td>Fiber</td>
</tr>
<tr>
<td>Signaling</td>
<td>Diff Manchester</td>
<td>Diff. Manchester</td>
<td>MLT-3</td>
<td>4B5B, NRZI</td>
<td>8B/10B</td>
</tr>
<tr>
<td>Max frame size</td>
<td>4550</td>
<td>18,200</td>
<td>18,200</td>
<td>18,200</td>
<td>18,200</td>
</tr>
<tr>
<td>Access control</td>
<td>TP or DTR</td>
<td>TP or DTR</td>
<td>DTR</td>
<td>DTR</td>
<td>DTR</td>
</tr>
</tbody>
</table>

TP = token passing access control  
DTR = dedicated token ring

---

### Fibre Channel - Background

- **I/O channel**
  - Direct point to point or multipoint communication link  
  - Hardware based  
  - High Speed  
  - Very short distance  
  - User data moved from source buffer to destination buffer

- **Network connection**
  - Interconnected access points  
  - Software based protocol  
  - Flow control, error detection & recovery  
  - End systems connections
Fibre Channel

- Best of both technologies
- Channel oriented
  - Data type qualifiers for routing frame payload
  - Link level constructs associated with I/O ops
  - Protocol interface specifications to support existing I/O architectures
    - e.g. SCSI
- Network oriented
  - Full multiplexing between multiple destinations
  - Peer to peer connectivity
  - Internetworking to other connection technologies

Fibre Channel Requirements

- Full duplex links with two fibers per link
- 100 Mbps to 800 Mbps on single line
  - Full duplex 200 Mbps to 1600 Mbps per link
- Up to 10 km
- Small connectors
- High-capacity utilization, distance insensitivity
- Greater connectivity than existing multidrop channels
- Broad availability
  - i.e. standard components
- Multiple cost/performance levels
  - Small systems to supercomputers
- Carry multiple existing interface command sets for existing channel and network protocols
- Uses generic transport mechanism based on point-to-point links and a switching network
- Supports simple encoding and framing scheme
- In turn supports a variety of channel and network protocols
Fibre Channel Elements

- End systems - Nodes
- Switched elements - the network or fabric
- Communication across point to point links

Fibre Channel Network
Fibre Channel Protocol Architecture (1)

- FC-0 Physical Media
  - Optical fiber for long distance
  - coaxial cable for high speed short distance
  - STP for lower speed short distance
- FC-1 Transmission Protocol
  - 8B/10B signal encoding
- FC-2 Framing Protocol
  - Topologies
  - Framing formats
  - Flow and error control
  - Sequences and exchanges (logical grouping of frames)

Fibre Channel Protocol Architecture (2)

- FC-3 Common Services
  - Including multicasting
- FC-4 Mapping
  - Mapping of channel and network services onto fibre channel
    - e.g. IEEE 802, ATM, IP, SCSI
Fibre Channel Physical Media

<table>
<thead>
<tr>
<th></th>
<th>800 Mbps</th>
<th>400 Mbps</th>
<th>200 Mbps</th>
<th>100 Mbps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single mode fiber</td>
<td>10 km</td>
<td>10 km</td>
<td>10 km</td>
<td>—</td>
</tr>
<tr>
<td>50-μm multimode fiber</td>
<td>0.5 km</td>
<td>1 km</td>
<td>2 km</td>
<td>—</td>
</tr>
<tr>
<td>62.5-μm multimode fiber</td>
<td>175 m</td>
<td>1 km</td>
<td>1 km</td>
<td>—</td>
</tr>
<tr>
<td>Video coaxial cable</td>
<td>50 m</td>
<td>71 m</td>
<td>100 m</td>
<td>100 m</td>
</tr>
<tr>
<td>Miniature coaxial cable</td>
<td>14 m</td>
<td>19 m</td>
<td>28 m</td>
<td>42 m</td>
</tr>
<tr>
<td>Shielded twisted pair</td>
<td>28 m</td>
<td>46 m</td>
<td>57 m</td>
<td>80 m</td>
</tr>
</tbody>
</table>

Fibre Channel Fabric

- General topology called fabric or switched topology
- Arbitrary topology includes at least one switch to interconnect number of end systems
- May also consist of switched network
  - Some of these switches supporting end nodes
- Routing transparent to nodes
  - Each port has unique address
  - When data transmitted into fabric, edge switch to which node attached uses destination port address to determine location
  - Either deliver frame to node attached to same switch or transfers frame to adjacent switch to begin routing to remote destination
Fabric Advantages

- Scalability of capacity
  - As additional ports added, aggregate capacity of network increases
  - Minimizes congestion and contention
  - Increases throughput
- Protocol independent
- Distance insensitive
- Switch and transmission link technologies may change without affecting overall configuration
- Burden on nodes minimized
  - Fibre Channel node responsible for managing point-to-point connection between itself and fabric
  - Fabric responsible for routing and error detection

Alternative Topologies

- Point-to-point topology
  - Only two ports
  - Directly connected, with no intervening switches
  - No routing
- Arbitrated loop topology
  - Simple, low-cost topology
  - Up to 126 nodes in loop
  - Operates roughly equivalent to token ring
- Topologies, transmission media, and data rates may be combined
Five Applications of Fibre Channel

1. Linking high-performance workstation clusters
2. Connecting mainframes to each other
3. Giving server farms high-speed pipes
4. Linking LANs and WANs to the backbone
5. Clustering disk farms

Fibre Channel Prospects

- Backed by Fibre Channel Association
- Interface cards for different applications available
- Most widely accepted as peripheral device interconnect
  - To replace such schemes as SCSI
- Technically attractive to general high-speed LAN requirements
- Must compete with Ethernet and ATM LANs
- Cost and performance issues should dominate the consideration of these competing technologies
Summary

• High speed LANs emergence
• Ethernet technologies
  — CSMA & CSMA/CD media access
  — 10Mbps ethernet
  — 100Mbps ethernet
  — 1Gbps ethernet
  — 10Gbps ethernet
• Fibre Channel