



CS120: Computer Networks

Lecture 6. Medium Access Control 1

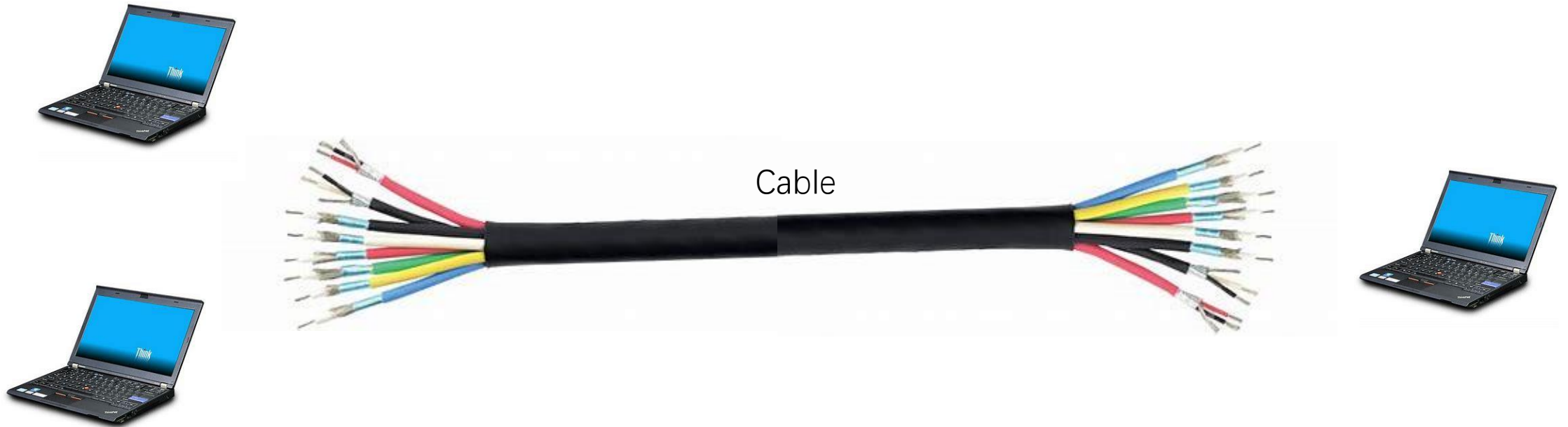
Zhice Yang

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 \Rightarrow collisions
- Core Design Goals
 - How to detect collisions
 - How to recover from 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%



Slotted ALOHA

- Cons:

- Collisions waste the entire slot
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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



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

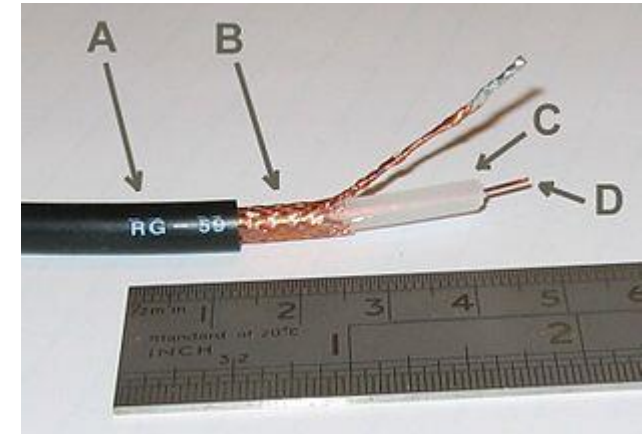
- Legacy Ethernet
 - 10BASE-T (10 Mbps)
 - Shared Medium

Transceiver



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

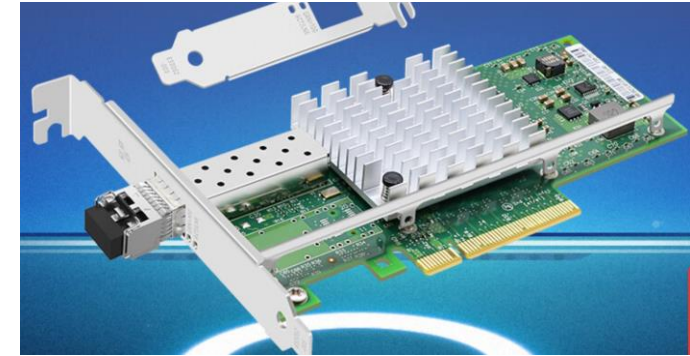
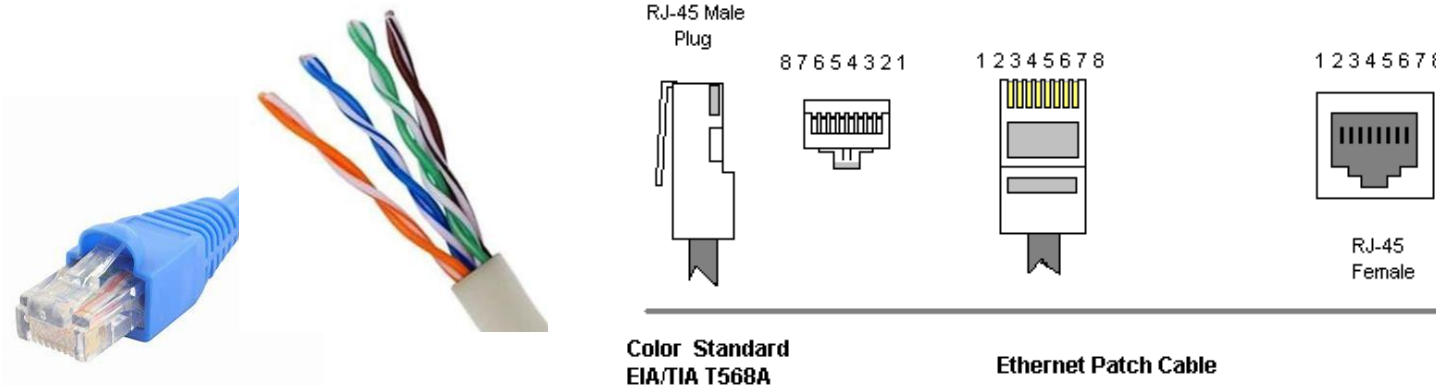
Coaxial Cable



<https://upload.wikimedia.org/wikipedia/commons/thumb/7/73/RG-59.jpg/620px-RG-59.jpg>

Ethernet

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

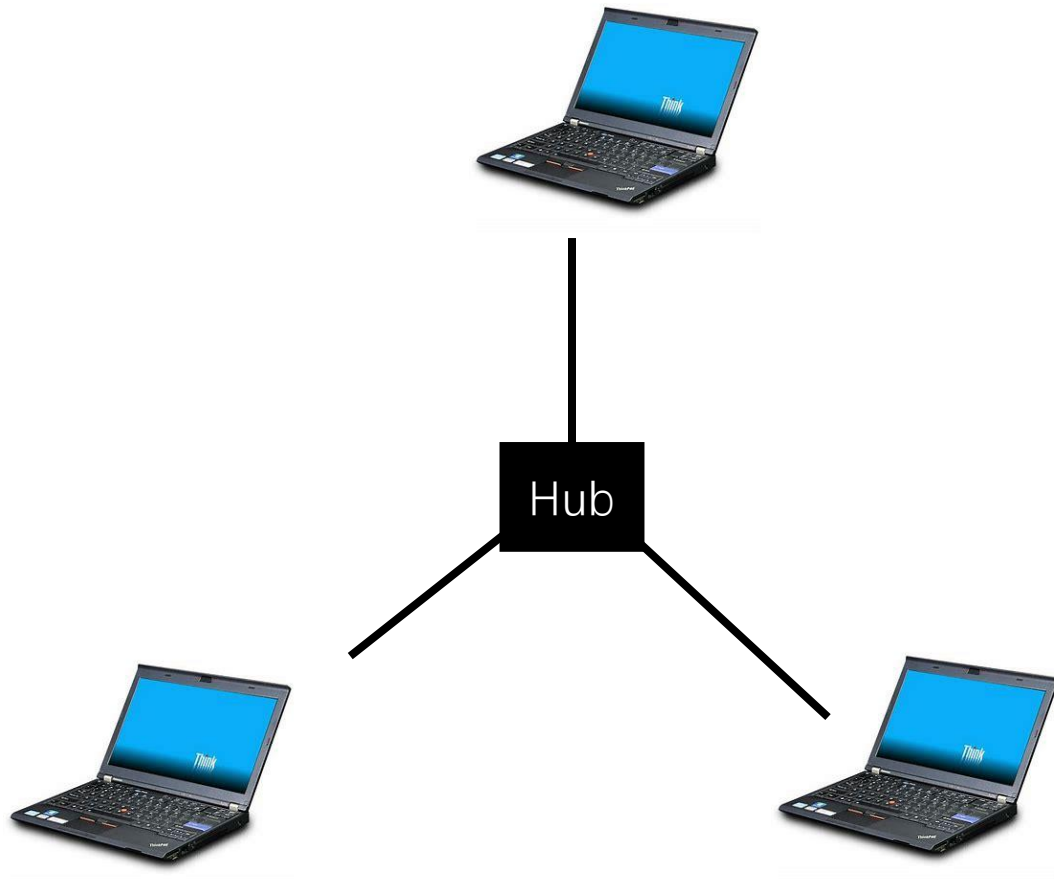


<https://item.jd.com/100010808958.html>



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)

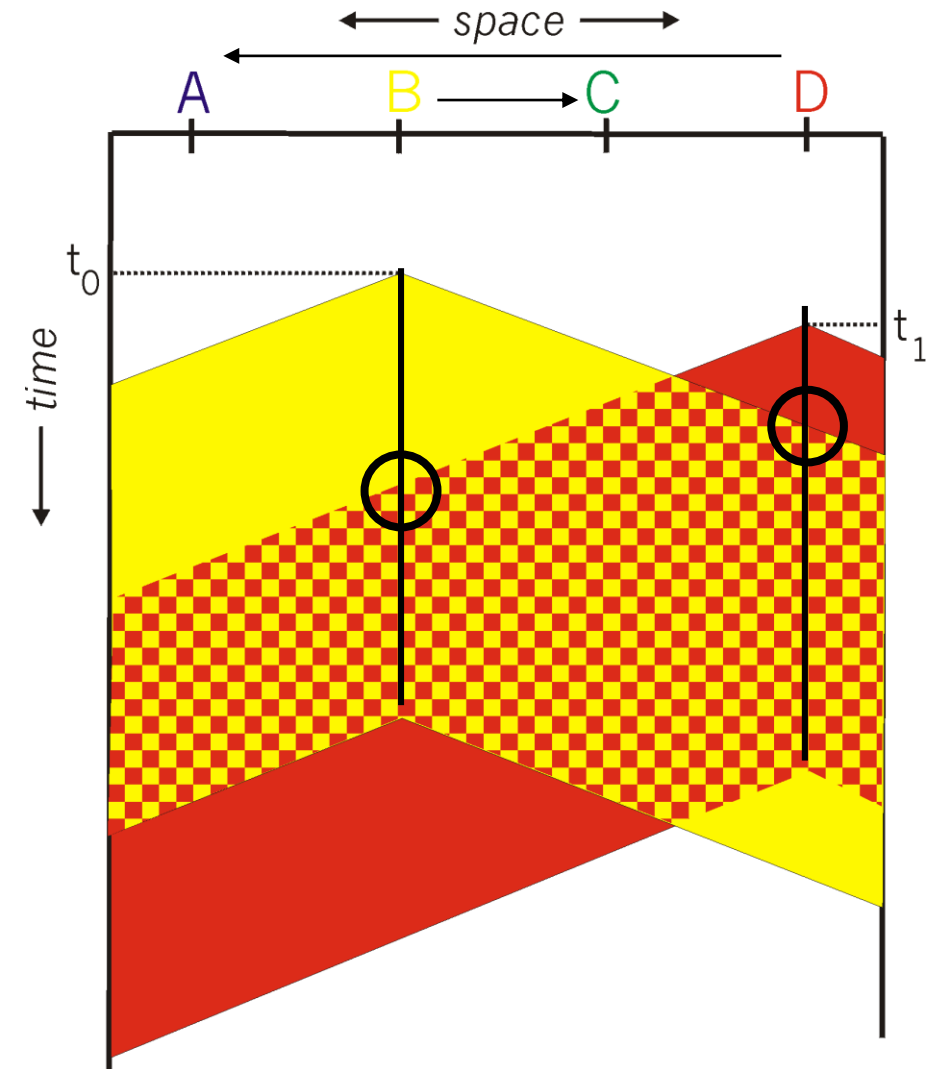
- CSMA: Listen before Transmit
 - If the channel is sensed idle: transmit the entire frame
 - If the channel is sensed busy: defer the transmission

Can collisions still occur?

CSMA: Collisions

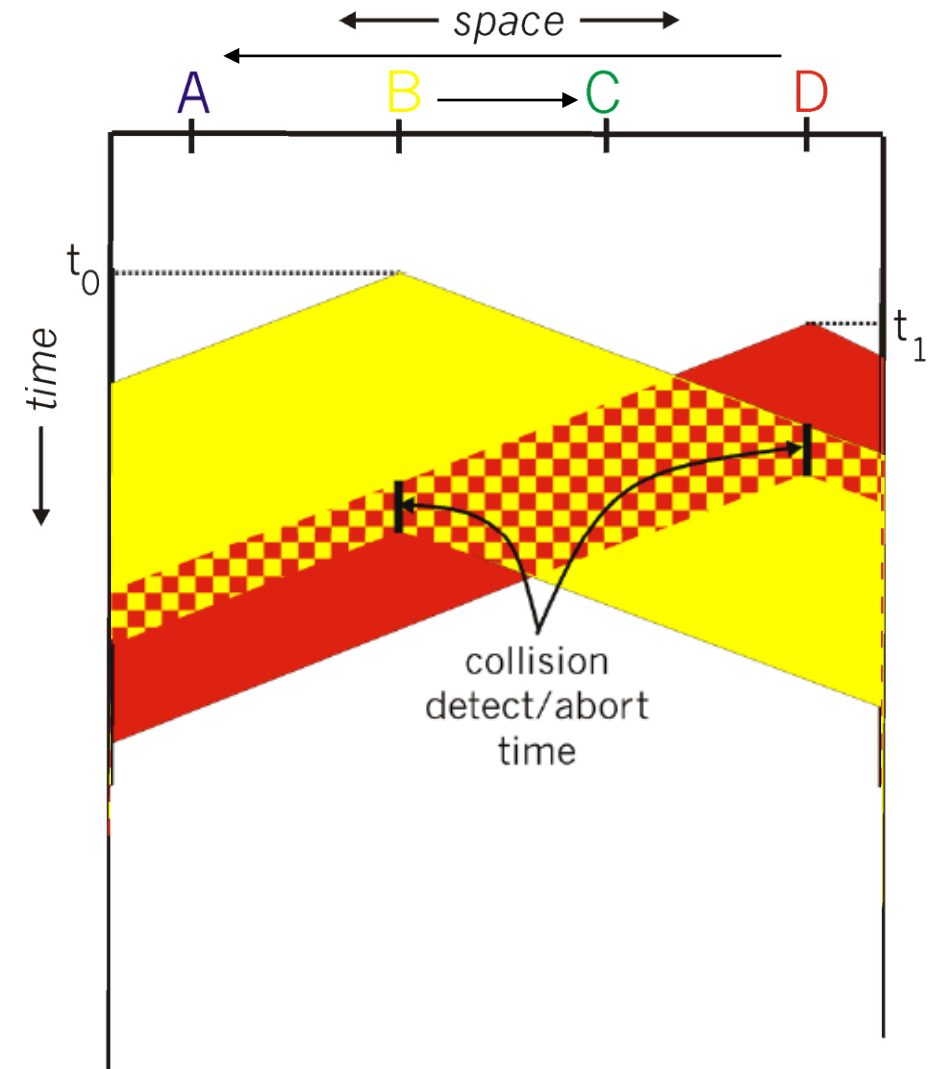
- Collisions can still occur
 - Due to propagation delay
- When collision occurs
 - Entire packet wasted

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 \neq sensed signal
 - Opt2: energy detection
 - Then, retransmit



Ethernet CSMA/CD

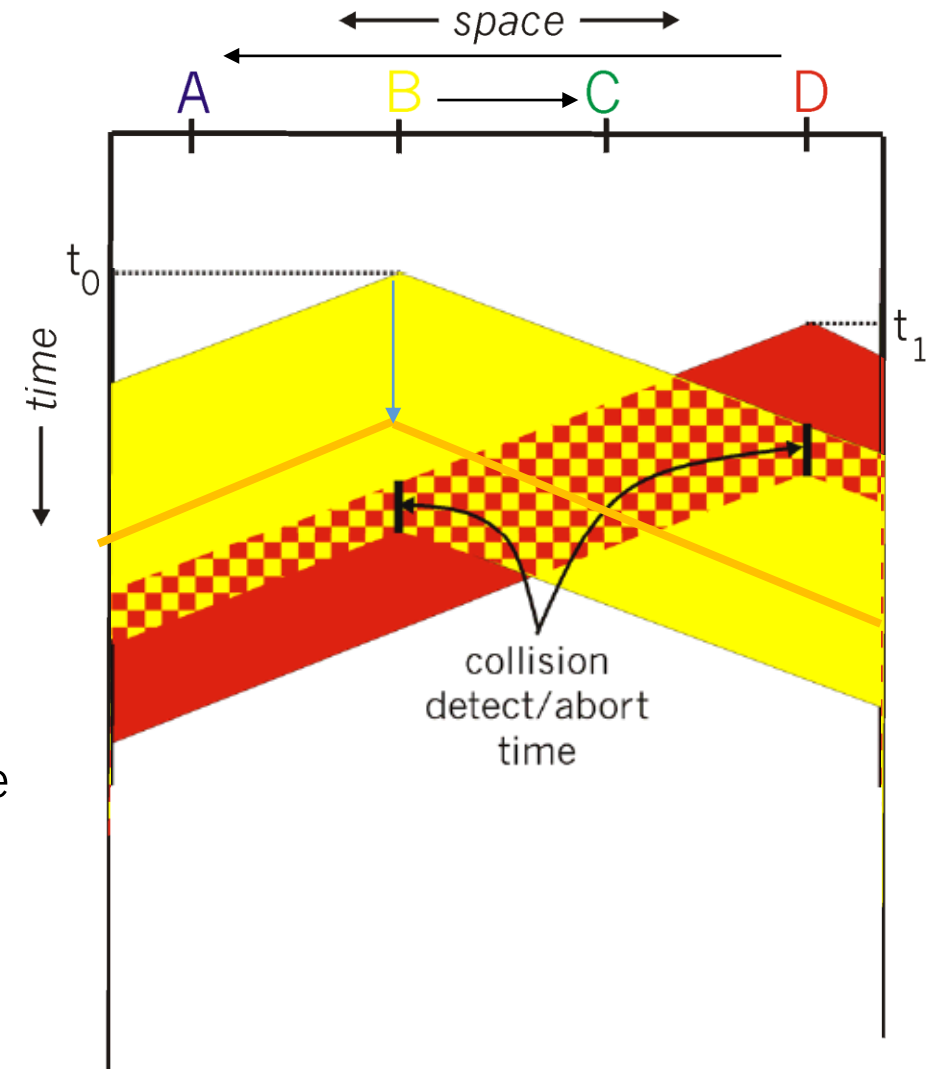
- If channel idle
 - starts transmission
- Else (channel busy)
 - Waits until channel idle.
- If the entire frame is transmitted without detecting another transmission
 - done
 - go idle
- Else
 - Aborts the transmission and sends jam signals
 - to make sure that all the transmitting adapters become 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 $\{0, 1, 2, \dots, 2^m - 1\}$
 - if $m > 11$
 - chooses K at random from $\{0, 1, 2, \dots, 1023\}$
 - if $m = 16$
 - done
 - go idle
 - Waits $K \times \text{one time slot}$

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

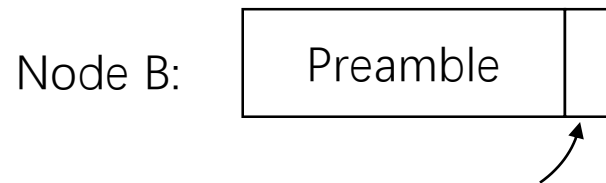


More about Ethernet CSMA/CD

- Number of nodes
 - The more nodes are connected, the 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)

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



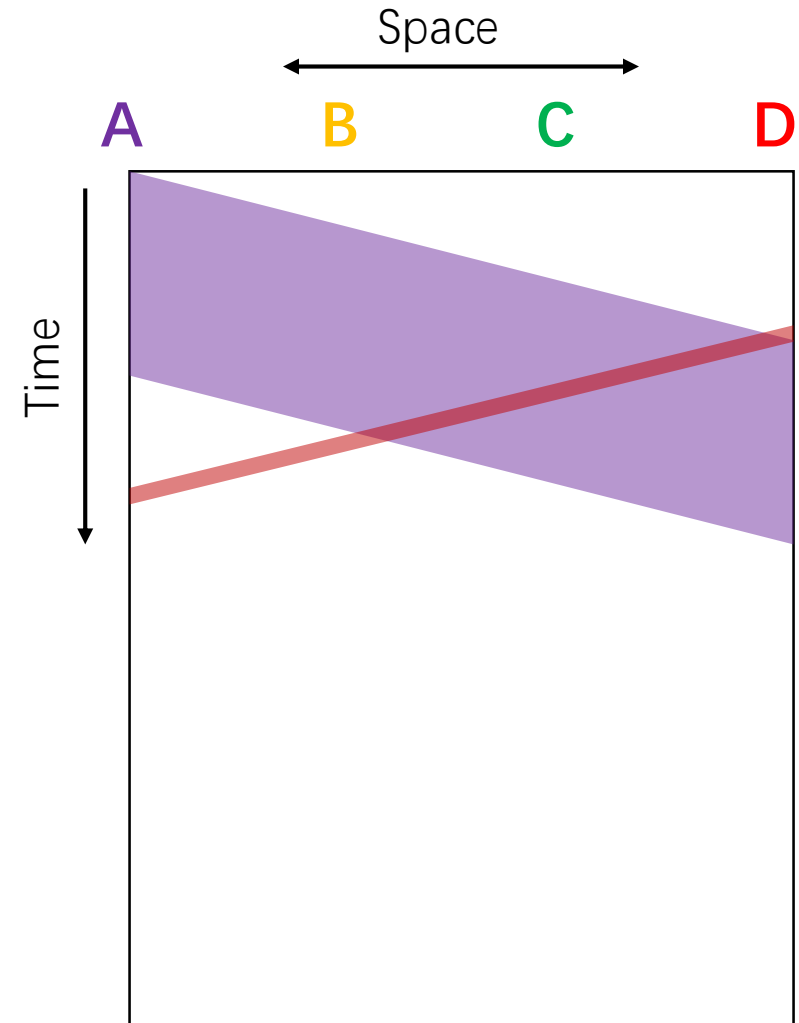
B detects collision and stops immediately, but A may not detect it and continue transmitting. A's destination gets CRC error, but A does not know it, so it will not retransmit.



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

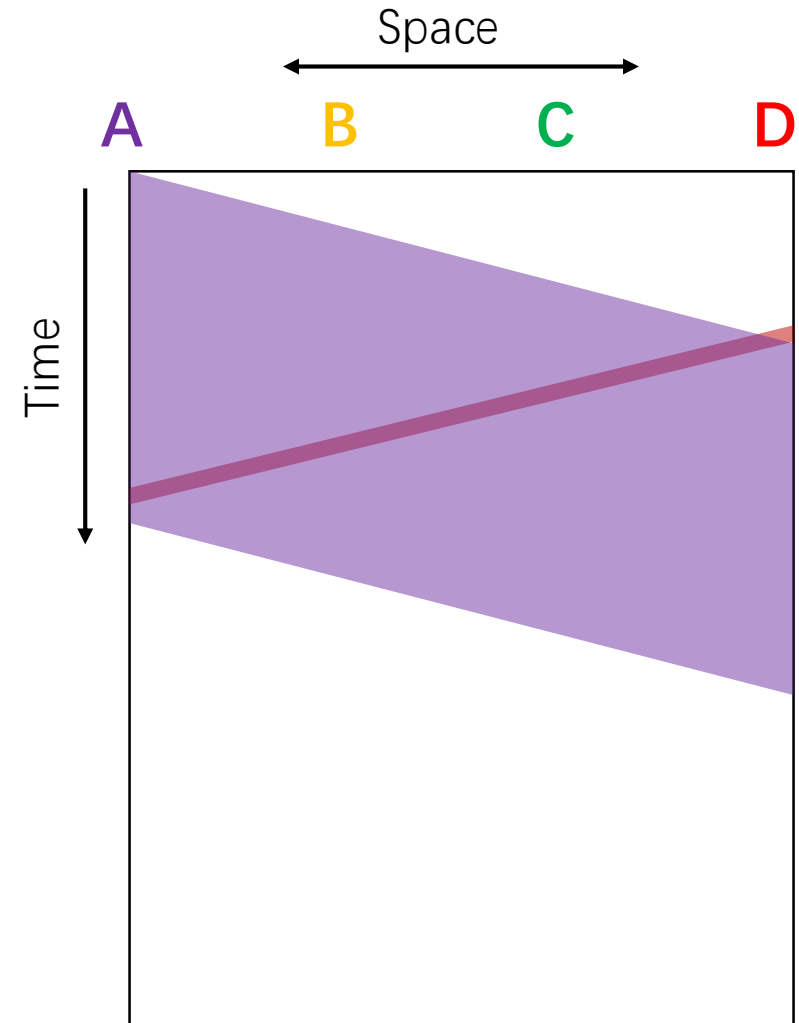
How to Detect All Collisions with CSMA/CD

- 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 arrives at A
 - C receives A's frame with error



How to Detect All Collisions with CSMA/CD

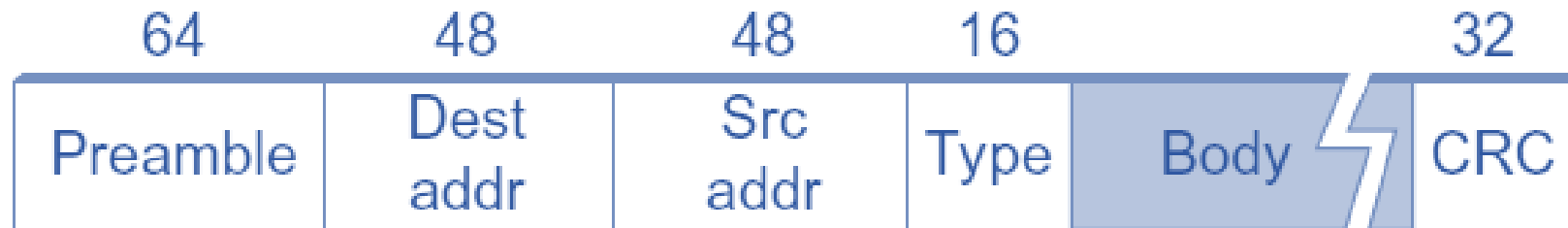
- Extreme Case 2
 - Two nodes are far apart
 - Define a Minimum Frame Size to eliminate this situation
 - A has to transmit a frame lasting for at least a round trip time from A to D
 - e.g., 2500m is approximately equivalent to 512 bits (51.2 μ s) in 10BASE-T Ethernet



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



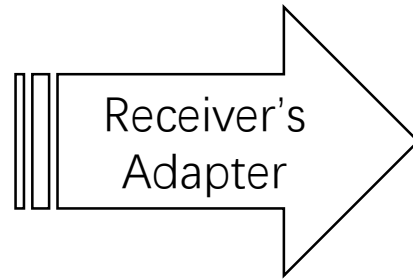
Ethernet Frame Structure

- Every Ethernet network card has an address, called MAC address
 - 6 bytes
 - Find your MAC address
 - `ifconfig`
 - `ipconfig /all`
 - Find the manufacturer of your adapter
 - http://coffer.com/mac_find/

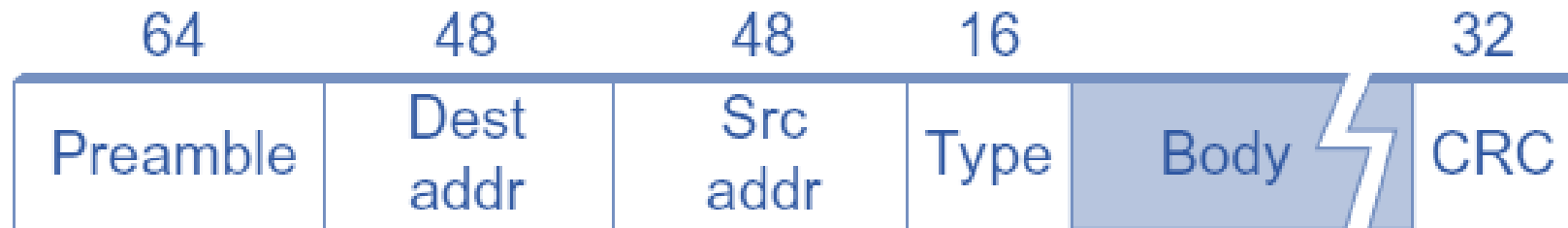


Ethernet Frame Structure

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

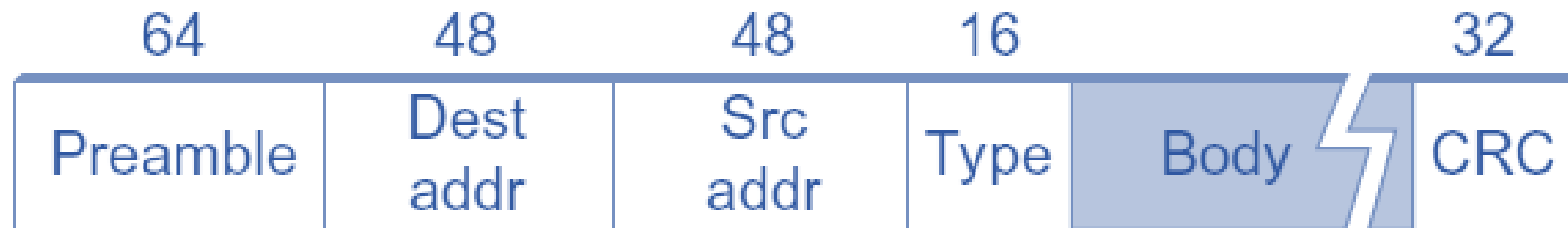


if the packet dest addr is the receiver's address, then pass the error free packet to the host

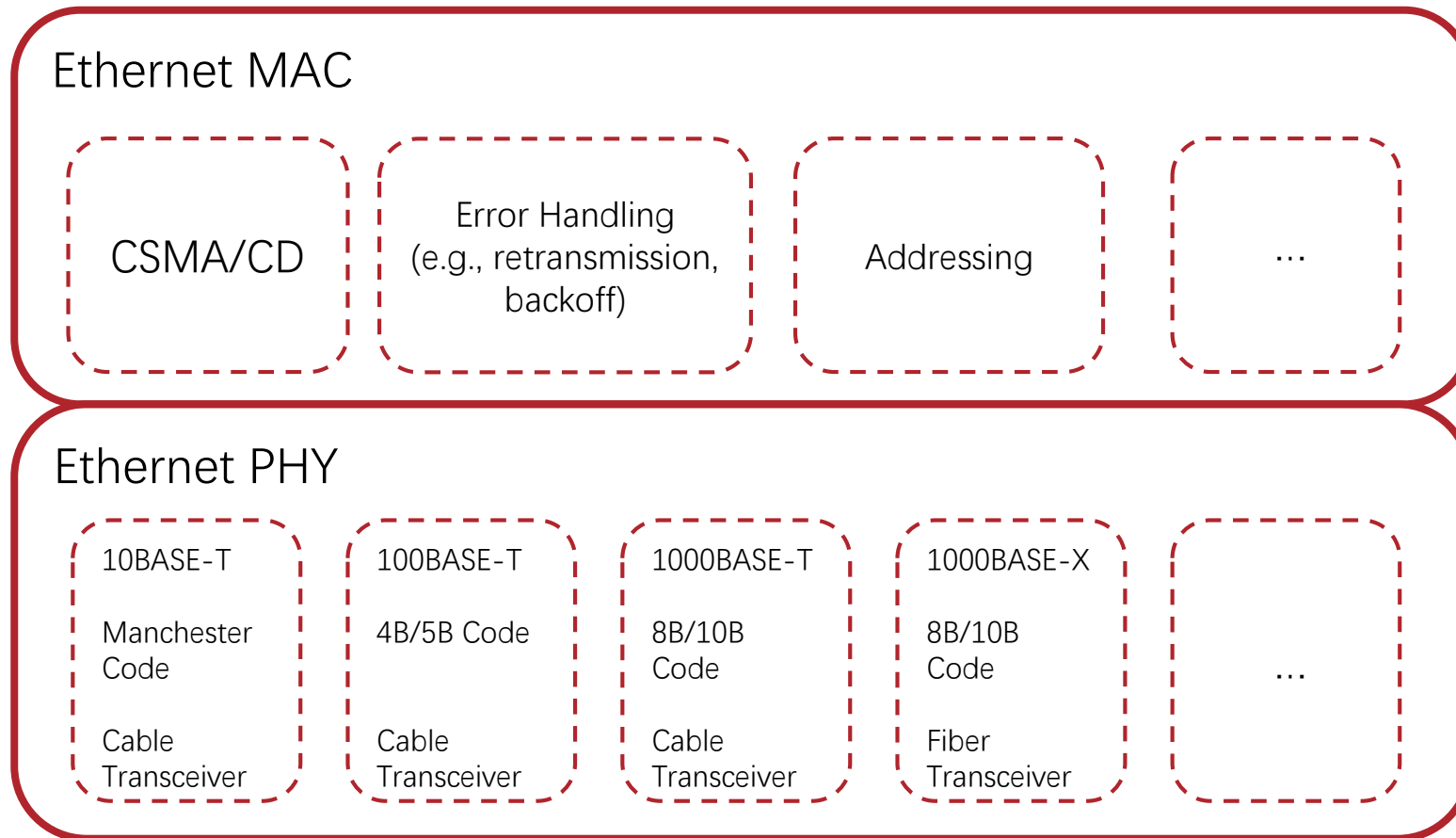


Ethernet Frame Structure

- 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>