Lecture 6: Example LANs: Ethernet vs. Wi-Fi

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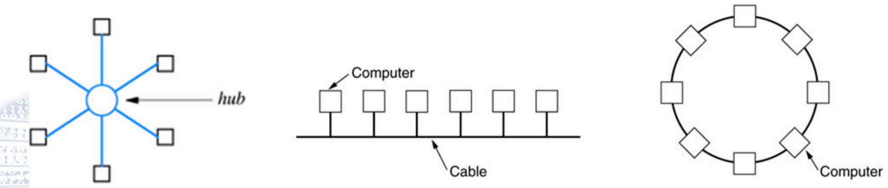
Network Types

- **Local Area Networks (LANs):** privately-owned networks within a single building or campus of up to few kilometers in size:
  - Ethernet, IBM Token Ring, FDDI and IEEE 802.11 Wi-Fi.
- **Metropolitan Area Networks (MANs):** spans a city or part of a city:
  - IEEE 802.16 WiMAX.
- **Wide Area Networks (WANs):** spans a large geographical area, often a country or continent:
  - ATM and Frame Relay.
- **Personal Area Networks (PANs):** spans a single room and connects personal devices:
  - Bluetooth, NFC and UWB.

LAN Network Topologies: Star vs. Bus vs. Ring

- Each LAN utilizes a single high-bandwidth shared medium (e.g., a cable), to which many computers are attached (*reduces* cost).
- Different computers take turns (coordinate) among each other to send frames on the shared medium. Handled by MAC (Medium Access Control) sublayer.



LANs: Ethernet & ALOHA

- Ethernet was inspired by the ALOHA protocol, which was the first LAN created.
- ALOHA, built at the University of Hawaii in early 1970s, ran at 9.6 kbps data rate and used a shared wireless medium.
- ALOHA allowed remote terminals at distant locations (different islands) to access a main computer in a central location.
- Ethernet was a variation of the ALOHA protocol, and inherited many of its features, but then *evolved significantly* over the years to support higher data rates and longer distances.

Ethernet

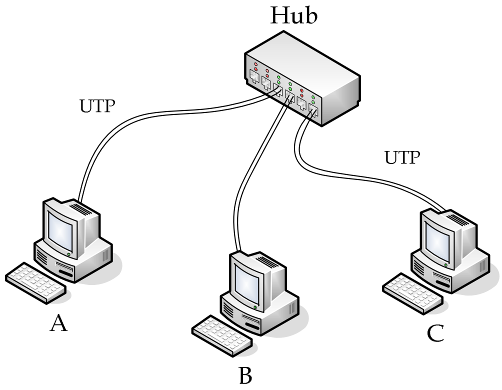
- Ethernet is a widely used LAN technology. It is also being expanded into MAN and WAN.
- Invented at Xerox Palo Alto Research Center in late 1970s .
- Operated at a rate of **10 Mbps** and was called DIX Ethernet (DEC, Intel and Xerox).
- IEEE now maintains the Ethernet standard, known as IEEE 802.3 (standardized in 1983).
- In its original 10 Mbps version, Ethernet used a single coaxial cable, called the **ether**, to which multiple computers connect through taps.
- Later versions of the 10 Mbps Ethernet used UTP cables with hubs and switches.
- A popular version of Ethernet was Fast Ethernet, operating at **100 Mbps**, and uses UTP with switches.

Ethernet [2]

- Next version, becoming dominant nowadays, is Gigabit Ethernet (GigE or GbE) operating at 1 Gbps (1000 Mbps).
- The next version, popular in hi-end Ethernet core switches, is 10 Gigabit Ethernet (10GigE or 10GbE) operating at 10 Gbps, was finalized in 2002.
- IEEE 802.3cu (released Feb 2021) defines 100 Gbit/s (100GbE) and 400 Gbit/s (400GbE) over SMF (single-mode fiber).
- Scheduled for mid 2024 is support for 800 Gb/s and 1600 Gb/s (i.e., 1.6 Tb/s) using multiple lanes.
- IEEE 802.3av defines 10G-EPON and IEEE 802.3ca defines 50G-EPON (for passive optical networks).
- Ethernet Over SDH (EoS or EoSDH) & Ethernet over SONET.

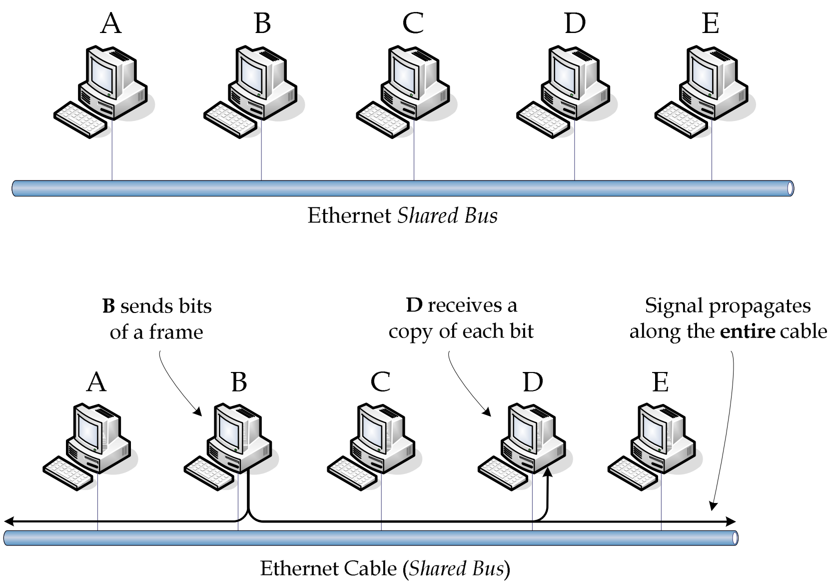
Ethernet: IEEE 802.3 Standard

802.2 LLC	LLC	
802.3	MAC	2
CSMA/CD	PHY	1



Ethernet MAC: CSMA/CD

- Ethernet MAC protocol is known as Carrier Sense Multiple Access with Collision Detection (CSMA/CD).
- CSMA/CD coordinate access among different users to the shared bus. It is very similar to ALOHA but with improvements.
- If a station wants to send a frame, it first listens to the channel, called **carrier sense** or listen-before-talk (LBT). Carrier sense avoids interrupting an ongoing transmission.
- If the station senses a busy channel, it waits for the cable to become idle again then sends its frame after an "interframe gap time" (9.6 μs).
- If two stations sense an idle channel and start transmitting at the same time, the two signals will interfere with each other: called collision or contention.
- While a station is transmitting, it monitors the current flowing through the channel. If the current is higher than normal, then it detects a collision: **collision detect**.



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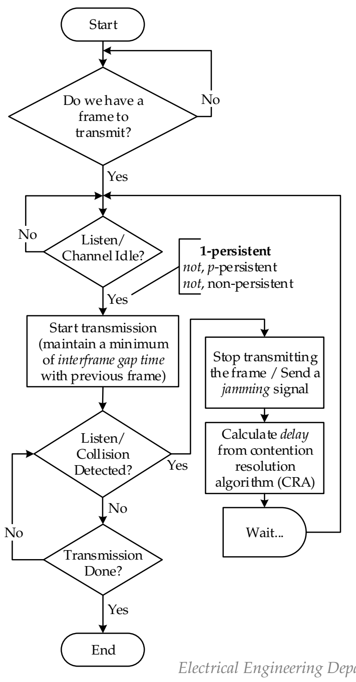

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Binary exponential backoff algorithm

- If a frame has collided n successive times (where $n < 16$) then the sending station must choose a **random number *K*** with equal probabilities from the set {0, 1, 2, 3, …, $2^m - 1$}, where m = min (n, 10)
- The station must wait for ***K* x 512 bit times** (at 10 Mbps, one bit time = 10^{-7} seconds) before starting another transmission attempt.
- Give up transmission attempt of the frame if it encounters 16 successive collisions, or reset counters (i.e., set $n = 0$) if the frame is successfully transmitted.

Persistance

- **1-persistent:** If the transmitting node senses an idle channel, it immediately starts transmitting its frame. If the channel is sensed busy, the node continues listening until the channel is idle again, then starts transmitting its frame after a small interframe gap.
- **p-persistent:** If the transmitting node senses an idle channel, it starts transmitting its frame with probability p (i.e., it might not transmit with probability $1 - p$). If the channel is sensed busy, the node continues listening until the channel is idle again, then starts transmitting with probability p. If the node decides not to transmit (with probability $1 - p$), it defers transmission by one time slot (which is typically τ), and at the start of the next time slot, …

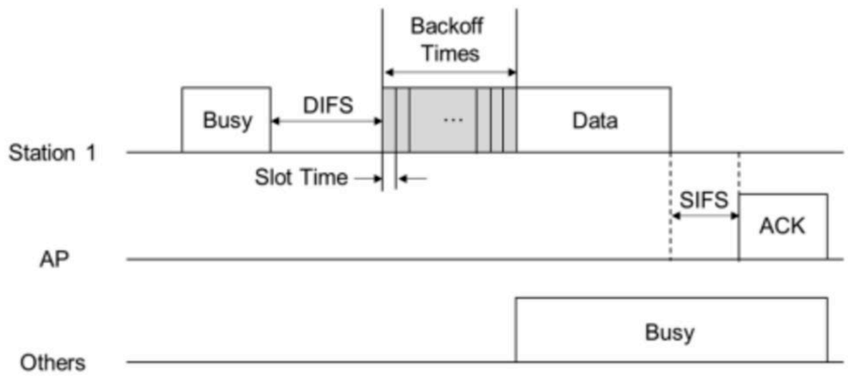
Persistance (*Cont.*)

- …, the nodes checks the channel again and transmits with probability p if the channel is idle (or defers again with probability 1-p). This process is repeated until either the frame is transmitted or the channel becomes busy again. When the channel becomes busy, the station acts as though there had been a collision and waits for a random amount of time before the next attempt.
- **non-persistent:** If the transmitting node senses an idle channel, it starts transmitting its frame immediately. If the channel is sensed busy, the node does not continue listening until the channel is idle again; rather it waits a random amount of time and re-senses the channel again after that delay.

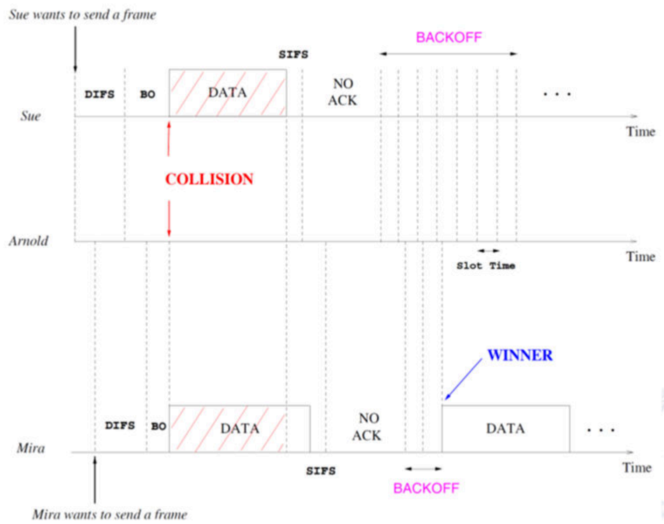
Wi-Fi MAC: CSMA/CA

- CSMA/CA (Carrier-Sense Multiple Access with Collision Avoidance) used in DCF mode (vs. PCF).
- Nodes sense the channel before transmitting (carrier-sense) and send if the channel is idle.
- Collision detection is not possible in wireless channels, since nodes transmit much higher power (to overcome attenuation) compared to the received signal power.
- So, the node receiver hardware is turned off during packet transmission as it will just be overwhelmed by its own transmitter hardware power.
- Hence, nodes transmit the full packet and do not stop.
- An ACK from the destination tells the source if it was successful or a collision has occurred.

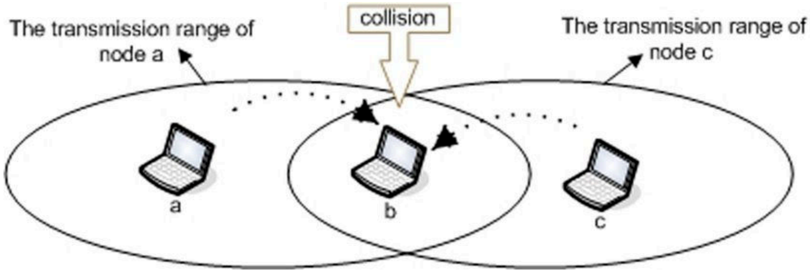
Data / ACK (*No Collision*)



Collision Wastes Time (*Large Packets*)



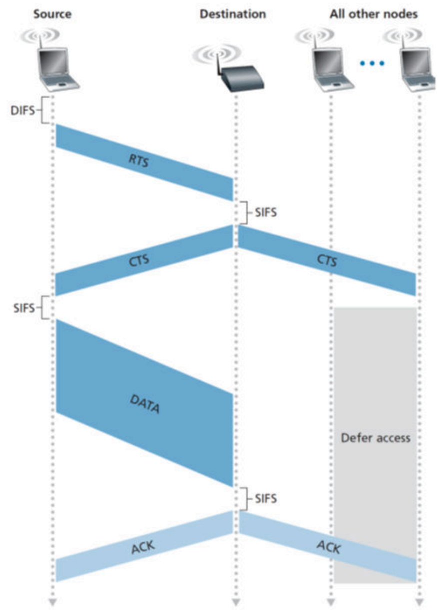
Hidden Terminal Problem



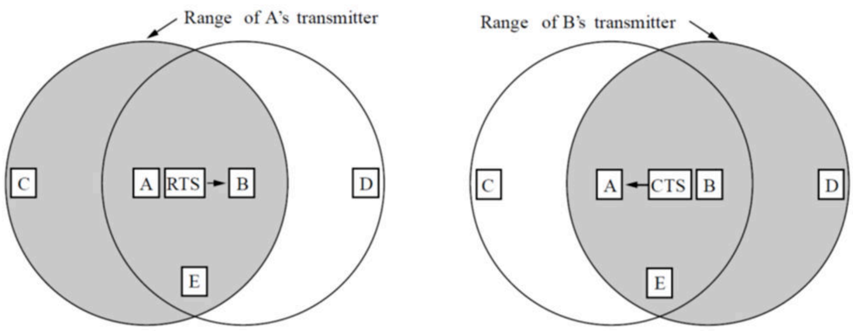
- A transmits to B
- C cannot detect A via sensing; transmits to B
- Collision (interference) occurs at B
- C is hidden terminal to A, and A is hidden to C.

Collisions Avoidance

- Collision avoidance: Request To Send/Clear To Send (RTS/CTS) handshake.
- Can be executed to reduce wasted time and alleviate *hidden terminal problem* (or hidden node problem or hidden station problem).
- Send *short* RTS packets to request permission to send data packet. Intended destination sends *short* CTS *only* to one sender at a time.
- Both hidden nodes see CTS and avoid collision.
- Collision of RTS packets possible, but wastes less time.
- RTS/CTS handshake can add latency, and the overhead can often exceed the cost, particularly for short data packets (so *optional*).



Other Nodes might be Blocked (*but avoid Exposed Terminal Problem*)



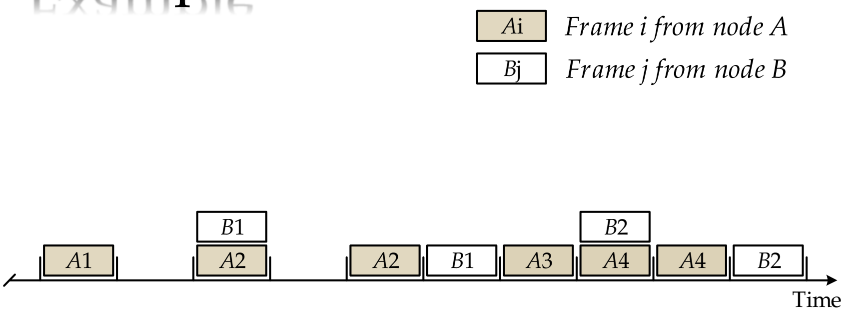
Wi-Fi Standards

IEEE standard (Generation)	Adopted	Maximum link rate	Radio Frequency (GHz)
802.11	1997	1-2 Mbps	2.4
802.11b	1999	11 Mbps	2.4
802.11a	1999	54 Mbps	5
802.11g	2003	54 Mbps	2.4
802.11n (Wi-Fi 4)	2008	600 Mbps	2.4, 5
802.11ac (Wi-Fi 5)	2014	6.933 Gbps	5
802.11ax (Wi-Fi 6)	2019	9.608 Gbps	2.4, 5
802.11ax (Wi-Fi 6E)	2020	9.608 Gbps	6
802.11be (Wi-Fi 7)	2024	46.120 Gbps	2.4, 5, 6
802.11bn (Wi-Fi 8)	2028*	100 Gbps	2.4, 5, 6, 42, 71

Performance Parameters vs. Load

- **Throughput** (S *or* Y): average rate of successful frame delivery. Calculated as the number of successful bits sent in a period of time divided by that time period (bit/s).
- **Delay** (D): the time period the frame needs to successfully reach the destination (includes transmission, queueing, processing and propagation delays). Usually average delay is calculated.
- **Utilization** (U): proportion of the channel time which is used by the traffic which arrives at it.
- **Frame drop probability** (P): proportion of total frames sent by the source that are not received by the destination.

Example



Total Time Slots: 10

Total Attempted Frames = 10; ***Load*** = **G** = 10/10 = 1

Successful Frames = 6; ***Throughput*** = **S** = 6/10 = 0.6

***Utilization* = U** = Percentage of *Busy Slots* = 8/10 = 0.8

Throughput vs. Load (L *or* G)

$$L = \frac{\text{Total frame transmission attempts in } N \text{ time slots}}{\text{Number of time slots } N} = \frac{\text{frame}}{\text{slot}}$$

$$L = \frac{\text{Total bits attempted to be transmitted in period } T}{\text{Period legnth } T} = \frac{\text{bit}}{\text{second}}$$

$$S = \frac{\text{Successful frames transmitted within } N \text{ time slots}}{\text{Number of time slots } N} = \frac{\text{frame}}{\text{slot}}$$

$$S = \frac{\text{Successful bits transmitted in period } T}{\text{Period legnth } T} = \frac{\text{bit}}{\text{second}}$$

- If one frame requires exactly one time slot to be transmitted, can be written as percentage *or* unitless.

Calculations

$$U = \frac{Time\ slots\ used\ for\ transmission\ (successful\ or\ not)}{\text{Total number of time slots}} = \frac{\text{slot}}{\text{slot}} = \%$$

$$U = \frac{Time\ used\ for\ transmission\ (successful\ or\ not)}{\text{Total time}} = \frac{\text{second}}{\text{second}} = \%$$

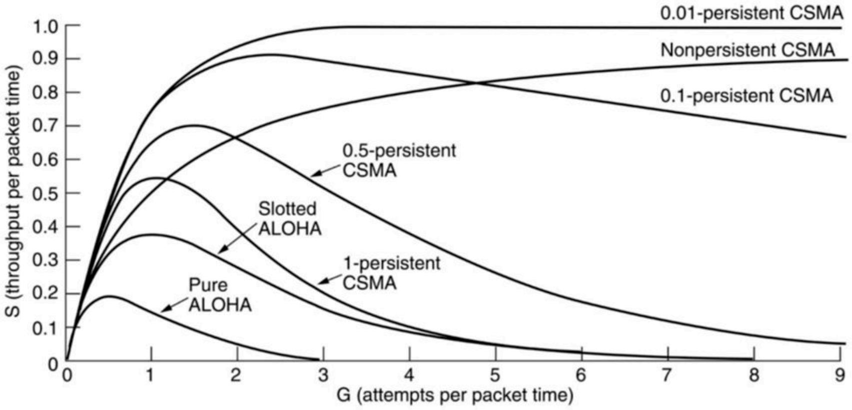
Delay:

$$D_{A1} = 1, D_{A2} = 3, D_{B1} = 4, D_{A3} = 1, D_{A4} = 2, D_{B2} = 3$$

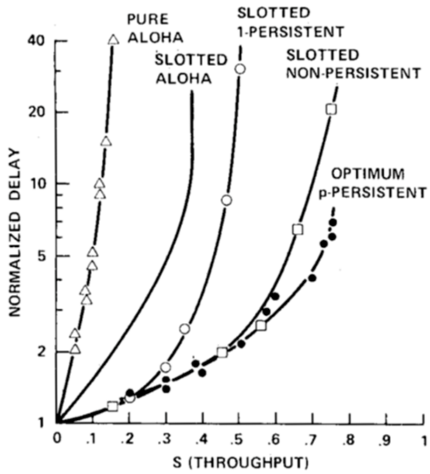
$$\overline{D} = \frac{D_{A1} + D_{A2} + D_{B1} + D_{A3} + D_{A4} + D_{B2}}{6} = \frac{1+3+4+1+2+3}{6}$$

$$\overline{D} = 14/6 = 2.3333 \text{ slot}$$

Throughput



Average Delay vs. Throughput



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