Link Layer: Wired Media

Multi-Access Communication

Bandwidth sharing: two approaches

- contention-free

  → e.g., TDMA, FDMA, mixture of FDMA + TDMA, CDMA, SDMA, token ring

  → used in telephony and broadband data networks

- contention-based

  → e.g., CSMA/CD, CSMA/CA

  → used in Ethernet, WLAN, RFID

Also called MAC (medium access control)

→ 48-bit NIC address: MAC address

Contention-free MAC:

→ emphasis on orderliness

→ how to keep discussion orderly: moderator

→ prior allocation of shared resources (e.g., FDMA, TDMA, CDMA)

→ centralized

Contention-based MAC:

→ single carrier frequency shared by many

→ no moderator

→ much less orderly

→ decentralized

→ interference between conversations

→ simultaneous access: collision

Basic features:

- when NIC has data to send, just send

  → called multiple access (MA)

  → only send if link seems idle: carrier sense (CS)

- if two or more users send at the same time, data can become junk

  → interference makes signal too weak to detect

  → interference causes bit flips

  → collision: at receiver NIC

Collision need not always cause bit flips

→ if two packets collide and one packet has much stronger signal strength than the other: stronger packet may be successfully decoded

→ called capture effect

→ "survival of the strongest"

Much less orderly than contention-free MACs:

→ used in real systems?

→ yes!

→ pure MA (not even CS): ALOHA (1970s)

→ packet network connecting Univ. of Hawaii island campuses

→ deployed system solving real-world problem

→ ∼30 years before boom of wireless data networks

→ later adopted by Ethernet, and today, WLANs

→ visionary work by Norman Abramson

Question: why not use carrier sense (CS)?

Additional features:

- NIC can detect if someone else is using the channel

  → carrier sense (CS)

  → rule: if someone else talks, don't talk

  → imposes gentlemanly (i.e., cooperative) behavior

  → not always practically feasible

  → where else does it not make sense?

- NIC can detect if collision has occurred

  → called collision detection (CD)

  → not always feasible: especially wireless

In real systems:

⟶ Ethernet: MA, CS, CD

⟶ WLAN: MA, CS

Why not just use TDMA, FDMA, or CDMA?

Benefits of contention-based MAC:

- when not too many users, faster response time

  → minimal coordination overhead

  → e.g., in TDMA need to request and reserve slots

- decentralized

  → minimal configuration overhead

  → to join: just send

  → except for security concerns (e.g., Purdue's PAL)

  → a good idea?

Drawbacks of contention-based MAC:

- when many users share, degraded throughput

  → collision wastes bandwidth

- lack of QoS (quality of service) assurances

  → "you get what you get"

  → called best effort

  → problematic for real-time traffic (e.g., VoIP, video conferencing)

  → IEEE 802.11 WLAN standard has provisions to suppport telephony: not used in practice

When to use what?

⟶ contention-free vs. contention-based

Ethernet

$\longrightarrow$ copper, fiber

Types (some just historical):

- 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 or better
- 40, 100 Gbps Ethernet

  $\rightarrow$ mainly carrier grade

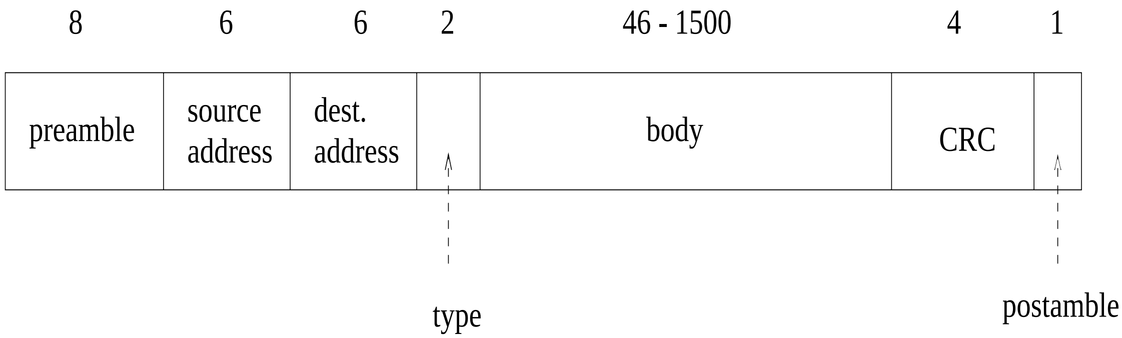
High-speed Ethernets have shorter network diameter

- 2500 m for 10 Mbps Ethernet
- 200 m for 100 Mbps Ethernet
- even shorter for 1 Gbps Ethernet

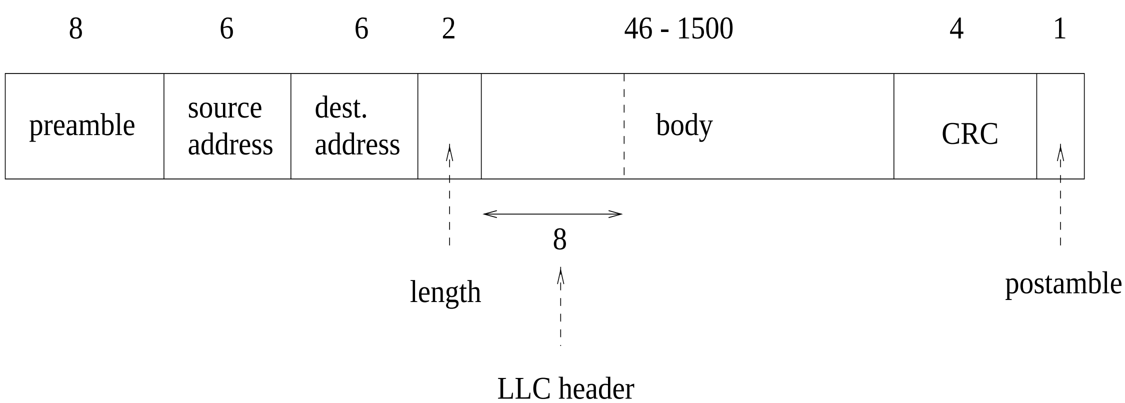
  $\rightarrow$ unless fully switched (later discussion)

  $\rightarrow$ distance limitations: due to Ethernet protocol

DIX Ethernet frame:



IEEE 802.3 Ethernet frame:



$\longrightarrow$ IEEE 802.2 LLC (Logical Link Control)

$\longrightarrow$ two Ethernet types co-exist (DIX dominant)

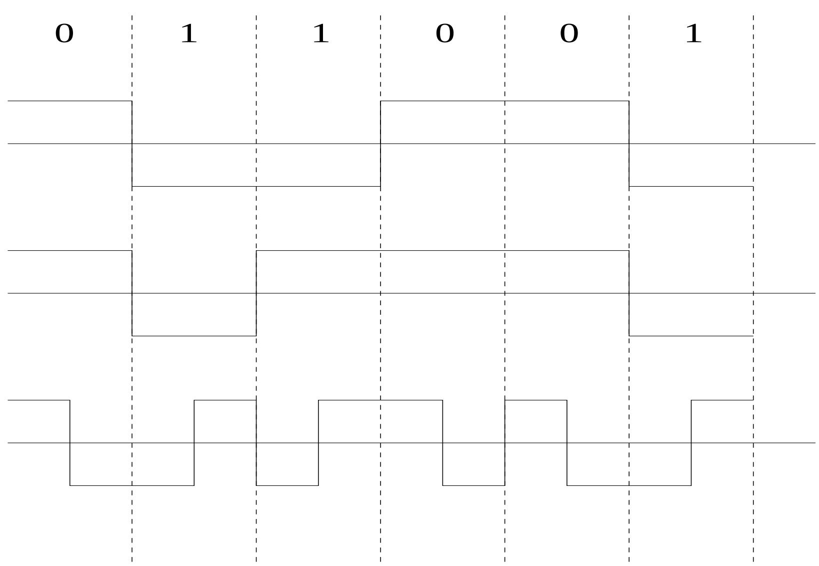
Traditional Ethernet:

→ digital transmission of digital data

→ dominant today: analog transmission of digital data

Using square waves to represent bits

- NRZ-L (non-return to zero, level)
- NRZI (NRZ invert on ones)
- Manchester (biphase or self-clocking codes)



Trade-offs:

- NRZ codes—long sequences of 0's (or 1's) causes synchronization problem
- Manchester codes—synchronization achieved through self-clocking

  $\rightarrow$ penalty: 50% utilization

  $\rightarrow$ 1/2 bit per baud

4B/5B code

Encode 4 bits of data using 5 bit code where the code word has at most one leading 0 and two trailing 0's.

0000 $\leftrightarrow$ 11110, 0001 $\leftrightarrow$ 01001, etc.

$\longrightarrow$ at most three consecutive 0's

$\longrightarrow$ efficiency: 80%

Traditional Ethernet encoding: Manchester

Addressing:

- 48 bit unique address
- broadcast address: all 1's

Receiver: Ethernet NIC accepts frames with matching destination address.

- default
- accepts all frames

  → called promiscuous mode

  → can set with root privilege

  → useful for traffic monitoring/sniffing

Ethernet MAC protocol: CSMA/CD

- MA (Multiple Access): multiple nodes are allowed simultaneous access

  → just send

- CS (Carrier Sense): can detect if some other node is using the link

  → rule: if busy, wait until channel is not busy

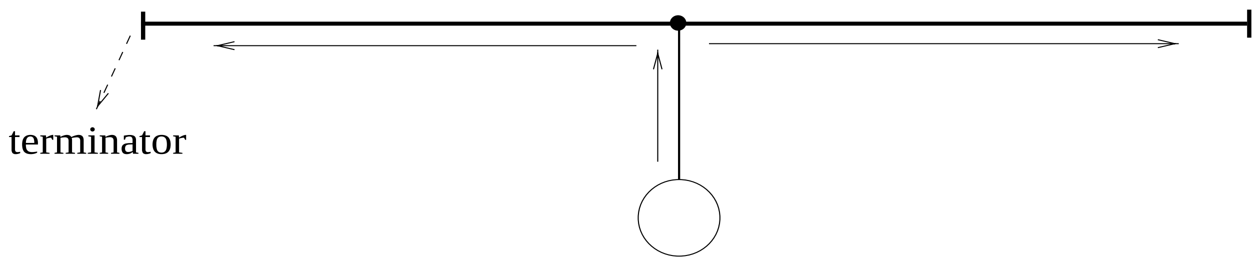
- CD (Collision Detection): can detect frame collision due to simultaneous transmissions

  → rule: if collision, retry later

  → key question: when is later?

Collision detection mechanism:

Bi-directional signal propagation



→ terminator absorbs signal: prevent bounce back

→ recall PSO lab: TDR

→ collision and collision detection: applies to thicknet/thinnet (old) Ethernet

→ today: switched Ethernet

→ CSMA/CD maintained to backward compatibility

Collision even: 2 stations

→ could be 3 or more

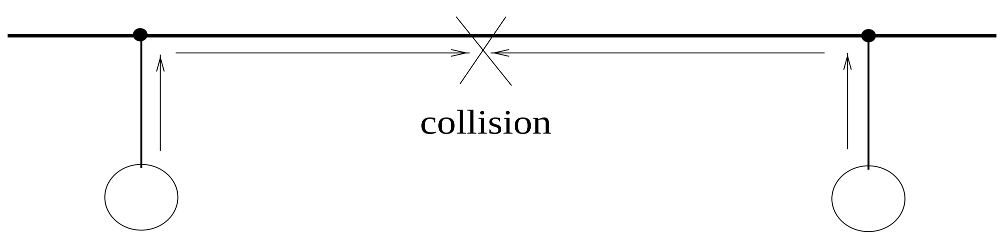
→ while transmitting data frame, hears collided signal

→ data frame cannot be too small

→ otherwise: data transmission completed before collision is detected

Example: collision scenario

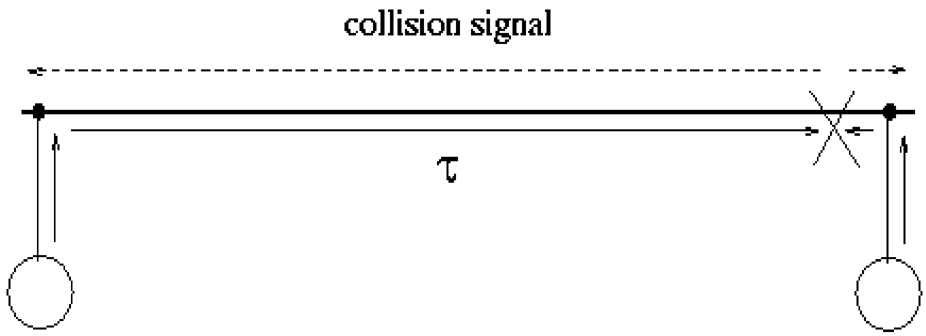
→ meet in the middle



→ best-case

→ why?

Worst-case collision scenario:



- τ: one-way propagation delay
- sender needs to wait 2τ sec before detecting collision

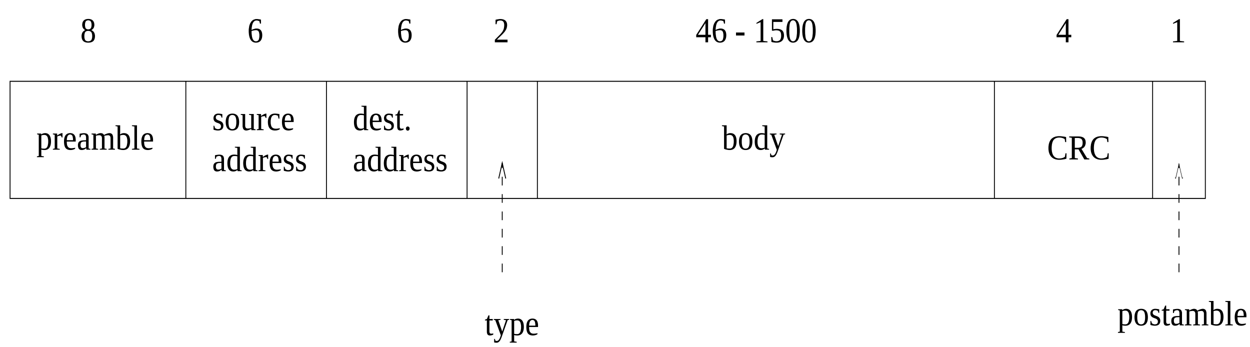
  $\rightarrow$ time for echo to bounce back
- for 2500 m length, 51.2 μs round-trip time (2τ)
- enforce 51.2 μs slot time
- at 10 Mbps, 512 bits: minimum frame size

  $\rightarrow$ assures collision detection

Transmit at least 512 bits

$\rightarrow 6 + 6 + 2 + 46 + 4 = 64$ B $= 512$ bits

$\rightarrow$ influences minimum payload size of packet



Question: to achieve collision detection (CD) in 100 Mbps Ethernet, what must happen?

When to retry upon collision: use exponential backoff

Retransmission protocol:

1. Wait for random $0 \leq X \leq 51.2$ μs before 1st retry
2. Two consecutive collisions: wait for random $0 \leq X \leq 102.4$ μs before 2nd retry
3. Three consecutive collisions: wait for random $0 \leq X \leq 204.8$ μs before 3rd retry
4. i consecutive collisions: wait for $0 \leq X \leq 2^{i-1}\,51.2$ μs before next attempt
5. Give up if $i > 16$

→ a form of stop-and-wait (ARQ)

→ what's the ACK?

→ guaranteed reliability?

→ why exponential backoff?