- History
  - Xerox: LAN for open office automation (1970s)
    - 3Mbps on 75 Ohm Coax, coverage 1km area
  - DEC, Intel, and Xerox: Co-proposed “Ethernet v1.0” (9/1980)
  - D.I.X. ⇒ Ethernet ver 2.0 (11/1982): 50Ohm Coax, 2.8 km

- ANSI/IEEE 802.3 (ISO 8802.3)
  - Reformulated Ethernet v2 in 1985
  - Drop cable, connector technology, times and fields are redefined
  - It’s used with Ethernet interchangeably, but less meaningful than Ethernet (retain the original name)
  - Supplementary documents (regarding to various medium)
    + Upgrades are published after Feb.1989 ⇒ IEEE 802.3x

Notation of Ethernet Technology

- Bit rate in Mbps:
  -1, -10, -100, -1000, -10000

- Distance in 100m:
  - 2, 5, 36, or

- Signaling method:
  - Baseband
  - Broadband

- Medium:
  - 10/100 ⇒ T?/TX or F/FX
  - 1GE ⇒ (C/S/L)X or T
  - 10GE ⇒ (S/L/E)(X/R/W)

More on Ethernet Family
**Bus Topology -- 10Base2/5/36**

- Connecting nodes via (tap to) coaxial cable
- Transmission and receiving over the same media (line)
- Basic configuration (Ex: A 10Base5 segment = a coax):

![Diagram of Bus Topology](image)

- Important parameters: TRL, DBT, NPS, MSL, and MND.

**Star/Tree Topology -- 10BaseT/F, 1Base5**

- Connecting nodes via (tap to) UTP / FO
- Transmission and receiving over separate media (line)
- Basic configuration (Ex: one 10BaseT segment)

![Diagram of Star/Tree Topology](image)

**Explanation of the Abbreviations**

- **TRL** ~ Transceiver’s cable Length
- **DBN** ~ Distance Between Nodes
- **NPS** ~ Nodes Per Segment
- **MSL** ~ Maximum Segment Length
- **MES** ~ Maximum Extendable Segments

**Transmitting and Receiving Frames**

- All stations are in the same “collision domain”
- Physically a star, logically a bus

![Diagram of Transmitting and Receiving Frames](image)
**IEEE 802.3 (MAC) Frame Format**

<table>
<thead>
<tr>
<th>7</th>
<th>1</th>
<th>6</th>
<th>6</th>
<th>2</th>
<th>46 ≤ bytes ≤ 1500</th>
<th>4 bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td>2</td>
<td>46 ≤ bytes ≤ 1500</td>
<td>4 bytes</td>
</tr>
</tbody>
</table>

- **Preamble** (10101010 ... 10101010) for receiving synchronization
- **SFD**: Start Frame Delimiter (10101011)
- **DA**: Destination Address
- **SA**: Source Address
- **L/T**: Length of LLC-Frame / Protocol type
- **LLC-Frame**: Greater than 46 but up to 1500 bytes
- **PAD**: Padding when LLC-Frame < 46 bytes
- **FCS**: Frame Check Sequence (CRC-32)

MAC-frame size -- from DA to FCS
- Min (18+46) bytes to distinguish from collision
- Max (18+1500) bytes to prevent dominating bandwidth/channel

**IEEE 802.3 versus Ethernet II**

In practice, however, both frame formats can coexist on the same physical coax. This is done by using protocol type numbers (type field) greater than 1,500 in the Ethernet frame. However, different device drivers are needed to handle each of these formats.

**Length/Type field**

- Used in two different way:
  ~ indicating “length of data field”, not including any padding (by IEEE -- a true standard way)
  ~ indicating the “type of data” (by DIX)
- How do we know which one is being interpreted?
  If 1500 ≥ L/T > 0 ⇒ data size/length ← IEEE frame (802.3)
  If L/T > 1500 ⇒ protocol type ← Ethernet II / DIX frame

- The reason for this is rooted in how Ethernet become a standard.
- Fortunately, Ethernets’ hardware never use L/T field.
  It is there strictly for the convenience of the higher-layer protocols.

**Node’s operation**

- **Repeater**’s operation: Copy what received and sent to all, no filtering. Refresh preamble and regenerate incoming frames
- **Node’s (NIC) operation modes (upon sensing a frame):**
  1. **Address filtering - unicast and multicasting**
     - selects (if MAC address matched) and copies to node
  2. **Broadcast**
     - sent to all by letting MAC = 48 1’s
     - used very often for searching for other stations (Discovery)
  3. **Promiscuous** ← copies any presented-frames
     - turn off filtering and copy all frames received (regardless of Destination’s MAC address)
     - for diagnostic and network traffic monitoring
Some Key Parameters

Path Delay Value = time difference between two nodes, in terms of propagation delay

- Collision Window (= Maximum PDV)*
  - the time between when a MAC transmits the first bit of a frame and when it detects a collision with any node on the LAN
  - proportional to network diameter (positively)
- Max allowable C.W. = 512 bit times (in specification)
  - called Slot time
  - It determines Min frame size and Max network diameter.
- Min Frame Size = 512 bits (64 bytes)
- Network Diameter
  - the max. cable distance between any two stations
  - Collision domain
  - the nodes that share an Ethernet using the CSMA/CD rules

Other Key Parameters:

- InterFrame gap (IPG) = 96 bit-time
  - the minimum period to be waiting for the end of the last transmitted frame/packet
  - Let stations to sense channel idle

- JamSize = 32 bit (For collision enforcement)
- AttempLimit = 16 (Max # of retransmissions)
- BackoffLimit = 10 (Max # of backoff times)
- MaxFrameSize = 1518 bytes
- MinFrameSize = 64 bytes
- AddressSize = 48 bits

CSMA/CD

The soul of Ethernet and IEEE 802.3

• Operation:
  A station with data ready for transmission first listens (senses) to the channel/medium before its frame transmission:
  1. If the channel → Idle ⇒ transmits frame; otherwise, go to 2.
  2. If the channel → busy ⇒ continues to listen until idle, then transmits frame immediately (1-persistent CSMA/CD)
  3. Senses carrier while transmission. If collision detected during transmission ⇒ transmits jamming signal and ceases its transmission
  4. Waits a random time (back-off) and attempt to transmit again (back to step 1)

Transmitting a Frame
Back-off Algorithm - Collision Recovery

- **Collision back-off and retransmission in Ethernets**
  ~ **Truncated Binary Exponential Back-off Algorithm (BEBA)**

Let \( n = \text{number of collisions experienced} \) \( (n \leq 16) \)

\[ k = \min(n, 10) \]

Let \( r = \min(n, 10) \) \( \Rightarrow \) Truncation

Then retry in the \( r \)-th slot-time, \( 1 \leq r \leq 2^k \)

~ Back-off time = \( \text{RAND}(0, 2^{\min(n, 10)}) \) \( \Rightarrow \) Waiting for # of slot-time

- **Disadvantage of BEBA** ~ unfair

  ✈ Last-in-First-out effect:
  - Stations with no or few collisions will have a better chance to transmit before stations that have waited longer.

Example: 10Base5 Medium Specification

- **10Mbps, Manchester encoding**
  - Use a 50-ohm(D=10mm) coaxial cable (characteristic impedance = 50 ohm)
    (Impedance is a measure of how much voltage must be applied to the cable to achieve a certain signal strength)
  - The maximum length of a segment is **500m**
  - The maximum length of a 10Base5 network is 2500m
  - The distance between any two adjacent taps being a multiple of 2.5m (Tap); A maximum of 100 taps is allowed
  - Slot time = 51.2 us; IFG = 9.6us
  - Packet size: 64 bytes (Min) ~ 1518 bytes (Max)
Manchester Encoding for 10Base Ethernet

Coaxial Cable -- speed = 0.77C

- Bit interval

For 10BaseTx:
- 1/(10Mbps) = 0.1 us

- Basic 10Base2 Ethernet LAN (one segment)

- Thin cable (for 10Base2) is thinner and supports fewer taps over shorter distance than thick cable (for 10Base5)
- For 10base2 Ethernet, a transceiver is replaced by a simple T-connector

10Base2 Example

CSMA/CD Collision for the Farest Stations

TIME t1:
A's transmission
C's transmission
Signal on bus

TIME t2:
A's transmission
C's transmission
Signal on bus

TIME t3:
A's transmission
C's transmission
Signal on bus

t1: B and C ready to TX, but B defers upon sensing the carrier from A

t2: C detects collision and ceases TX

t3: collision propagates to A and A ceases TX
Collision Detection and Late Collision

- An undetected collision

Extensions of Bus (10Base2/5) Networks

- Two segments (Cable) Ethernet (10Base5 for each segment)

Extending 10Base5 Ethernet with Repeater/Half-repeater

(max length A ⊕ N = 2,500m)

Slot time (Collision window) calculation

<table>
<thead>
<tr>
<th>元件</th>
<th>元件満定延遲</th>
<th>元件啟動延遲</th>
<th>元件前進路程</th>
<th>元件回程路程</th>
<th>整體延遲</th>
</tr>
</thead>
<tbody>
<tr>
<td>編碼器</td>
<td>0.1us</td>
<td>0.1us</td>
<td>5</td>
<td>5</td>
<td>2.0us</td>
</tr>
<tr>
<td>收發器電路</td>
<td>5.13us/公里</td>
<td>0</td>
<td>300公里</td>
<td>300公里</td>
<td>3.08us</td>
</tr>
<tr>
<td>收發器（前進路程）</td>
<td>0.05us</td>
<td>0.3us</td>
<td>3</td>
<td>3</td>
<td>2.10us</td>
</tr>
<tr>
<td>收發器（回程路程）</td>
<td>0.05us</td>
<td>0.6us</td>
<td>0</td>
<td>3</td>
<td>1.95us</td>
</tr>
<tr>
<td>半訊號增益器 (repeater)</td>
<td>0</td>
<td>0.9us</td>
<td>0</td>
<td>3</td>
<td>2.7us</td>
</tr>
<tr>
<td>同軸電纜</td>
<td>4.33us/公里</td>
<td>0</td>
<td>1500公里</td>
<td>1500公里</td>
<td>12.99us</td>
</tr>
<tr>
<td>半訊號增益器間電纜</td>
<td>5.13us/公里</td>
<td>0</td>
<td>1000公里</td>
<td>1000公里</td>
<td>10.26us</td>
</tr>
<tr>
<td>電纜終端</td>
<td>0.1us</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0.40us</td>
</tr>
<tr>
<td>電纜接收器</td>
<td>0.1us</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0.40us</td>
</tr>
<tr>
<td>變換訊號器 (接收器)</td>
<td>0.2us</td>
<td>0.4us</td>
<td>2</td>
<td>0</td>
<td>1.20us</td>
</tr>
<tr>
<td>變換訊號器 (發射器)</td>
<td>0.2us</td>
<td>0.2us</td>
<td>0</td>
<td>2</td>
<td>0.80us</td>
</tr>
<tr>
<td>電流感受器</td>
<td>0</td>
<td>0.2us</td>
<td>5</td>
<td>0</td>
<td>1.00us</td>
</tr>
<tr>
<td>電流感受器</td>
<td>0</td>
<td>0.2us</td>
<td>0</td>
<td>5</td>
<td>1.00us</td>
</tr>
<tr>
<td>訊號上升時間 (到 70% 的500公里處)</td>
<td>0.2us</td>
<td>0</td>
<td>3</td>
<td>6.00us</td>
<td></td>
</tr>
<tr>
<td>訊號上升時間 (到 50% 的500公里處)</td>
<td>0</td>
<td>0.2us</td>
<td>0</td>
<td>1</td>
<td>0.20us</td>
</tr>
</tbody>
</table>
Approximating the Slot-time

- (refer to five-segment 10Base5 configuration)
- Round-trip propagation delay (A to N) = \(46.38 \text{ us}\)
- For 10Mbps Ethernet, Data bits that can be transmitted in this duration
  \[= 46.38 \times 10^{-6} \times 10^7 = 463.8 \text{ bits}\]
- For convenient,
  Let slot time = \(51.2 \text{ us} \Rightarrow 512 \text{ bits}\)

5-4-3-2-1 Design Rule for Bused Ethernet

- Design of an cabled Ethernet network:
  - Max no of segments = 5
  - Max no of repeaters = 4
  - Max no of populated segments = 3
  - Min. TWO of five segments function as an inter-link between repeater, called IRL.
  - All stations are located in the same ONE collision domain

- Repeaters ~ extending the length of the network; segment are not “isolated” (collision ??)

- No loop allowed ~ limiting one path (of segments and repeater) between any two stations
  (It is user’s responsibility to make it loop-free)

5-4 --1 Rule for 10BaseT Ethernet

- 5 ~ limited to Five segments; 4 ~ limited to Four Hubs; 1 ~ One collision domain

- restrictions \(\Rightarrow\) time constraint of Ethernet (512 bit time = 51.2 uS)
- if violated \(\Rightarrow\) packets lost \(\Rightarrow\) excessive re-sends degrade network performance or create trouble for application

Ethernet Wiring Examples

10Base5

10Base2

10BaseT
### Comparison of various Ethernet Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>10BASE2</th>
<th>10BASE5</th>
<th>10BASET</th>
<th>10BROAD36</th>
<th>10BaseFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>50BASE</td>
<td>50BASE</td>
<td>50BASE</td>
<td>50BASE</td>
<td>50BASE</td>
</tr>
<tr>
<td>Encoding</td>
<td>Manchester</td>
<td>Manchester</td>
<td>Manchester</td>
<td>Manchester</td>
<td>Manchester</td>
</tr>
<tr>
<td>Data rate</td>
<td>10 Mbps</td>
<td>10 Mbps</td>
<td>1 Mbps</td>
<td>10 Mbps</td>
<td>10 Mbps</td>
</tr>
<tr>
<td>Max distance</td>
<td>185 ft</td>
<td>500 ft</td>
<td>100 ft</td>
<td>1000 ft</td>
<td>3000 ft</td>
</tr>
<tr>
<td>Max distance</td>
<td>185 ft</td>
<td>500 ft</td>
<td>100 ft</td>
<td>1000 ft</td>
<td>3000 ft</td>
</tr>
<tr>
<td>Work area (ft)</td>
<td>100 ft</td>
<td>100 ft</td>
<td>100 ft</td>
<td>1000 ft</td>
<td>3000 ft</td>
</tr>
<tr>
<td>Topology</td>
<td>Bus</td>
<td>Bus</td>
<td>Star</td>
<td>Star</td>
<td>Bus/Tree</td>
</tr>
</tbody>
</table>

* "1" if per-media segment

### Throughput - Performance of CSMA/CD

- **Recall**
  - Packet starts at time 0
  - Packet almost at B at time t

- **Consider time on the medium to be organized into slots**
  - (slot time = the max time (2*W), from the start of transmission, required to detected a collision)

### Maximum Throughput (w/o collision)

<table>
<thead>
<tr>
<th>Frame Size (bytes)</th>
<th>Data Payload (bytes)</th>
<th>Max Frames/sec</th>
<th>Throughput (Bytes/sec)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1518</td>
<td>1500</td>
<td>1299116</td>
<td>97.53</td>
<td></td>
</tr>
<tr>
<td>1280</td>
<td>1262</td>
<td>1213461</td>
<td>97.08</td>
<td></td>
</tr>
<tr>
<td>1024</td>
<td>1006</td>
<td>1204502</td>
<td>96.36</td>
<td></td>
</tr>
<tr>
<td>512</td>
<td>494</td>
<td>1160714</td>
<td>92.86</td>
<td></td>
</tr>
<tr>
<td>256*</td>
<td>238</td>
<td>1077899</td>
<td>86.23*</td>
<td></td>
</tr>
<tr>
<td>128</td>
<td>110</td>
<td>929074</td>
<td>74.32</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>46</td>
<td>684524</td>
<td>54.76</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>32</td>
<td>476191</td>
<td>38.10</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>24</td>
<td>357143</td>
<td>28.57</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>16</td>
<td>238095</td>
<td>19.05</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>8</td>
<td>119048</td>
<td>9.52</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>3</td>
<td>44643</td>
<td>3.57</td>
<td></td>
</tr>
</tbody>
</table>

=* Sometimes, whole thing excluding IPG → a packet in Layer 1 |

### Frame in Ethernets

<table>
<thead>
<tr>
<th>Frame</th>
<th>Payload</th>
<th>I/T</th>
<th>LLC</th>
<th>PAD</th>
<th>FCS</th>
<th>IPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>56</td>
<td>8</td>
<td>48</td>
<td>48</td>
<td>16</td>
<td>12,000 max</td>
<td>32</td>
</tr>
<tr>
<td>96</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

=wire-speed traffic

### Throughput

- **Recall**
  - Packet starts at time 0
  - Packet almost at B at time t

- **Consider time on the medium to be organized into slots**
  - (slot time = the max time (2*W), from the start of transmission, required to detected a collision)
Why Faster Ethernet?

- Applications Driving Network Growth
  - Intranets, Extranets, and tons of Internet applications emerge
  - Multimedia, Video Conferencing
  - Scientific Modeling, CAD/CAM, Medical Applications
  - Data/Information Warehousing, Document Management
  - Killer applications? Call for higher bandwidth...

- Ethernet LANs - the Dominant Network Technology
  - Installed base of over 70 million nodes
  - > 80% Marketing share
  - Low cost of ownership
  - High reliability
  - Scaleable transmission capacity (10 → 100 → 1000 → higher?)
  - Simple to install and easy to manage

Characteristics of Fast Ethernet

- Data rate = 100 Mbps
- IEEE 802.3 CSMA/CD frame format (no priority) or Ethernet 2
- (Frame) Collision may encounter → still no “delay guarantee”
- Bandwidth utilization is not guaranteed to be fair
- Low bandwidth utilization under heavy load (1-persistence)
- Suitable for multimedia communications under moderate load
- Hub architecture → Good fault tolerance to links and nodes (dedicated/independent path for each station)

- 100BaseT4
  - Use Voice-grade Category 3 UTP or upper
  - Use four pairs of twisted-pair wires

- 100BaseX (TX and FX)
  - Category 5 UTP, STP, or Fiber optic

Autonegotiation (in 100Base-X)

- Allows PHYs to automatically detect layer-1 and layer-2 features of the device on the other end by QUERY, and determine the compatible mode of operation ~ called N-WAY Autonegotiation.
- Query ~ sending and listening a special link integrity pulse which encoding the PHY’ capabilities
- Allows plug-and-play operation
- Configuration the links with no users’ intervention (no DIP switch, configuration file, or setup screen)

- Priority for operation modes (from the highest to the lowest):
  1. 100BaseTX or 100BaseFX, FDX mode (Full Duplex)
  2. 100BaseT4
  3. 100BaseTX, HDX
  4. 10BaseT, FDX
  5. 10BaseT, HDX

- Autonegotiation can be disable (IEEE 802.3u) for explicitly configuration required

Fast Ethernet

- IEEE 802.3u, issued in 3/1995 (drafted in late 1994)
- Goal: to provide a low-cost, Ethernet compatible LAN operating at 100Mbps while retaining the same wiring systems, MAC method, and frame format

- Results: 100Base-T series (as shown)
Important Parameters for Fast Ethernet

- Max allowable C.W. = 512 bit times = **5.12μS**
  - called Slot time
  - It determines Min frame size and Max network diameter.
- Network Diameter = **205m** (generally)
- InterFrame gap (IPG) = 96 bit time = **0.96μS**
- JamSize = 32 bit (For collision enforcement)
- AttemptLimit = 16 (Max # of retransmissions)
- BackoffLimit = 10 (Max # of backoff times)
- MaxFrameSize = 1518 bytes
- MinFrameSize = 64 bytes
- AddressSize = 48 bits

Comparisons of Ethernet and Fast Ethernet

<table>
<thead>
<tr>
<th>Type of medium</th>
<th>Number of connections</th>
<th>Segment length</th>
<th>Attenuation per segment</th>
<th>Propagation speed</th>
<th>Max. delay per segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>10base5</td>
<td>100</td>
<td>500 m</td>
<td>8.5 dB</td>
<td>0.77 c</td>
<td>2165 ns</td>
</tr>
<tr>
<td>10base2</td>
<td>30</td>
<td>185 m</td>
<td>8.5 dB</td>
<td>0.65 c</td>
<td>950 ns</td>
</tr>
<tr>
<td>10base36</td>
<td>3</td>
<td>3.6 km</td>
<td>36 to 52 dB</td>
<td>0.87 c</td>
<td>14000 ns</td>
</tr>
<tr>
<td>10baseFP</td>
<td>33</td>
<td>2 x 300 m</td>
<td>26 dB</td>
<td>0.66 c</td>
<td>5000 ns</td>
</tr>
<tr>
<td>100baseT</td>
<td>4</td>
<td>1 km</td>
<td>9 dB</td>
<td>0.96 c</td>
<td>5000 ns</td>
</tr>
<tr>
<td>100baseF</td>
<td>2</td>
<td>250 m</td>
<td>6.5 dB</td>
<td>0.59 c</td>
<td>4000 ns</td>
</tr>
<tr>
<td>100baseT</td>
<td>2</td>
<td>100 m</td>
<td>11.5 dB</td>
<td>0.59 c</td>
<td>10000 ns</td>
</tr>
<tr>
<td>100baseFX</td>
<td>2</td>
<td>2 km</td>
<td>12.5 dB</td>
<td>0.66 c</td>
<td>10000 ns</td>
</tr>
<tr>
<td>100baseFX</td>
<td>2</td>
<td>250 m</td>
<td>12.5 dB</td>
<td>0.66 c</td>
<td>10000 ns</td>
</tr>
<tr>
<td>100baseTX</td>
<td>2</td>
<td>1000 m</td>
<td>12.5 dB</td>
<td>0.66 c</td>
<td>10000 ns</td>
</tr>
<tr>
<td>100baseFX</td>
<td>2</td>
<td>400 m</td>
<td>11 dB</td>
<td>0.66 c</td>
<td>20400 ns</td>
</tr>
<tr>
<td>AUI</td>
<td>50 m</td>
<td></td>
<td>5 dB</td>
<td>0.66 c</td>
<td>257 ns</td>
</tr>
<tr>
<td>MB</td>
<td>0.5 m</td>
<td></td>
<td>3 dB</td>
<td>0.65 c</td>
<td>2.5 μs</td>
</tr>
</tbody>
</table>

* Topology rules, encoding/signaling method, cost
* Network diameter: FE << E (How to overcome the topology limit?)
* FE cannot run over coaxial cable

Two Classes of Fast Ethernet Hubs

- **Class-I Hub**
  - Sharing after digitizing, long latency (<0.7μS)
  - T4 and TX/FX can be on the same hub (heterogeneous interface)
  - Can be only ONE class-I hub in a FE network
  - Can be stackable or even chasis-based to form a SINGLE hub
  - More flexible to use than Class-II hubs

- **Class-II Hub**
  - Sharing before digitizing, short latency (<0.46μS)
    (short delay provides higher cabling flexibility)
  - Difficult to build due to tight propagation delay (46 bit time)
  - Homogeneous interfaces (all TX/FX/T4s)
  - Use uplink UTP cable when connecting two Class-II Hubs
    and is limited to TWO-Hub only
  - stackable, too.

Difference between Class I and Class II Repeater/Hub

- **Class I repeater**
  ~ sharing after digitized

- **Class II repeater**
  ~ sharing in analog form
Plan networks containing both 10Mbps (before migration) and 100Mbps hosts (actually) two repeaters in one housing devices are automatically connected (by Nway detection) to the fastest repeater it can use.

- 10(100) Mbps repeater retransmits Ethernet (Fast Ethernet) transmission to all other ports operating at the same speed.

• The switching circuit does not join 10 and 100 Mbps collision domain together (two repeaters are two separate collision domains (in 916DX)).

Connection rule depends on what hub/hub stacks it connected to:
- 5-4 rule for 10BaseT Ethernet hubs/stacks, or
- 205m network diameter (of a collision domain) using two Class II Fast Ethernet hubs/hub stacks.
**Hub stacking**

- Use Daisy-chain connection to stack subs
- Do use the same brand and stackable hubs in stacking
- DC cables: D-sub 50 pin (SCSI II) and D-sub 25 pin
  * Cable conversion (D-sub 50 to D-sub 25) is also counted as ONE stack

**A few things to remember**

- MDI-X ~ Medium Dependent Interface, *cross-wired*
- MDI-II ~ Medium Dependent Interface, *straight-through*
- 1X \(\Rightarrow\) Uplink \(\leftrightarrow\) connected together (inside)
  Don’t use both the port 1X jack and the Uplink jack at the same time.
- Use *uplink* method to connect different brands and types of hubs.
- Daisy chain IN port and OUT port ~ for creating stack.
- If hubs are stacked, do not link them using Uplink again.
- Stacked hubs does not count as an additional repeater like an uplinked hub does. They are treated as ONE repeater in the network diameter. However, since the stacking cable still introduces a little delay, the MAX # of stacked hubs are limited. Generally, 5 to 7’s.

**Basic Configuration - One Class I/II Hub + stacking**

- Network diameter = 205m, Max.
  (100+5+100)
- If the “max. station-hub” <100m, the “hub-hub” distance can then > 5m.

**Expanded Configuration**

- Two Class II Hub/Hub stack
- (all 10Mbps devices) Collision Domain #1

<table>
<thead>
<tr>
<th>Ethernet 10BaseT-500m Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision Domain #2</td>
</tr>
</tbody>
</table>

- Fast Ethernet 100Mbps/205m Max
- Fast Ethernet 100Mbps/205m Max

**TIA/EIA 568 A/B standard**

- Straight
- Cross
- UTP
- MDI-II
General Model of a Switch

- Layer 2 device (operated at frame-basis, forwarding based on the MAC address)
- Exchange information based upon MAC address (learned & stored internally)
- Example: a 16x16 switch or a 16-Port switch
- Three operation modes: (viewpoints: latency, error forwarding, buffers, etc)
  
  **Store-and-forward switching, Cut-through switching, and modified/Runt-free/Interim cut-through switching**

Crossbar - An Example of switching Fabric

Switching Fabric

- IPC Subsystem(s)
- inbound
- outbound

Switch Fabric

Switch’s Basic Operation

**Hub (集線器) versus Switch (交換器)**

- Layer-1 device (hub)
- Multiple repeater
- TX/RX ONE pair at a time
- Connect multiple Ethernet segments into ONE network (1 collision domain as a whole)
- **Collision domain** in hubed ntwks

- Layer-2 device (switch)
- Multiport bridge
- TX/RX Multiple pairs at a time
- Multiple Ethernet segments operate separately but reachable (1 collision domain per port)
- **Broadcast domain** in switched ntwks

Switching Fabric

- IPC Subsystem(s)
- inbound
- outbound

Hub （集線器） versus Switch （交換器）

- Layer-1 device (hub)
- Multiple repeater
- TX/RX ONE pair at a time
- Connect multiple Ethernet segments into ONE network (1 collision domain as a whole)
- Collision domain in hubed ntwks

- Layer-2 device (switch)
- Multiport bridge
- TX/RX Multiple pairs at a time
- Multiple Ethernet segments operate separately but reachable (1 collision domain per port)
- Broadcast domain in switched ntwks

Switch’s Basic Operation

**HUB**

- Reduces Traffic
- Increases Performance

**SWITCH**

Hub (集線器) versus Switch (交換器)

- Layer-1 device (hub)
- Multiple repeater
- TX/RX ONE pair at a time
- Connect multiple Ethernet segments into ONE network (1 collision domain as a whole)
- Collision domain in hubed ntwks

- Layer-2 device (switch)
- Multiport bridge
- TX/RX Multiple pairs at a time
- Multiple Ethernet segments operate separately but reachable (1 collision domain per port)
- Broadcast domain in switched ntwks

Switch’s Basic Operation

**A switched network = a broadcast domain.**

A switched network = a broadcast domain.
**Ethernet Technology**

### Gigabit Ethernet

- Started 11/1995; Standardized 2/1998 ⇒ **IEEE 802.3z**
- Provides **10 times** the performance of Fast Ethernet
- Complete **interoperability** with Ethernet and Fast Ethernet
  - Retain the investment in installed base of network infrastructure
  - Leverages on the network management environment
- **Conforms** to the Ethernet standard
  - Preserve Frame format and frame sizes
  - CSMA/CD access method & BEBA
- Provide a **simple forwarding** mechanism between 10, 100, and 1000 Mbps (easy for migration)
  - No fragmentation, encapsulation, and translation of frames

---

**Design of Switched Ethernet**

- Extending Fast Ethertnics with Switches to overcome the topology limitation

---

**Example - Switch** (交換器)

- Managed
- 10/100Mbps Switches

### Features
- Port to Port parallel, non-blocking interconnection
- 100% bandwidth utilization
- Bufferless switching
- Direct connection to end stations
- Requires additional port to port bandwidth
- Electronic switch with FDDI, Fiber, and SONET support

### Performance
- Time of arrival, or throughput switching methods
- RAM (byte or bit rate)
- Input/output of network configuration
- Throughput capacity, internal memory
- Packet switching, point-to-multipoint (switch connection)
- VoIP traffic

### Management
- Simple management
- User-friendly GUI
- Easy management through SNMP
- Remote management through Telnet
- Remote configuration
- Comprehensive management tool

---

**Example - Switch** (交換器)

- FE Switch
- FE 100Mbps Hub
- 100m Max
- 500m or more

### Between A and B
- dedicated bandwidth 100Mbps per port/node

---

**Basically . . . GE is a Ethernet, only FASTER**

- But, two new supports: Carrier extension and frame burst

* Reference: [http://www.gigabit-ethernet.org](http://www.gigabit-ethernet.org)
Gigabit Ethernet Communication Architecture

**MAC**
- Full-Duplex and/or Half-Duplex
- Media Access Control (MAC)

**PHY**
- Gigabit “Media Independent Interface”
- 1300nm LWL optics
- 780nm SWL optics
- Copper wire

Fiber Channel Technology
- Full-Duplex Links
  - 802.3z physical layer
  - Supports 200 m to 10 km link distances
- Half-Duplex Transceiver
  - 802.3ab physical layer
  - Supports 200 m network diameters

1000BaseT UTP (1997/3)
- Encoder/Decoder
- Single-Mode Fiber
  - (9um) 2 km - 10 km
- Multi-Mode Fiber
  - (200 m to 550 m)

Twisted Pair Transceiver
- Copper wire
- Twisted Pair Cabling
  - 100 m (Cat-5 UTP)
- 50 µm or 62.5 µm Multi-Mode Fiber
  - (200 m to 550 m)

**Important Parameters for Gigabit Ethernet**

- **Max allowable C.W.** = 4096 bit times = \(4.096 \mu s\)
- InterFrame gap (IPG) = 96 bit-time = \(0.096 \mu s\)
- JamSize = 32 bit (For collision enforcement)
- AttempLimit = 16 (Max # of retransmissions)
- BackoffLimit = 10 (Max # of backoff times)
- MaxFrameSize = 1518 bytes
- MinFrameSize = 64 bytes
- AddressSize = 48 bits

- A calculation of GE network delays \(\Rightarrow\) network diameter
- **Solution: increase slot-time**

**802.3z and 802.3ab Physical Media**

- 50um Multimode
- 62.5um Multimode
- Copper wire
- Balanced Shielded 2-pair STP Cable
- 25m - 550m - 3 km or more*

**Carrier Extension**

- **Remedy** (to overcome the discrepancy between MinFrame and slot-time)
  - Extend the CSMA/CD slot-time \(\Rightarrow\) **Carrier extension**
  - (recall: slot-time = the time unit for Ethernet MAC to handle collisions)
  - In this way, the smaller packet sizes (less than 512 bytes) can coincide with the minimum slot-time and allow seamless operation with current Ethernet CSMA/CD.
Frame Bursting

- **Goal:** Compensating carrier extension scheme to improve utilization
- **Method:**
  - adopts *pipelining scheme* but no change on the MAC interface (transmit and receive ONE frame at a time)
  - transmits multiple frames/packets in a burst

- Carrier extension must be applied to the first frame so that the collision will only affect the first frame of a burst
- Txer and Rxer are considering "one frame at a time" as usual
- Burst size would vary between 1518 byte frame (12144 bits) to a maximum of 8192-byte (65,536 bits, 5/1997 by IEEE 802.3z)

---

**Designing and Planning a Ethernet-based LAN**

**Step 1:** Placing nodes and determining the speed for nodes: fixed, dual (or auto-negotiable)

**Step 2:** Clarifying/Planning the collision domains according to the different working population, geographical distribution, and traffic/performance consideration (requirement and balance)

**Step 3:** Equipping the Devices (E/FE, Hub/Switch) and build up the infrastructure

**Step 4:** Determining the Cabling (Fiber or UTP, wires) according to the node distribution and future expansion

**Step 5:** Operating and testing performance (Baseline) and then modifies somehow if necessary

---

**Note:** Be provide with high-bandwidth link for server access. Be design with high-bandwidth for the LAN backbone links.

*high-bandwidth → 100/1000 Mbps Hub/Switch links

---

**Gigabit Ethernet Migration**

- **Upgrading Switch to Server Links**
  - to obtain high-speed access to applications and file systems

- **Upgrading Switch to Switch Connections**
  - to obtain 1000Mbps pipes between 100/100 switches (to support a greater number of both switched and shared fast Ethernet segments)
• **Upgrading a Switched Fast Ethernet Backbone**
  - by aggregating fast Ethernet switches with a Gigabit Ethernet switch or repeater
  (to support more nodes and bandwidth per segment)

**Diagram:**
- Fast Ethernet Switch
- Gigabit Ethernet Switch or Repeater

**Diagram Details:**
- FE (Fast Ethernet) 100Mbps
- Hub 1
- Hub 2
- FE Switch 1
- FE Switch 2
- Station A
- Station B

- Station A sends a broadcast frame (w/ 48 1's in DA)
- Stations A and B receive the same frame
- A sends a frame back to HUB 1
- Eventually, the broadcast sending by A is back to FE Hub1
- Called **Frame Cloning**

**Solution:**
- By **Spanning-tree algorithm** to prune a looped network automatically into a loop-free network (from a graph to a tree)

**Problems in Switched Networks**

**Broadcast Storming**
- The broadcast sent by A is back to FE Hub1 — called **Frame Cloning**
- Caused by a *looping* (i.e., a graph)
- **Solution** — by **Spanning-tree algorithm** to prune a looped network automatically into a loop-free network (from a graph to a tree)

---

**Cyclic Redundancy Check (CRC)**

- **Idea of CRC**
  - Generates F by P(x) or a number, P
  - k-bit message, M
  - n-bit FCS, F

**Diagram:**
- Transmitter’s action
- Receiver’s action
- Frame transmitted, T
- Received frame, Tr

**Diagram Details:**
- Transmitter’s action
- Receiver’s action

- If remainder = 0 → No error

**Expression:**
- Effectively,
  - \[ T = 2^n \cdot M + F \]

**In case of no error:**
- We want T to be divisible by P (pattern of n+1 bits):
  - \[ \frac{2^n \cdot M}{P} = Q + \frac{R}{P} \]
  - \[ T = 2^n \cdot M + R \]

**Q:** Does this R satisfy the condition that \( T/P \) have no remainder?

**A:**
- \[ \frac{R}{P} = Q \]
- \[ \frac{R}{P} = \frac{R}{P} \]
- \[ Q \]

**Really?**
- true, if modulo-2 arithmetic is applied.

**Thus, taking FCS = Remainder of \( 2^n \cdot M \) divided by P.**
Modulo-2 Arithmetic
~ binary operation without carriers/borrower (i.e., the “exclusive” logic)

\[
\begin{array}{c}
1111 \\
+ 1010 \\
\hline
1, \ 0101 \\
\end{array}
\times 11
\begin{array}{c}
1001011
\end{array}
\]

Example: (CRC calculation)

\[
\begin{align*}
M &= 1010001101 \\
P &= 110101 \\
FCS R &= 01110
\end{align*}
\]

If \( T = T + E \) (may be) & \( T / P = 0 \) \( \Rightarrow E = 0 \), no error

Polynomial representation

- ~ k-bit block data \( \leftrightarrow \) k-terms of \( x^i \)
  - Coefficients of \( F(x) \) \( \leftrightarrow \) the bits in the binary data
  - Examples:
    1. ‘101’ \( \leftrightarrow x^2+1 = F(x) \) (‘0’ \( \rightarrow \) missing term)
    2. \( F(x) = (x^2+1)(x^3+x+1) = x^5+x^2+x+1 \leftrightarrow ‘10011’ \)

* Remark:
  - If an \( F(x) \) contains \( (x+1) \) as a factor, then \( F(1) = 0 \). (Why?)

- Notations
  - \( M(x) \) = Message/data block polynomial
  - \( P(x) \) = Generating polynomial (check-bit generator) (known to the Txer and Rxer) or \( G(x) \)
  - \( n = \) the degree/order of \( P(x) \)
  - \( R(x) = \) Remainder polynomial

CRC encoding process

1. Appends \( n \)'s ‘0’ to \( M(x) \) \( \Rightarrow x^n M(x) \)
2. Divide \( x^n M(x) \) by \( P(x) \)
   \[ x^n M(x) = Q(x) P(x) + R(x) \]
3. Transmit the encoded message
   \[ T(x) = x^n M(x) + R(x) \] (FCS)
**Some International standard of \(P(x)\) or \(G(x)\)**

- **CRC–12:** \(P(x) = x^{12} + x^{11} + x^3 + x^2 + 1\)
- **CRC–16:** \(P(x) = x^{16} + x^{15} + x^2 + 1\)
- **CRC–CCITT:** \(P(x) = x^{16} + x^{12} + x^5 + 1\)
- **CRC–32:** \(P(x) = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1\)
- **CRC–8:** \(P(x) = x^8 + x^2 + x + 1\) (in ATM cell)

- CRC does not covers preamble and SFD

**CRC Error Detection**

- **Error detection capability of CRC**
  - All single-bit error
  - All double-bit errors, as long as \(P(x)\) has at least three 1’s
  - Any odd number of errors, as long as \(P(x)\) contains \(x+1\)
  - Any burst error with burst length < length of \(P(x)\) (i.e., the length of FCS)
  - Most larger burst error (a small set of bits near a single location)

**Implementation of CRC by digital logic**

(by XOR gates and 1-bit shift registers (SR))

- # of registers = \(n\) = the length of the FCS
- # of XOR gates up to \(n\)
- the presence (absence) of an XOR
  - \(\Rightarrow\) the presence (absence) of a term in \(P(x)\)
- All SRs are clocked simultaneously and thus shift along SRs

**General CRC implementation architecture for \(P(x)\)**

- \(P(x) = x^n + a_{n-1}x^{n-1} + \cdots + a_2x^2 + a_1x + 1\)
  - Input bits
  - XOR
  - SR

**Transmitter’s action:**

- Reset all \(SR = 0\) and shift in message one-by-one, MSB first
- Checksum (FCS) is left in SR after the last data bit is transmitted
- Shift FCS to channel

**Receiver’s action:**

- Implementing the same H/W as the Txer does
- Rxed data is shifted to the input end and resulted in R in SR, then R is coming on in
  - If \(SR = 0\) \(\Rightarrow\) no error
  - If \(SR \neq 0\) \(\Rightarrow\) errored
Example
Message \( M = 1010001101 \) \( \Rightarrow \) \( M(x) = x^8 + x^7 + x^5 + x^2 + 1 \)

Divisor \( P = 110101 \) \( \Rightarrow \) \( P(x) = x^5 + x^4 + x^2 + 1 \)

\[
\begin{align*}
M(x) &= x^8 + x^7 + x^5 + x^2 + 1 \\
P(x) &= x^5 + x^4 + x^2 + 1
\end{align*}
\]

- Message to be sent
- Five zeros added
- MSB first

- 4-bit data are encoded into a symbol with 5 code bits (only 16 4-bit data block out of 32 cases are selected)
- select the code group with at least two transitions presented
- no more than three '0's are allowed across one or more code groups
- encode 5-bit code groups using NRZI (differential encoding is more reliable in detecting a transition in the presence of noise and distortion than in comparing a value to a threshold)
- Coding efficiency is raised to 80% 
  ~ 100 Mbps (data rate) is achieved with 125 Mbaud rate

4B/5B-NRZI Data Encoding for 100Base-FX

- Use "bit encoding", instead of clock encoding which is not appropriate for high speed (like 100Mbps transmission)
- Encoding rules:
  - 4-bit data are encoded into a symbol with 5 code bits (only 16 4-bit data block out of 32 cases are selected)
  - select the code group with at least two transitions presented
  - no more than three '0's are allowed across one or more code groups
  - encode 5-bit code groups using NRZI (differential encoding is more reliable in detecting a transition in the presence of noise and distortion than in comparing a value to a threshold)
- Coding efficiency is raised to 80% ~ 100 Mbps (data rate) is achieved with 125 Mbaud rate

MLT-3 Encoding for 100BaseTX Fast Ethernet

- 4B/5B-NRZI is effective over Fiber, but in a twisted pair . . . 
  \( \Rightarrow \) the signal energy is concentrated and thus may produce undesirable emission from the wire
- Overcome \( \Rightarrow \) Use MIL-3 encoding scheme to concentrate most of the Txed-signal energy below 30MHz

- MIL-3 encoding steps (rooted from 4B/5B NRZI):
  1. Convert NRZI back to NRZ
  2. Scramble bit stream to produce a more uniform spectrum
  3. Follows the encoding procedure as shown in the state diagram (Scramble – No reduction in data rate)

- Keynote: Every time there is an input of 1, there is a transition. The Occurrences of +V and –V alternate.
MIL-3 Encoder’s State Diagram

Example (assumed not being scrambled)