CS120: Computer Networks

Lecture 6. Medium Access Control 1

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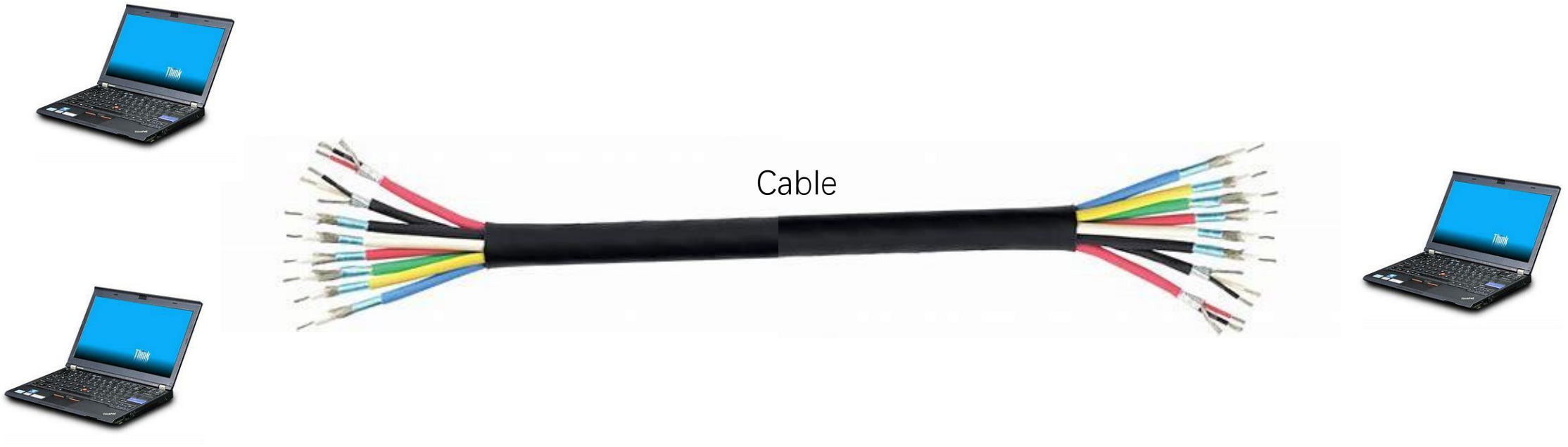
Data Link Layer

- Main Function: transfer data between (multiple) neighboring nodes via physical layer, might include following components:
  - Error handling, e.g., ACK and transmission
  - Flow control, e.g., flow control in RDMA
  - Rate control, e.g., rate adaptation in Wi-Fi
  - Simple addressing, e.g., specify receiver/sender address
  - Medium access control (MAC), e.g., CSMA
- Also called layer 2, or simply MAC layer

Multiplexing Approaches

- FDM
- TDM
- Packet Switching



Medium Access Control

- Medium (or Media) Access Control (MAC) protocol determines how multiple nodes share the multiplexed resource

Multiplexing Method – Multiple Seats in One Cabin

Access Control Method

Ticket

First come first served

The Medium Access Problem

- Two Types of Physical Links:
  - Private
    - Point-to-point link between nodes, e.g., USB
  - ✓Broadcast
    - Shared communication medium, e.g., Wi-Fi, Legacy Ethernet (10Mbps)
      - Two or more simultaneous transmissions => collisions
- Protocol: Medium Access Control (MAC)
  - Real examples:
    - Ethernet (this lecture)
    - Wi-Fi (next lecture)

An Ideal Access Control Method

- Consider a Broadcast Channel of Rate **R** bps
  - When one node wants to transmit, it can send at rate **R**.
  - When **M** nodes want to transmit, each can send at average rate **R/M**
  - Fully decentralized
    - No special node to coordinate transmissions
    - No synchronization of clocks, slots, etc.

Existing Practices

- Fixed Partitioning and Assignment
  - Avoid Collisions
  - e.g., TDMA, FDMA in 4G
- Random Access
  - Allow Collisions
  - e.g., CSMA in Ethernet and Wi-Fi

Random Access

- When a node has packet to send
  - Try best to transmit at full channel data rate **R**
  - Two or more concurrent transmitting nodes => collisions
- Core Design Issue
  - How to handle collisions ?
- Example Protocols
  - Transmit and Pray
  - ALOHA random access
  - CSMA

Transmit and Pray

- Good solution at low load
- Plenty of collisions at high load
  - Low throughput

Slotted ALOHA

- Assumptions
  - Same frame length
  - Nodes are synchronized
  - Nodes start to transmit only at the beginning of slot
  - Nodes can detect collision
- Operation Rule
  - No collision: node sends a new frame in the next slot
  - Collision: node retransmits the frame in each subsequent slot with probability **p** until success

Slotted ALOHA

- Cons:
  - Collisions waste the entire slot
  - There are idle slots
    - None of the transmitter gain the slot
  - (minor) Clock synchronization
    - Improved in un-slotted ALOHA

- For each slot, the probability of successful transmission is Np(1-p)^(N-1)
- p is the probability of transmission. It is determined by the number of nodes N in the network, when N is large, p should be small.
- The optimal p can be calculated by derivation
  - f(p)=Np(1-p)^(N-1)
  - f'(p)=N(1-p)^(N-1)-Np(N-1)(1-p)^(N-2)
  - Thus the optimal p is 1/N
- So when p=1/N, the probability of successful transmission is (1-1/N)^(N-1), when N is large, it is close to 1/e. Thus the utilization of the channel is about 30%

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potential improvements:

1. take actions to handle collision
2. sense the idle slots

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Ethernet

- Popular Local Area Network (LAN)
- Brief History

parc
A Xerox Company

3com

IEEE 802.3

ACM has named Bob Metcalfe as recipient of the 2022 ACM A.M. Turing Award for the invention, standardization, and commercialization of Ethernet.

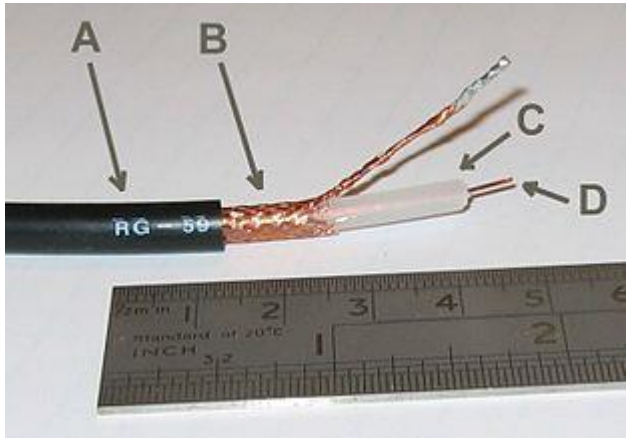
Ethernet

- Legacy Ethernet
  - 10BASE-T (10 Mbps)
  - Shared Medium

Transceiver

https://upload.wikimedia.org/wikipedia/commons/thumb/9/9e/Network_card.jpg/440px-Network_card.jpg

Coaxial Cable



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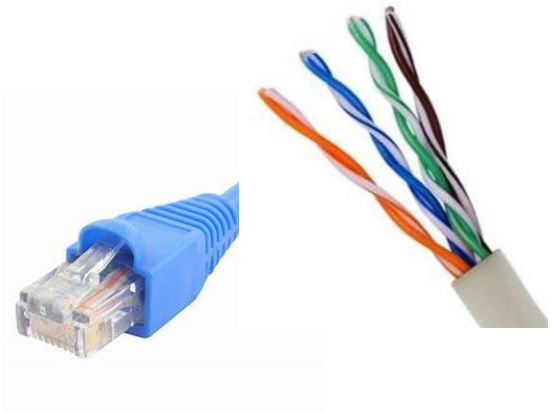
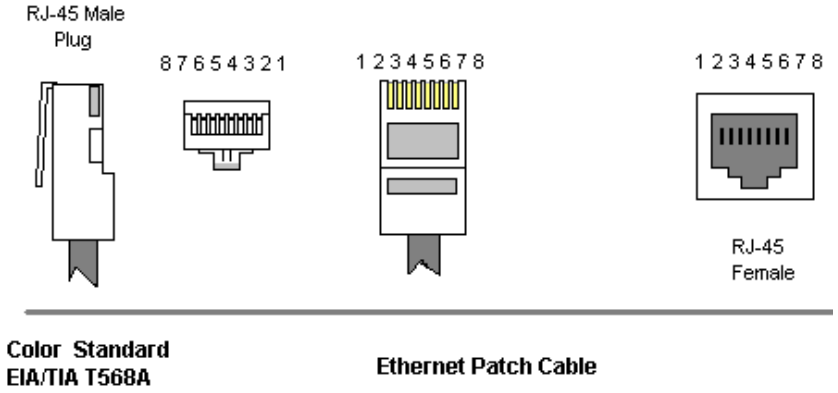
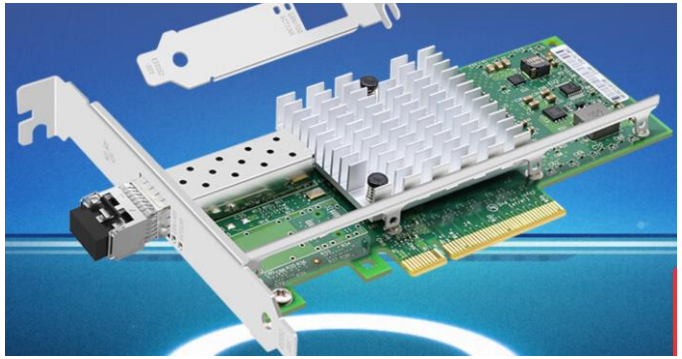
Ethernet

- Current Ethernet
  - 1 Gbps, 10 Gbps, 40 Gbps, etc.
  - Dedicated link to switch
  - Collision free
  - PHY: twisted pair or fiber



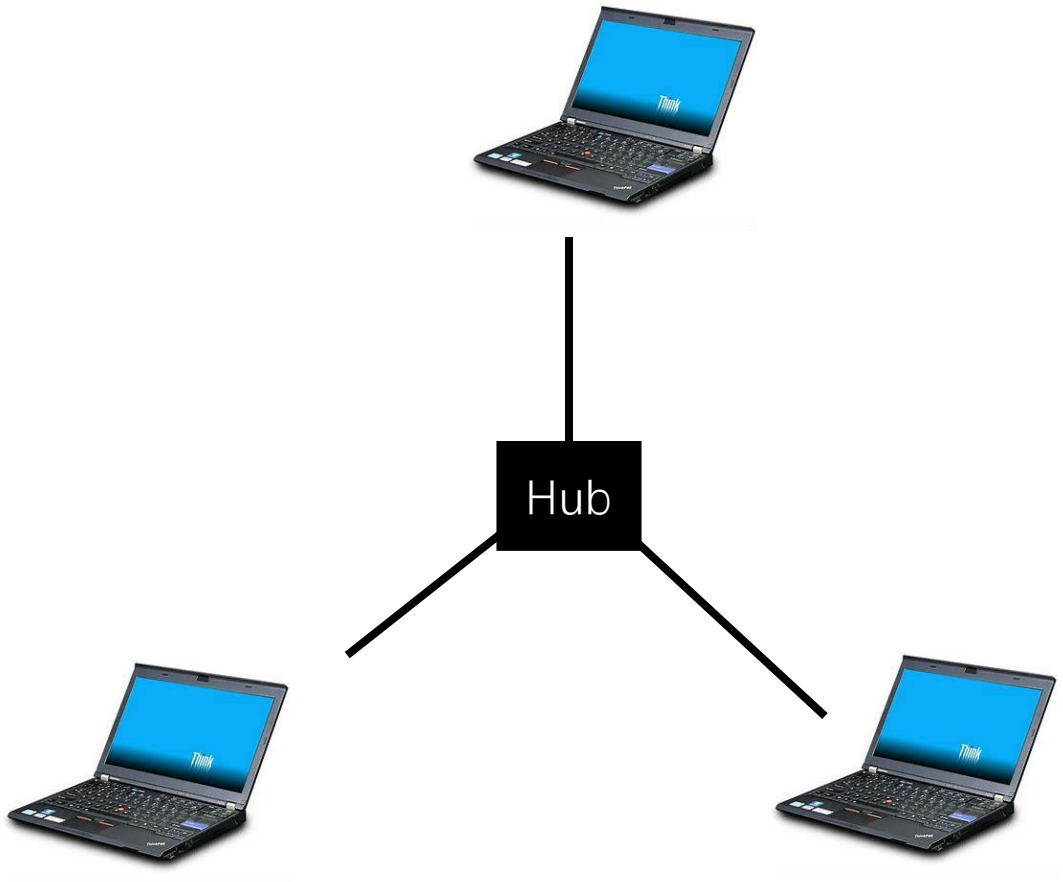




https://item.jd.com/100010808958.html

https://en.wikipedia.org/wiki/Small_Form-factor_Pluggable

Scope: Legacy Ethernet



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Similar to a Bus

Carrier Sense Multiple Access (CSMA)

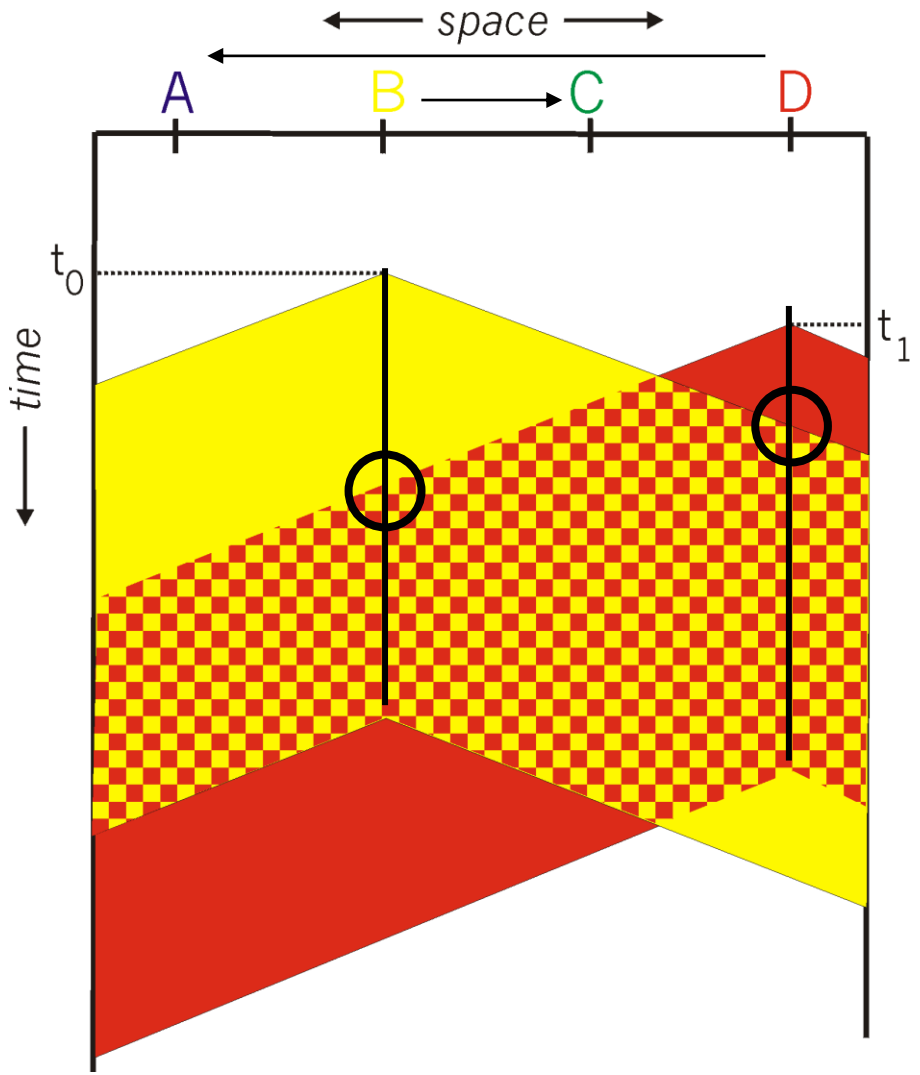
- CSMA: Listen before Transmit
  - If the channel is sensed idle: transmit the entire frame
  - If the channel is sensed busy: defer the transmission

Can collisions still occur?

CSMA: Collisions

- Collisions can still occur
  - Due to propagation delay
- When collision occurs
  - Entire frame wasted

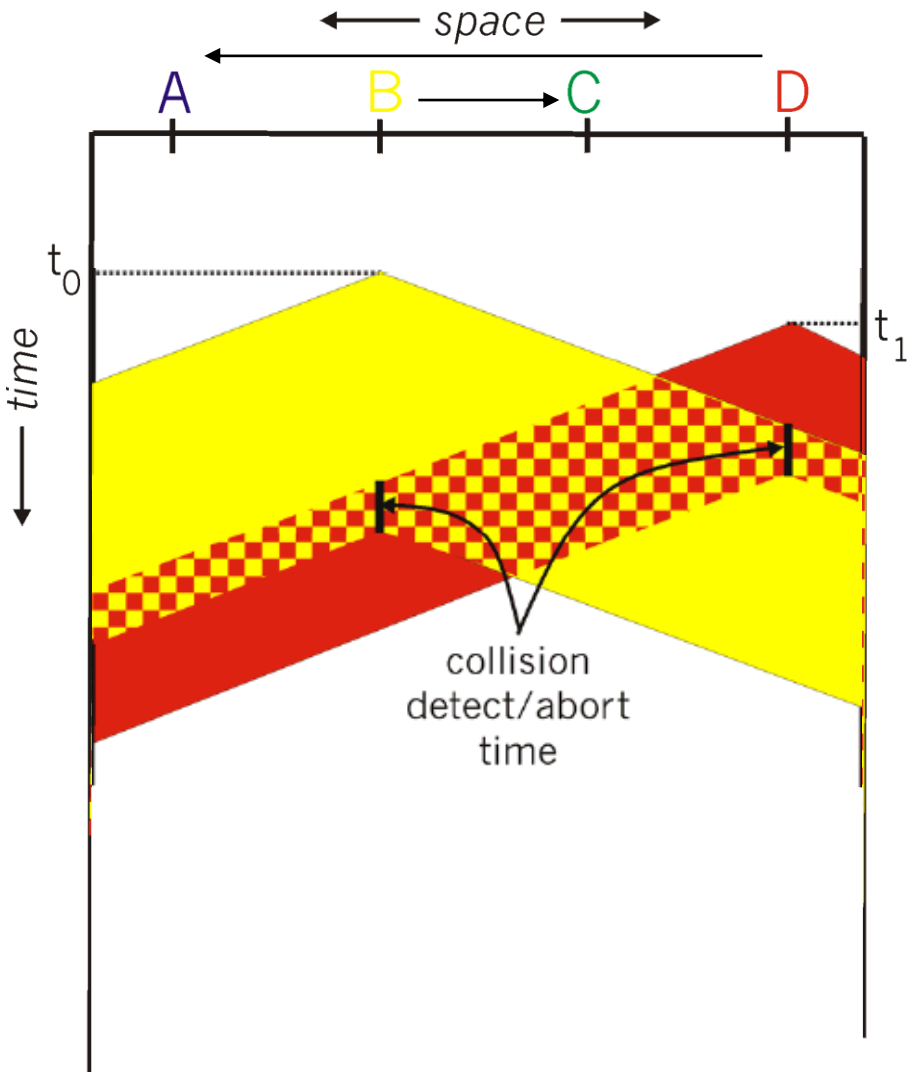
How to better handle collisions ?



CSMA + Collision Detection (CSMA/CD)

- Keep listening to the channel while transmitting

- Abort the transition if collision is detected
  - Opt1: transmitted signal != sensed signal
  - Opt2: energy detection
  - Then, retransmit



Ethernet CSMA/CD

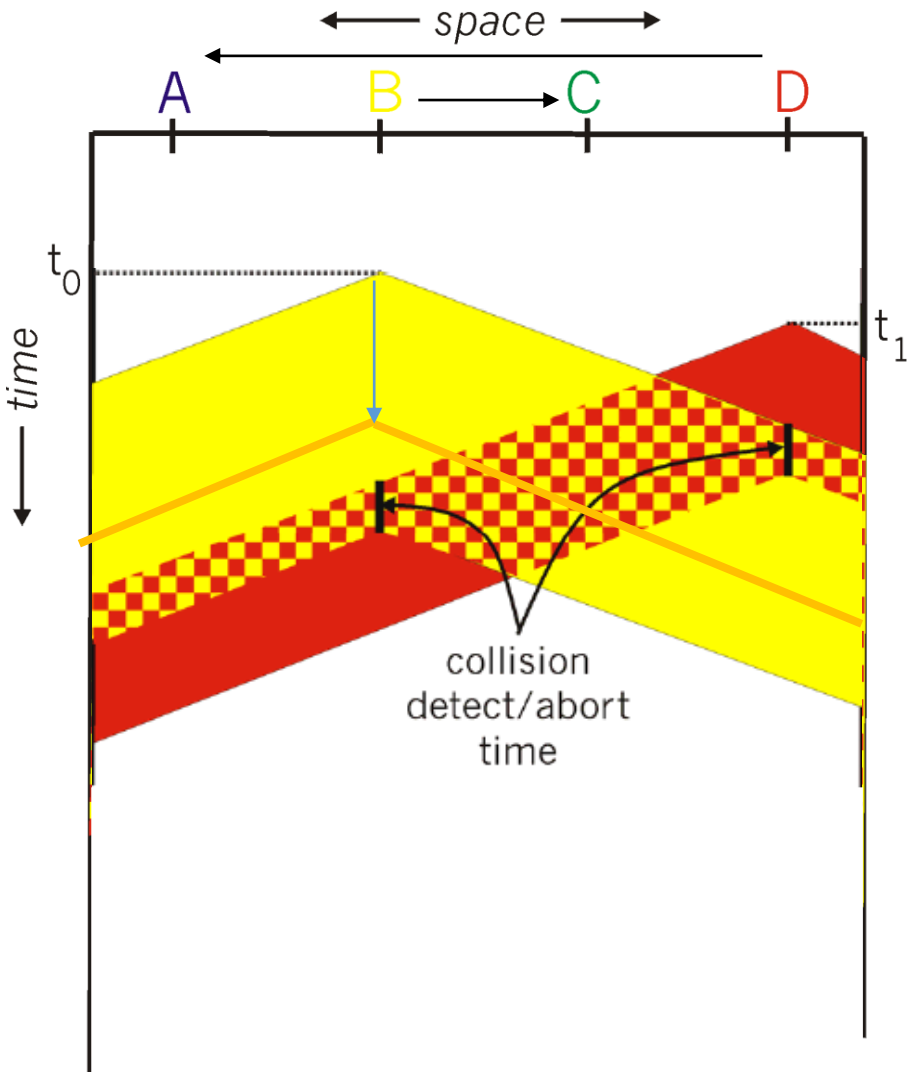
- If channel idle
  - starts transmission
- Else (channel busy)
  - Waits until channel idle.
- If the entire frame is transmitted without detecting another transmission
  - done
  - go idle
- Else
  - Aborts the transmission and sends jam signals
    - to make sure that all the transmitting adapters become aware of the collision
  - Backoff wait
  - go idle to retransmit (max 16 times)

Ethernet CSMA/CD

- Exponential Backoff
  - After m_{th} collisions, chooses K at random from {0,1,2, ⋯, 2^m-1}
    - if m>11
      - chooses K at random from {0,1,2, ⋯, 1023}
    - if m=16
      - done
      - go idle
  - Waits K*one time slot

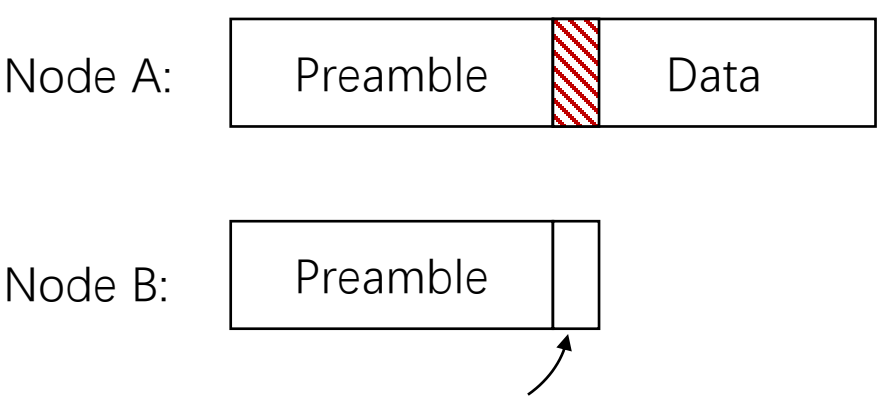
More about Ethernet CSMA/CD

- Ethernet does not use ACK
  - It uses local collision detection to estimate the receiver's conditions
    - collision free => success
    - collision => retransmit
- But what if B stopped transmission before it detects collisions ?
  - B failed to identify C's collision
    - => no retransmission => transmission failure

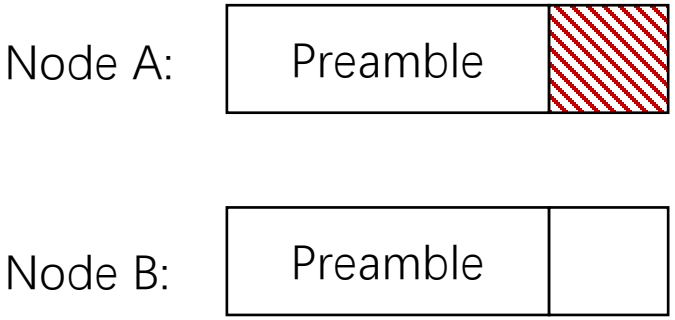


How to Detect All Collisions with CSMA/CD

- Extreme Case 1
  - Two nodes are close to each other
    - Transmit a jamming sequence to notify collision



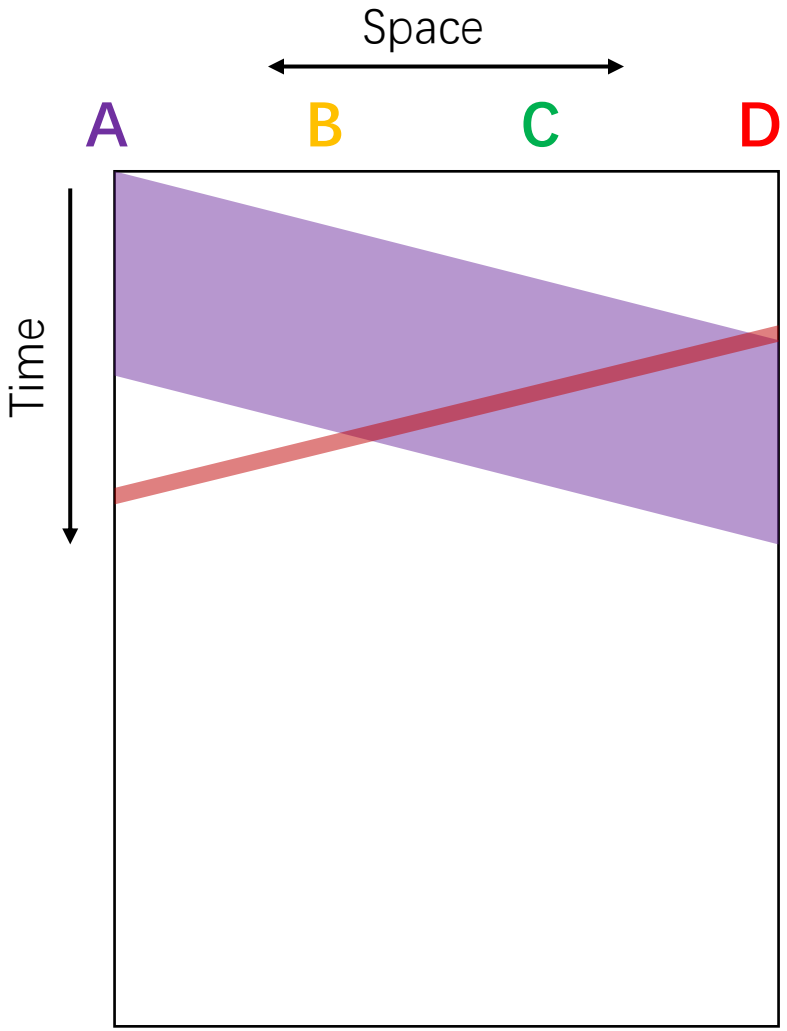
B detects collision and stops immediately, but A may not detect it and continue transmitting. A's destination gets CRC error, but A does not know it, so it will not retransmit.



B detects collision and continues jamming for a while before stops transmitting. A detects collision and stops transmitting. A will retransmit the frame later.

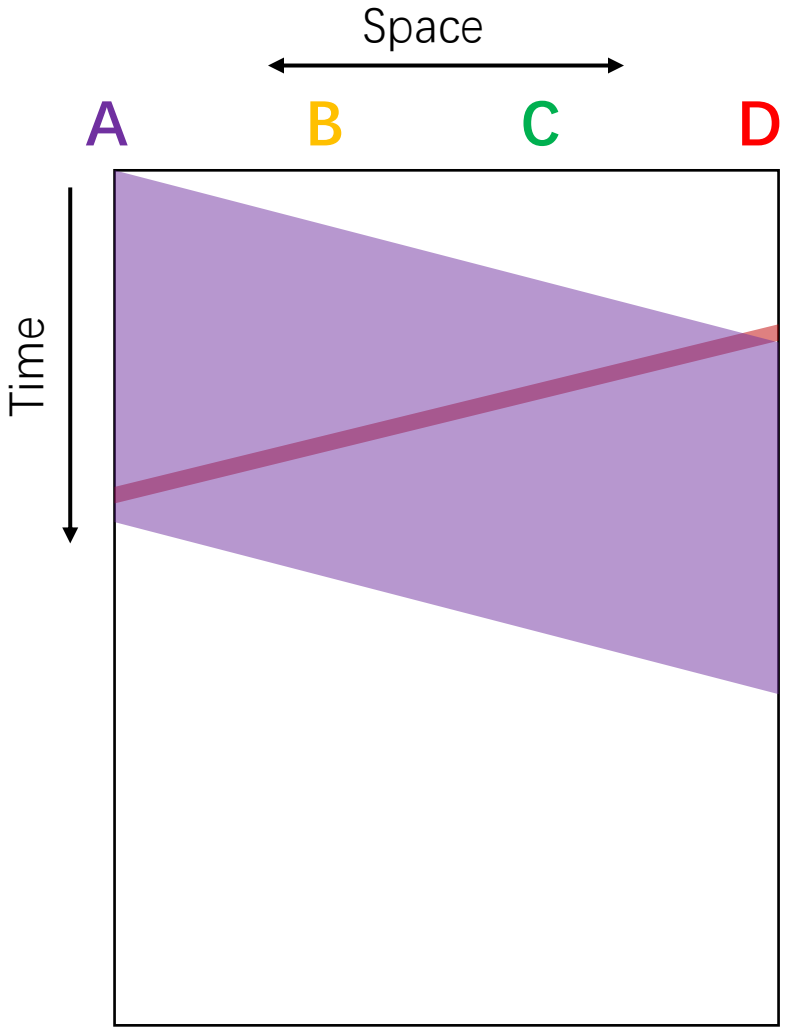
How to Detect All Collisions with CSMA/CD

- Extreme Case 2
  - Two nodes are far apart
    - A transmits a frame to C
    - D transmits a frame to B
      - before the arrival of A's signal
    - D detects collision, sends jamming, and stops
    - A does not detect the collision
      - as its transmission ends before D's frame arrivals at A
    - C receives A's frame with error



How to Detect All Collisions with CSMA/CD

- Extreme Case 2
  - Two nodes are far apart
  - Define a Minimum Frame Size to eliminate this situation
  - A has to transmit a frame lasting for at least a round trip time from A to D
    - e.g., 2500m is approximately equivalent to 512 bits (51.2 us) in 10BASE-T Ethernet



More about Ethernet CSMA/CD

- Number of nodes
  - more nodes more collisions
  - Maximum number of nodes
    - 1024
- Effective Range
  - The larger the network, the more likely to miss the collisions
  - Minimum Frame Size
    - e.g., Range 2500m (reason to call it a Local Area Network)

Other Aspects of Ethernet

Ethernet Frame Structure

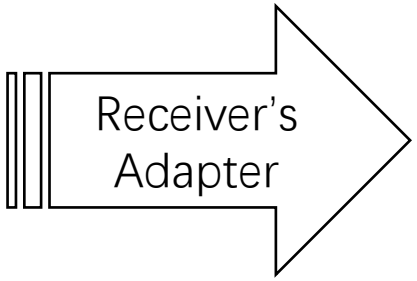
- Physical Layer
  - Manchester coded (10 Mbps), 4B5B (100 Mbps), 8B/10B (1000 Mbps)
  - Preamble
    - e.g., 7 bytes with pattern 10101010 followed by one byte with pattern 10101011
    - Sync and Clock Recovery

Ethernet Frame Structure

- Every Ethernet network card has an address, called MAC address
  - 6 bytes
  - Find your MAC address
    - `ifconfig`
    - `ipconfig /all`
  - Lookup the vendor of the adapter
    - https://mac-address.alldatafeeds.com/mac-address-lookup

Ethernet Frame Structure

- Unicast Address
- Broadcast Address
  - All 1s
- Multicast Address
  - First bit 1

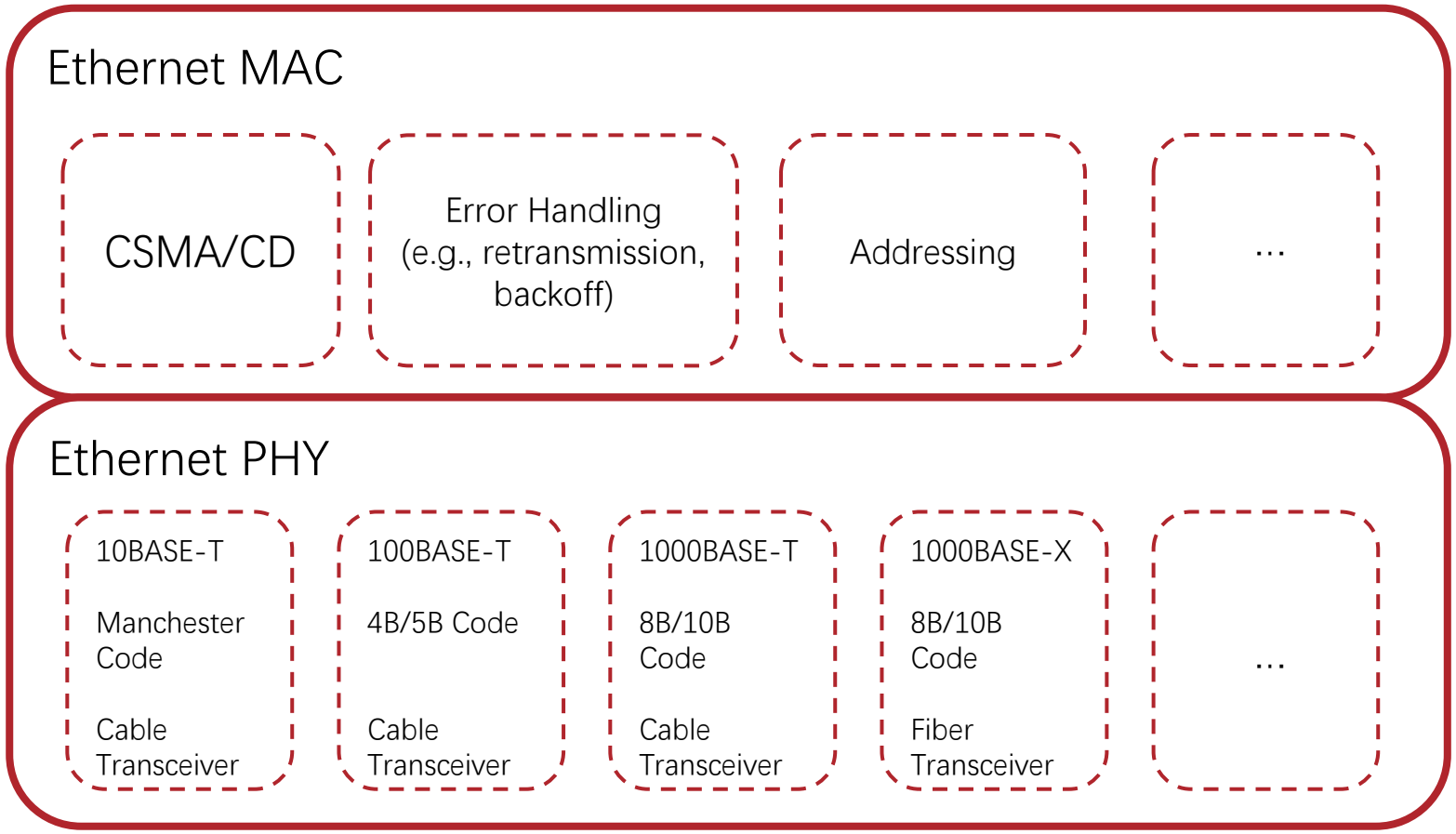


if the packet dest addr is the receiver's address, then pass the error free packet to the host

Ethernet Frame Structure

- Type
  - IPV4, ARP, RoCE, etc.
  - Length
- Body 46-1500 B
- CRC 32
- NO ACK

Ethernet Protocol Stack



Reference

- Textbook 2.6
- http://www.ee.columbia.edu/~bbathula/courses/HPCN/lecture04.pdf