Multi-Access Communication: Wireline

Ethernet and CSMA/CD

→ copper, fiber media

Types:

• 10Base2 (ThinNet): coax, segment length 200 m, 30 nodes/segment

• 10Base5 (ThickNet): coax, segment length 500 m, 100 nodes/segment

• 10Base-T: twisted pair, segment length 100 m, 1024 nodes/segment

• 100Base-T (Fast Ethernet): category 5 UTP, fiber (also 100VG-AnyLAN)

• Gigabit & 10 Gbps Ethernet: fiber, category 5 UTP
Connectivity example:

-→ physical network: bus (old) vs. switch (new)
-→ multihomed/singlehomed
-→ unique Ethernet address per NIC
Segments can be hooked up by repeaters, bridges, gateways, hubs or switches.

- maximum of 2 (4 for IEEE 802.3) repeaters between two hosts; 1500 m
- for Fast Ethernet, 2 repeater hops

High-bandwidth Ethernets have *shorter* network diameter.

- about 2500 m for 10 Mbps Ethernet
- about 200 m for 100 Mbps Ethernet
- even shorter for 1 Gbps Ethernet
DIX Ethernet frame:

<table>
<thead>
<tr>
<th>8</th>
<th>6</th>
<th>6</th>
<th>2</th>
<th>46-1500</th>
<th>4</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>preamble</td>
<td>source address</td>
<td>dest. address</td>
<td>type</td>
<td>body</td>
<td>CRC</td>
<td>postamble</td>
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IEEE 802.3 Ethernet frame:

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→ IEEE 802.2 LLC (Logical Link Control)

→ optional feature of LLC: ARQ
Encoding: Manchester

Addressing:

- 48 bit unique address
- point-to-point
- broadcast (all 1’s)

Receiver: Ethernet adaptor accepts frames with “relevant” address.

- accepts only own frame address
- accepts all frames: promiscuous mode
  \[ \rightarrow \text{NIC feature} \]
MAC (Medium Access Control) Approaches:

→ i.e., multiplexing problem

- broadband: FDM, CDMA
- baseband: TDM, multiple access
  → why not just use TDM?

Multiple access for baseband:

- Time slots are available for grab
  → like “on-demand” TDM
- To grab is to send
  → speak first (e.g., TV talk shows)
- If ≥ 2 users grab at the same time, slot becomes junk
  → collision
Benefits of multiple access:

- When not too many users, faster response time
  - don’t need to go through registration & reservation phase (TDM)
  - registration: admission control
- Decentralized
  - no central coordinator
  - simple; self-organization

Drawbacks of multiple access:

- When many users, degraded response & throughput
  - collision wastes slots, i.e., bandwidth
- Lack of quality of service assurances
  - “you get what you get”; a form of best effort
  - problematic for real-time traffic, e.g., telephony
Ethernet MAC: CSMA/CD

- **CS (Carrier Sense):** Can detect if some other node is using the link
  → rule: if so, abstein

- **MA (Multiple Access):** Multiple nodes are allowed simultaneous access
  → rule: if channel seems silent, send

- **CD (Collision Detection):** Can detect if simultaneous access has occurred
  → rule: if collision, retry later

Wired vs. wireless media:

→ CD is a key difference

→ difficult to detect collision while transmitting
Signal propagation and collision:

Bi-directional propagation

$\rightarrow$ terminator absorbs signal: prevent bounce back

Best-case collision

$\rightarrow$ meet in the middle

$\rightarrow$ worst-case?
Worst-case collision scenario:

- sender needs to wait $2\tau$ sec before detecting collision
- for 2500 m length, 51.2 $\mu$s round-trip time ($2\tau$)
- enforce 51.2 $\mu$s slot time
- at 10 Mbps, 512 bits; i.e., minimum frame size
  → assures collision detection
Hence, upon detecting collision:

- Make sure to transmit at least 512 bits
  
  \[ \Rightarrow 2 \times \text{delay-bandwidth product} \]

  \[ \Rightarrow 6 + 6 + 2 + 46 + 4 = 64 \text{ B} = 512 \text{ bits} \]

- When to retry: exponential backoff
  
  1. Wait for \( 0 \leq X \leq 51.2 \mu s \) before first retry
  2. On \( i \)'th collision, wait for \( 0 \leq X \leq (2^i - 1)51.2 \mu s \) before next attempt
  3. Give up if \( i > 16 \)

  \[ \Rightarrow \text{uniformly random waiting time} \]

How is reliable communication achieved?
Performance Analysis of CSMA/CD

Assumptions:

- Contention slot of duration $2\tau$
  \[\rightarrow\] slotted system
- $k$ hosts transmitting with constant probability $p$ at every contention slot
  \[\rightarrow\] note: $p$ represents traffic load
  \[\rightarrow\] workload assumption: realistic?

Fix contention slot; probability a fixed host (say host 1) successfully acquires slot \textit{successfully} $p(1 - p)^{k-1}$

\[\rightarrow\] only host 1 has attempted transmission

Hence, probability that \textit{some} host acquires the slot

\[\eta = kp(1 - p)^{k-1}\]
To increase the probability that a slot is successfully used for data transmission, determine best sending rate $p$:

\[\rightarrow\] a form of traffic control

\[\rightarrow\] traffic shaping & policing

For $k$ users, what is the best $p$?

\[\rightarrow\] fact: $\eta$ is maximized at $p = 1/k$

\[\rightarrow\] familiar ...

\[\rightarrow\] also: $\lim_{k \to \infty} \eta = 1/e$

\[\rightarrow\] so, for many users, $p = 0.3678...$

What is the throughput of the system under the above conditions?
Probability that contention interval $T$ lasts for exactly $i$ slots: $\eta(1 - \eta)^{i-1}$

Hence, the average contention duration is

$$E(T) = \sum_{i=0}^{\infty} i \eta(1 - \eta)^{i-1} = \frac{1}{\eta}$$

$\rightarrow$ note: $T$ is in units of $2\tau$

Mean contention duration: $2\tau / \eta = 2\tau e$ (sec)

Definition of throughput $\rho$: In the long run, sequences of slots will alternate between useful transmission and useless—collision or no send—slot states.

$$\rho = \frac{\text{useful slots}}{\text{useful slots} + \text{unuseful slots}}$$
Useful slots: average frame transmission time $t_0$ (sec)

Unuseful slots: mean contention duration $2\tau e$ (sec)

Hence:

$$\rho = \frac{t_0}{t_0 + 2\tau e}$$

Assume:

- mean frame length $F$
- bandwidth $B$
- length of wire $L$

$$\rightarrow t_0 = \frac{F}{B} \text{ and } \tau = \frac{L}{c}$$

$$\rho = \frac{F/B}{F/B + 2eL/c} = \frac{1}{1 + (2e/c)\frac{BL}{F}}$$
What does the formula
\[
\rho = \frac{1}{1 + (2e/c) \frac{BL}{F}}
\]
reveal to us?

- If $B$ or $L$ is increased, throughput $\rho$ deteriorates.
- If $F$ is increased, throughput $\rho$ improves.

\[\rightarrow\] note: $BL$ is delay-bandwidth product
\[\rightarrow\] for fixed $F$: $BL \uparrow \infty$ implies $\rho \downarrow 0$
\[\rightarrow\] bad news for broadband networks

In practice today: switched Ethernet

\[\rightarrow\] CSMA/CD is still there, but secondary
\[\rightarrow\] contention moved from bus to switch
Gigabit and Fast Ethernet: use compendium of tricks. However, subject to intrinsic limitations.

- Fast Ethernet (100Base-T) is switched
- 100Base-T uses same frame size
- 100VG-AnyLAN (IEEE 802.12) uses priority scheduling (not CSMA/CD)
- gigabit Ethernets use broadband signalling
- maintaining consistent frame format & backward compatibility is an important factor