



UNIVERSITY OF  
**WATERLOO**

# CS 456/656

## Computer Networks

### Lecture 16: Link Layer – Part 3

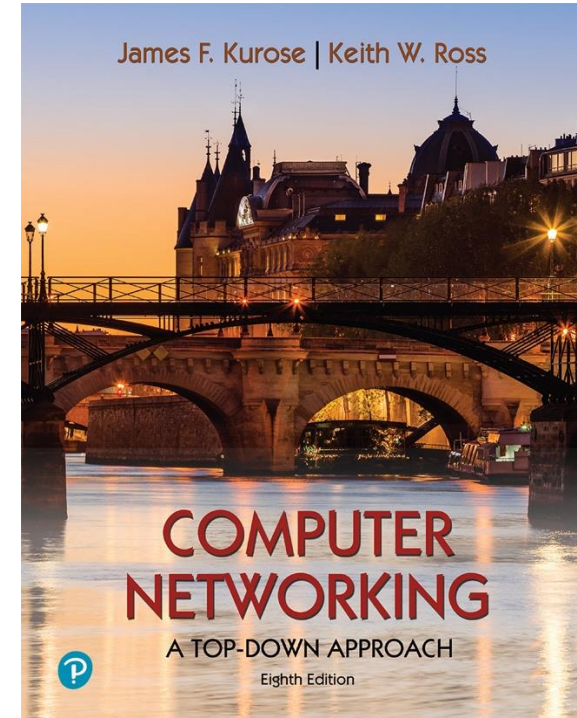
Mina Tahmasbi Arashloo and Uzma Maroof

Fall 2025

# A note on the slides

Adapted from the slides that  
accompany this book.

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## *Computer Networking: A Top-Down Approach*

8<sup>th</sup> edition  
Jim Kurose, Keith Ross  
Pearson, 2020

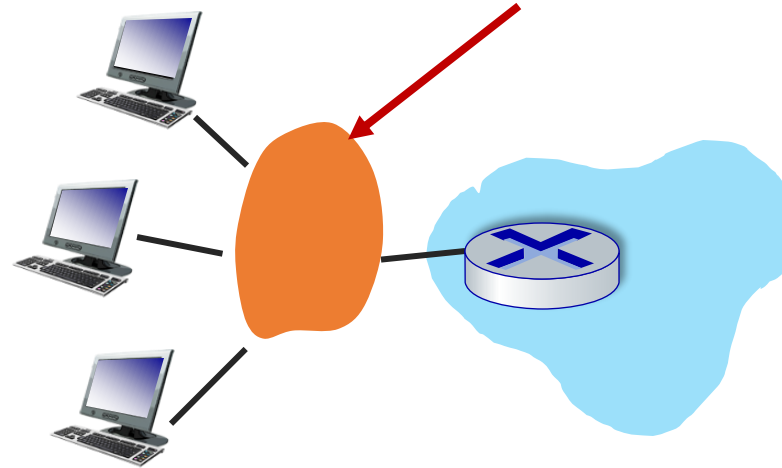
# Link layer: roadmap

- Link layer overview
  - Local Area Networks (LANs)
- Switched LANs
  - Ethernet and Addressing
  - Address Resolution Protocol (ARP)
  - Switches
- Virtual LANs (VLANs)
- Shared LANs and multiple access protocols
  - Random access

# Link layer: local connectivity

Also called a **Local Area Network (LAN)**

Either “shared link” or  
a link-layer network



# Multiple access links and protocols

two types of “links”:

- point-to-point
  - point-to-point link between Ethernet switches and hosts
- **shared wire or medium (broadcast)**
  - old-school Ethernet
  - 802.11 wireless LAN, 4G/4G. Satellite
  - ...



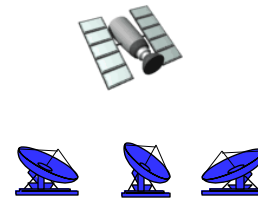
shared wire (e.g.,  
cabled Ethernet)



shared radio: 4G/5G



shared radio: WiFi



shared radio: satellite



humans at a cocktail party  
(shared air, acoustical)

# Multiple access protocols

- single shared communication channel
- two or more simultaneous transmissions by nodes can lead to interference
  - *collision* if node receives two or more signals at the same time

## multiple access protocol

- distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit
- communication about channel sharing must use channel itself!
  - no out-of-band channel for coordination

# An ideal multiple access protocol

given: multiple access channel (MAC) of rate  $R$  bps

what we ideally want:

1. when one node wants to transmit, it can send at rate  $R$ .
2. when  $M$  nodes want to transmit, each can send at average rate  $R/M$
3. fully decentralized:
  - no special node to coordinate transmissions
  - no synchronization of clocks, slots
4. simple

# MAC protocols: taxonomy

three broad classes:

- **channel partitioning**

- divide channel into smaller “pieces” (time slots, frequency, code)
- allocate piece to node for exclusive use

- **random access**

- channel not divided, allow collisions
- “recover” from collisions

- **“taking turns”**

- nodes take turns, but nodes with more to send can take longer turns



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# Random access protocols

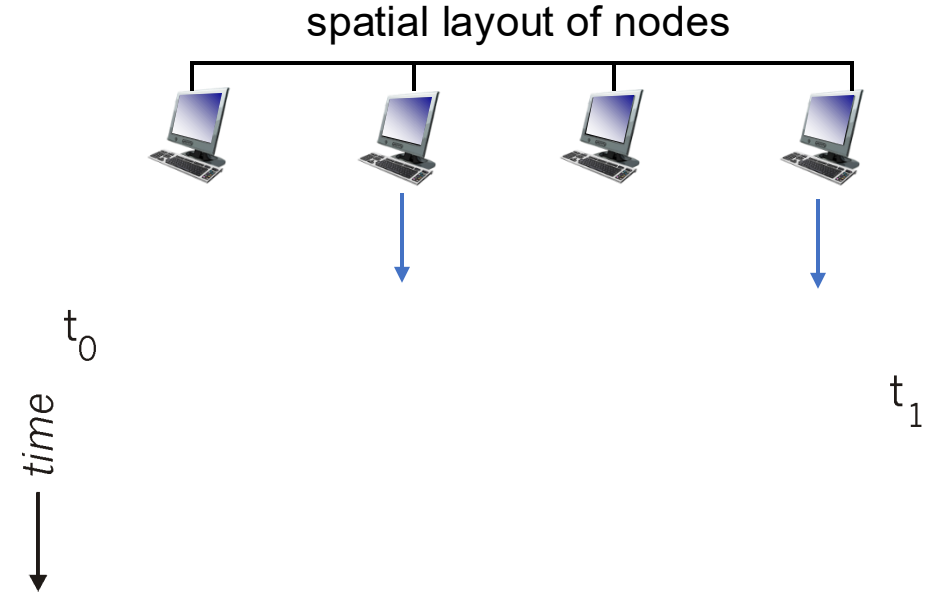
- when node has packet to send
  - transmit at full channel data rate  $R$
  - no *a priori* coordination among nodes
- two or more transmitting nodes:  
“collision”
- **random access protocol** specifies:
  - how to detect collisions
  - how to recover from collisions (e.g., via delayed retransmissions)
- examples of random access MAC protocols:
  - ALOHA, slotted ALOHA
  - CSMA, CSMA/CD, CSMA/CA

# CSMA (carrier sense multiple access)

- Probability of collision can be reduced if “Listen Before Talk”
- simple **CSMA**: listen before transmit:
  - if channel sensed idle: transmit entire frame
  - if channel sensed busy: defer transmission
- human analogy: don't interrupt others!

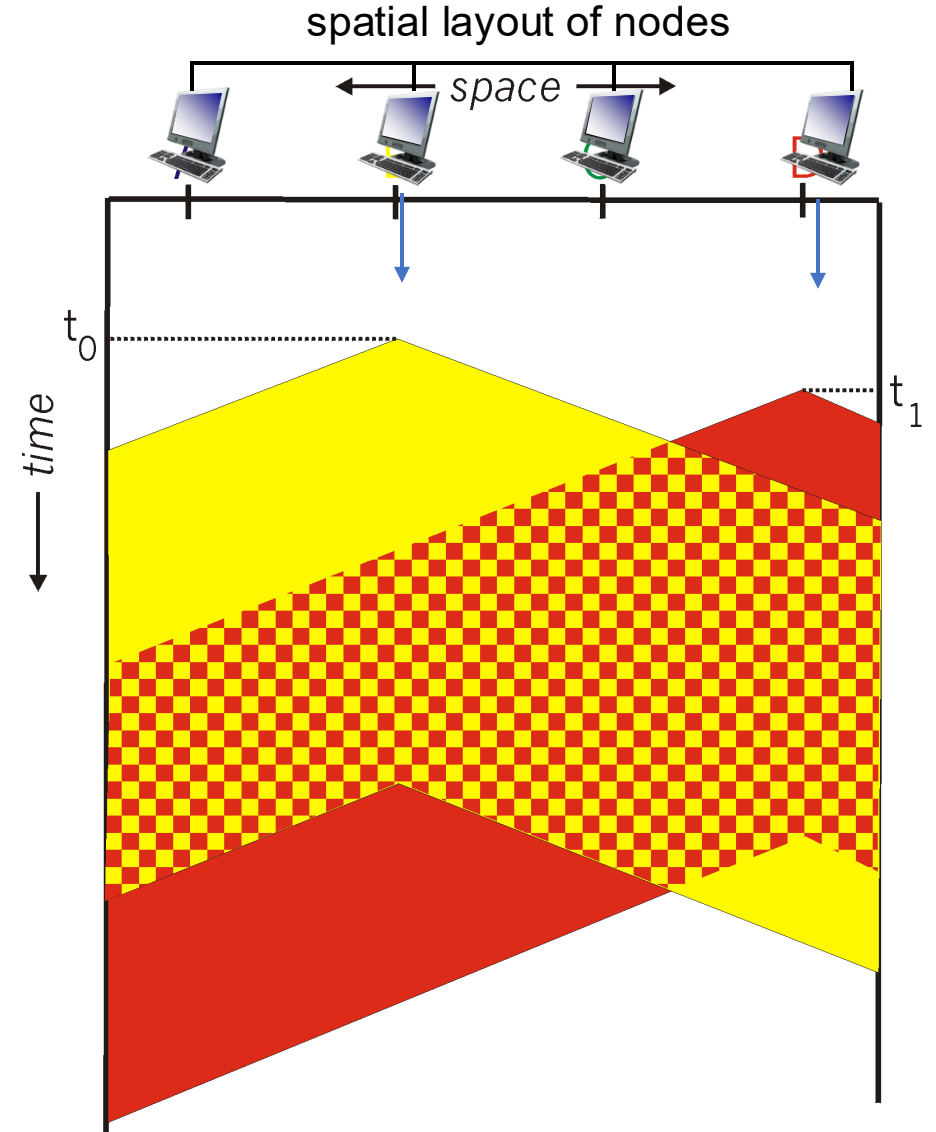
# CSMA: collisions

- collisions can *still* occur with carrier sensing:
  - **propagation delay** means two nodes may not hear each other's just-started transmission
- **collision**: entire packet transmission time wasted
  - distance & propagation delay play role in determining collision probability



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# CSMA (carrier sense multiple access)

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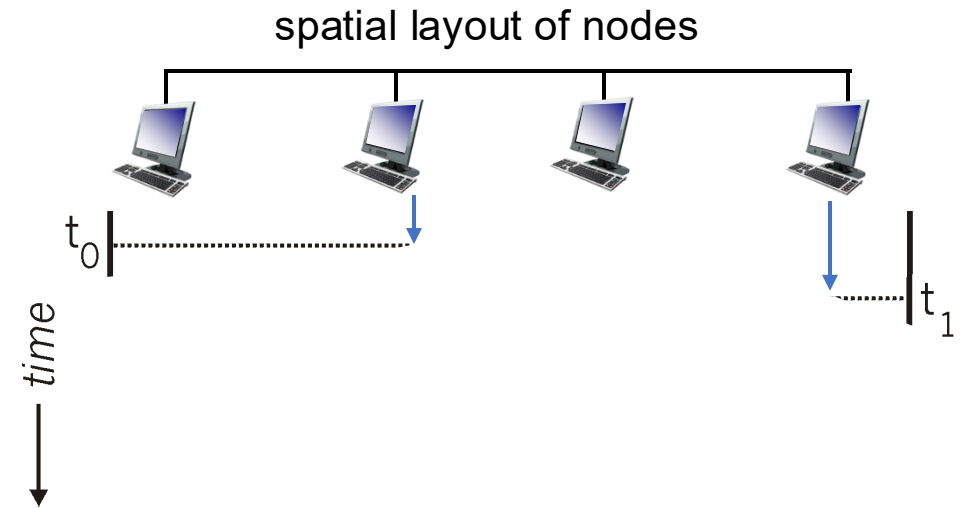
- if channel sensed idle: transmit entire frame
  - if channel sensed busy: defer transmission
- human analogy: don't interrupt others!

**CSMA/CD**: CSMA with *collision detection*

- monitor for incoming signals while transmitting
  - if collision detected: stop sending and retry later
- human analogy: If someone else starts talking at the same time, stop talking (the polite conversationalist).

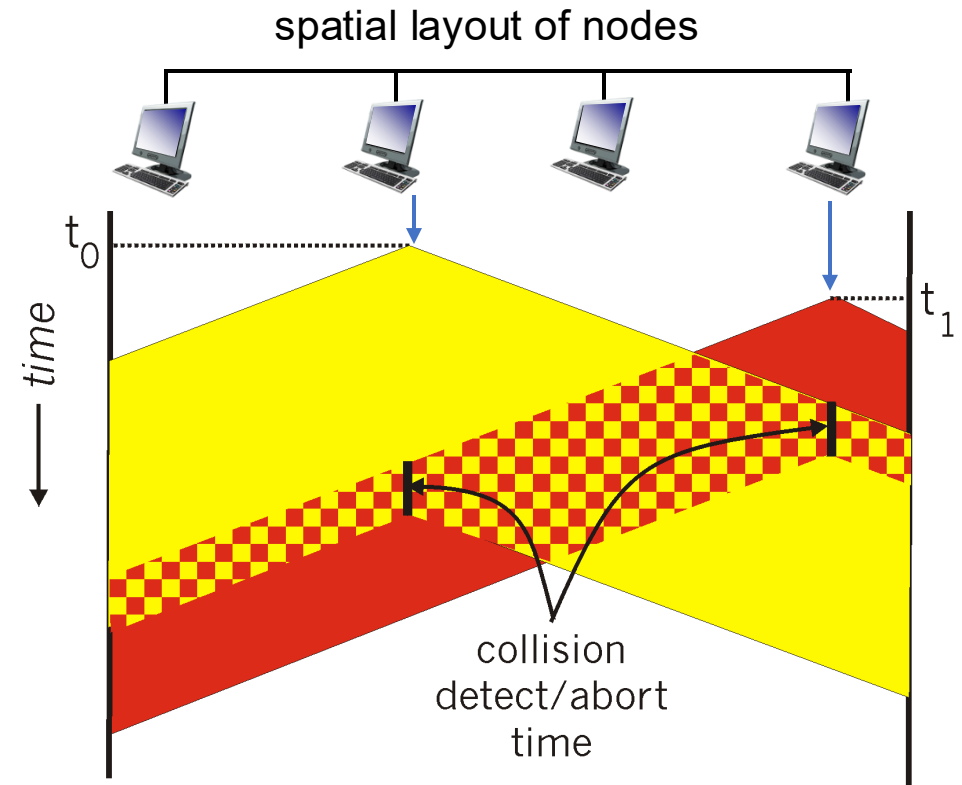
# CSMA/CD:

- CSMA/CD reduces the amount of time wasted in collisions
  - transmission aborted on collision detection



# CSMA/CD:

- CSMA/CD reduces the amount of time wasted in collisions
  - transmission aborted on collision detection
- collisions *detected* within short time
- colliding transmissions aborted, reducing channel wastage

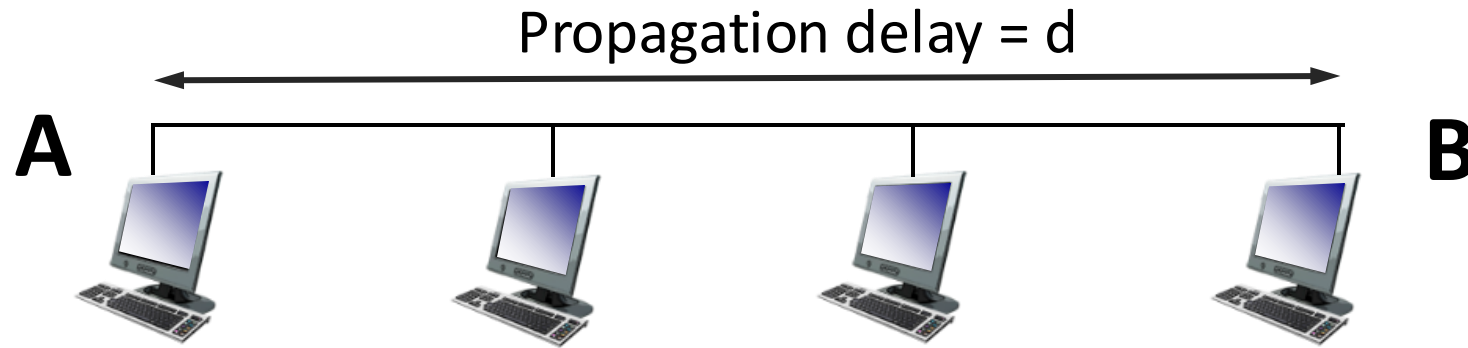




# Ethernet CSMA/CD algorithm

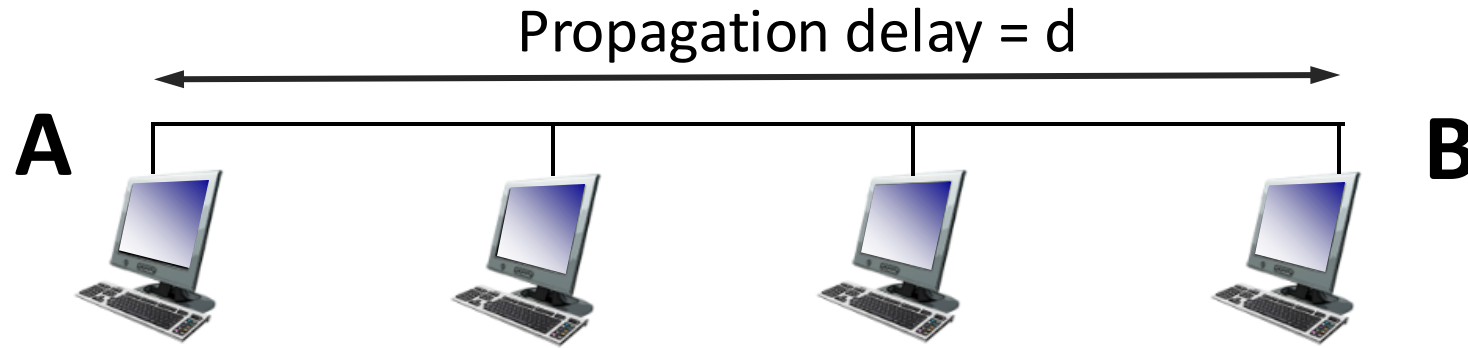
1. Ethernet receives datagram from network layer, creates frame
2. If Ethernet senses channel:
  - if **idle**: start frame transmission.
  - if **busy**: wait until channel idle, then transmit
3. If entire frame transmitted without collision - done!
4. If you detect collision, abort and wait a random amount of time (from a given range) and try again
  - If collision again, pick a random wait time from a larger range next time.

# Minimum frame size



- Suppose A sends a frame at time  $t$
- B sees an idle channel right before  $t + d$  and starts transmitting a frame
- A won't see a collision until  $t + 2d$

# Minimum frame size

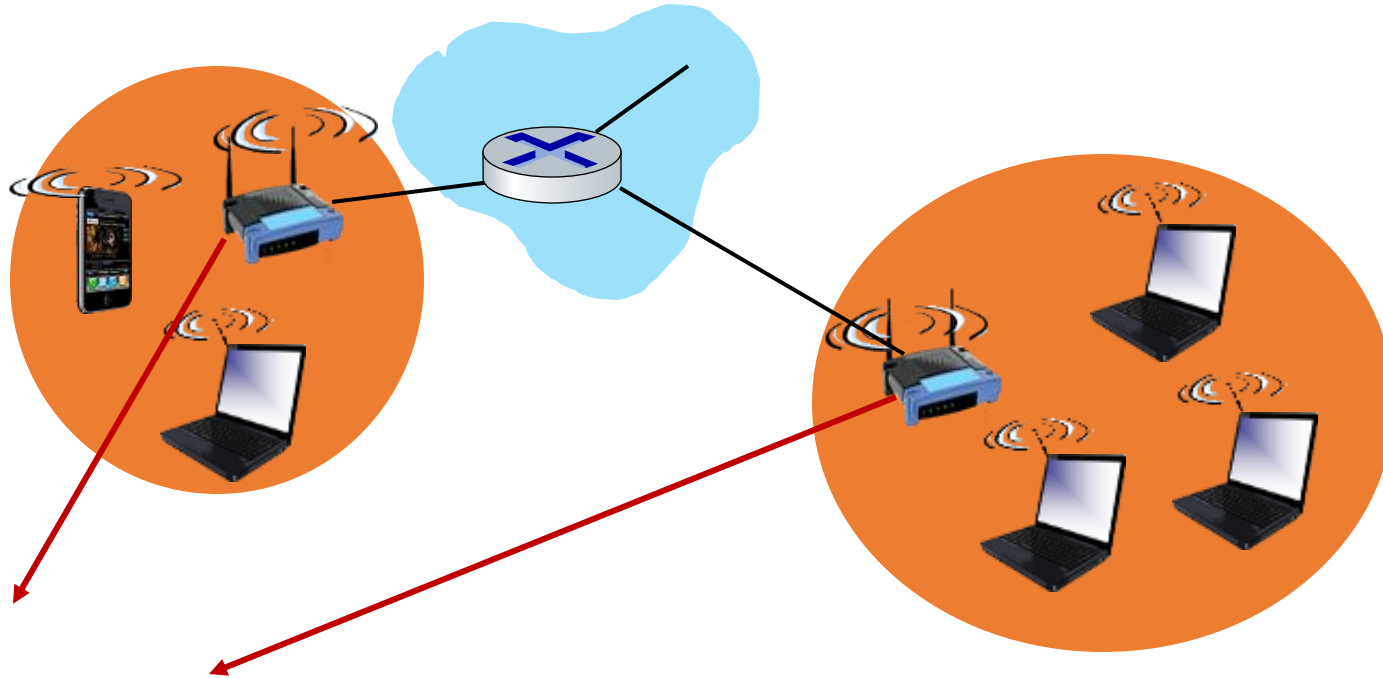


- A should wait for time  $2d$  to detect collision
  - So, it will keep transmitting during this period
- That's why there are restrictions on “classical” Ethernet
  - Maximum length of the wire: 2500 meters
  - Minimum length of the frame: 512 bits (64 bytes)

# Link characteristics affect protocol design

- In **wired LANs**, any two nodes on the shared medium can **detect collision** easily
  - measure signal strengths, and compare the transmitted and received signals
  - Ethernet uses CSMA/CD
- But, in **wireless LANs**, collision detection is difficult
  - due to characteristics of wireless links
  - wireless LANs (WiFi) uses CSMA/CA: CSMA with *collision avoidance*

# IEEE 802.11 (WiFi) MAC Protocol: CSMA/CA



Base stations (or Access point):

- Connects end points via a wireless “link”
  - Shared physical medium
- Connect to the wired network
  - E.g., the Internet
  - Provide connection from user devices to the wired network

# Wireless link characteristics

## fading (attenuation)

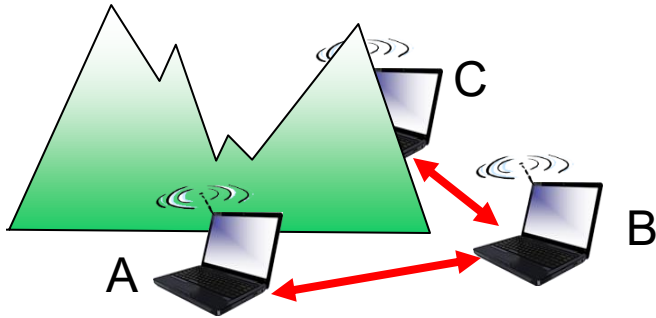
- radio signal attenuates (loses power) as it propagates (free space “path loss”)

## noise

- received signal is a combination of attenuated original signal and background noise in the environment -> more “lossy” than wired link
- SNR: signal-to-noise ratio
  - larger SNR -> lower bit error rate (BER) -- easier to extract signal from noise (a “good thing”)

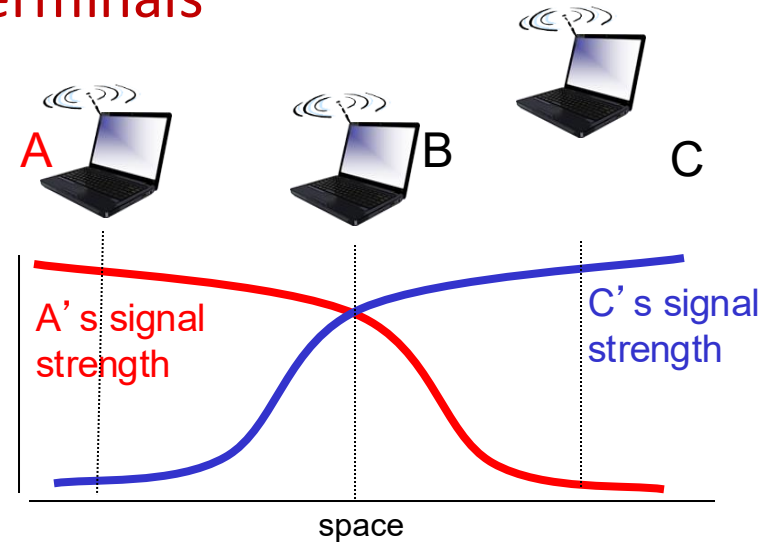
# Wireless link characteristics

## Hidden terminal problem



- B, A hear each other
- B, C hear each other
- A, C can not hear each other means A, C unaware of their interference at B

## Attenuation also causes “hidden terminals”



- B, A hear each other
- B, C hear each other
- A, C can not hear each other interfering at B

# Wireless vs. Wired for multi-access channel

- CSMA/CD tells whether or not there is some activity on the transmitter
- In a wired setting, the transmitter can see all the activity on the channel. So, this is enough.
- In a wireless setting, the transmitter does not necessarily see all the activity on the channel.
  - We need some extra mechanisms!



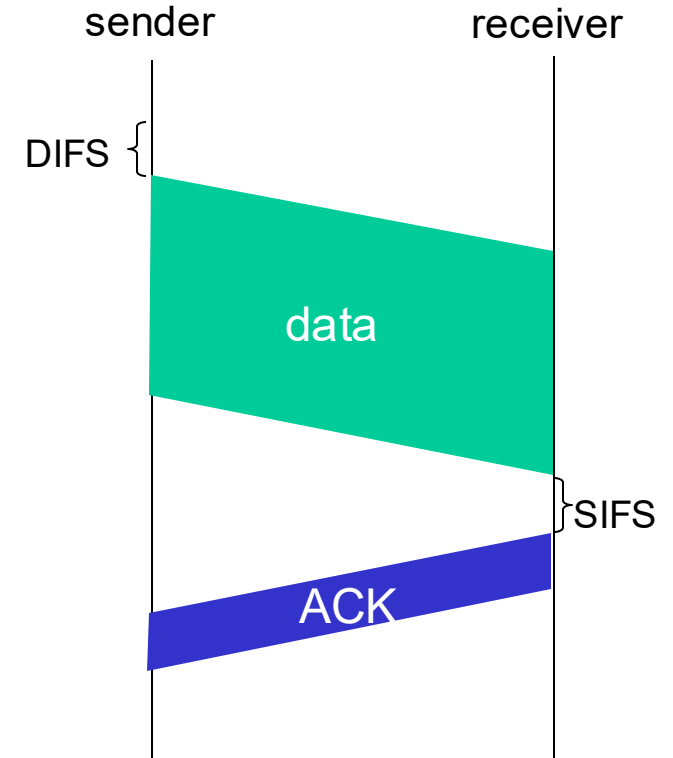
# WiFi CSMA/CA protocol

## 802.11 sender

- 1 if sense channel idle for **DIFS** then  
transmit entire frame (no CD)
- 2 if sense channel busy then  
start random backoff time  
timer counts down while channel idle  
transmit when timer expires  
if no ACK, increase random backoff interval, repeat 2

## 802.11 receiver

- if frame received OK  
return ACK after **SIFS** (ACK needed due to hidden terminal problem)



# WiFi CSMA/CA protocol

## 802.11 sender

Note the differences from CSMA/CD

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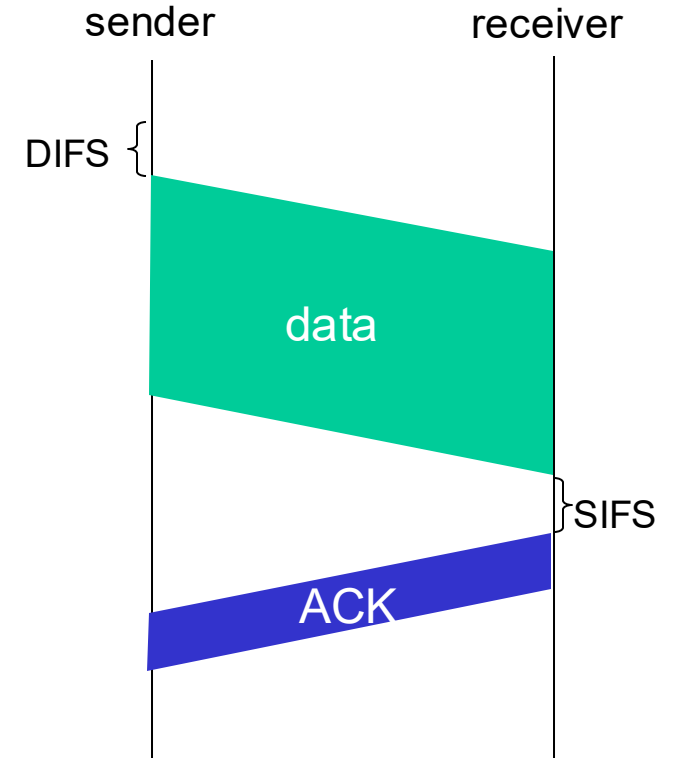
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# WiFi CSMA/CA protocol

Reliable delivery mechanisms  
in the link layer!

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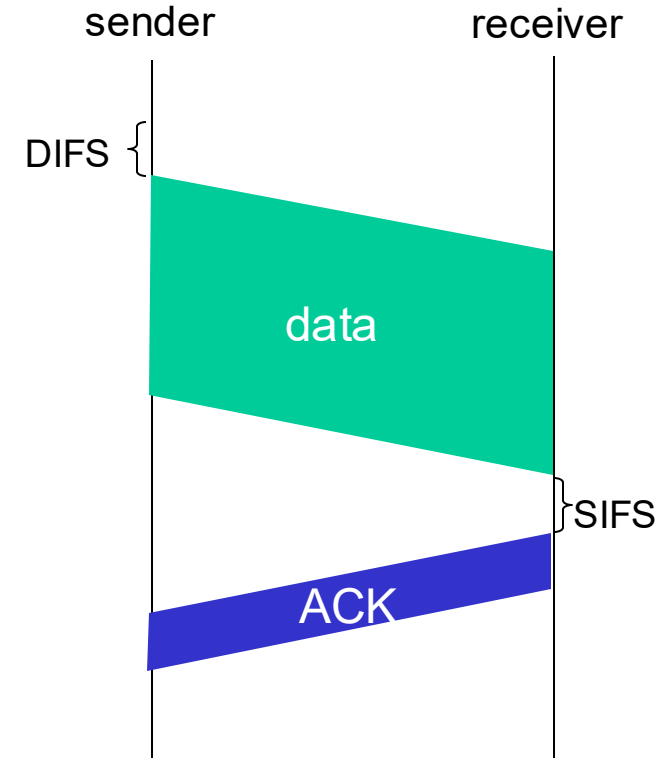
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# WiFi CSMA/CA protocol

The protocol has optional extensions to reduce collisions even more...

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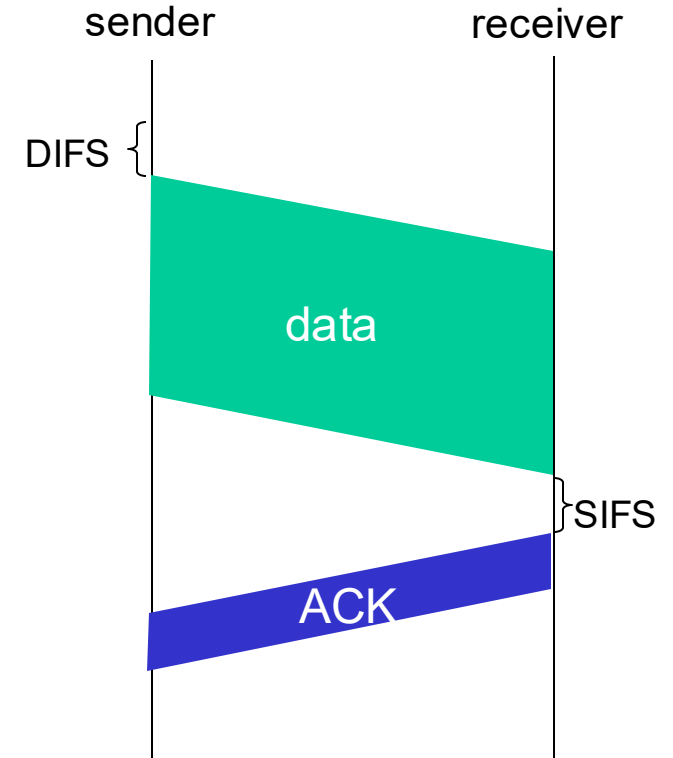
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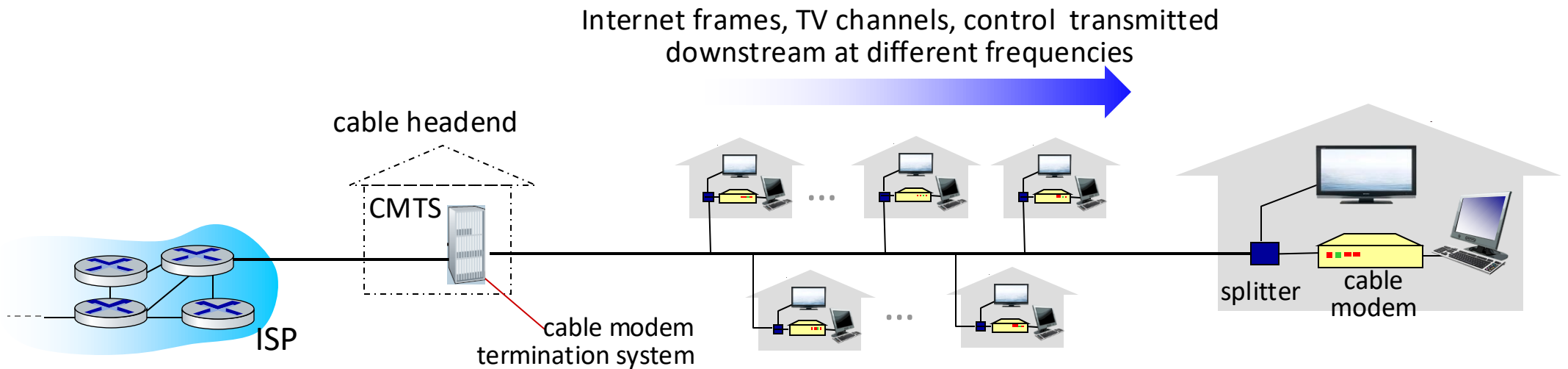
# Wireless links affect higher-layer protocols

- In wireless LAN, bit errors are much more common than in wired networks. Packets may often be corrupted or lost for reasons other than congestion
  - but TCP will interpret any packet loss as congestion and reduce its send window
- Solutions?
  - Have the “wireless” link layer protocol do retransmissions
  - Provide extra signals to TCP to convey if a loss is due to the nature of the wireless link rather than congestion
  - ...

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# Cable access network: channel partitioning *and* random access!



- **multiple** downstream (broadcast) channels (frequency-partitioned): up to 1.6 Gbps/channel
  - single CMTS transmits into channels
- **multiple** upstream channels (up to 1 Gbps/channel)
  - **multiple access**: all users contend (random access) for certain upstream channel time slots; others assigned (time-partitioned) channels

# What you need to know about multiple access channels

- Know what a multiple access (or shared, or broadcast) channel is.
- Know the details of CSMA/CD
  - E.g., if you are given a scenario with transmissions and how long nodes will back-off after detecting collision, you should be able to follow the protocol to figure out when collisions happen and when a frame will finally be transmitted.
- Know the characteristics of wireless links and how they affect protocols designs
  - How does CSMA/CA work?
  - How is TCP affected?



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# Final Remarks on MAC address vs IP addresses

- 32-bit IP address:
  - *network-layer* address for interface
  - used for layer 3 (network layer) forwarding
  - e.g.: 128.119.40.136
- MAC (or LAN or physical or Ethernet) address:
  - function: used “locally” to get frame from one interface to another physically-adjacent interface (same subnet, in IP-addressing sense)
  - 48-bit MAC address (for most LANs) burned in the ROM of the interface hardware, also sometimes software settable
  - e.g.: 1A-2F-BB-76-09-AD

Q: Why use a separate set of addresses in the link layer?

A: ??

*hexadecimal (base 16) notation  
(each “numeral” represents 4 bits)*

# What use a separate address space in the link layer?

- Network layer and link layer have different goals, hence different requirements
- Network layer: global connectivity
  - Need to aggregate addresses for interfaces close to each other to scale
  - So, IP addresses change when a device moves
- Link layer: local connectivity
  - Much smaller scale -- It is ok to have fixed “random” address for the interface
  - A fixed address makes it easier to bootstrap (we can still talk with the interface until it gets its IP address, more on this next week!)
- Also, each local network can have its own way to forward traffic
  - And still be able to connect to different kinds of networks...
  - through IP, or any other network layer protocol that they all agree on.
- Any other thoughts?

# Link layer: roadmap

- Link layer
  - Local
- Switching
  - Ethernet
  - Address
  - Switch
- Virtual
- Multiplexing
  - Random

We are done with the link layer!

**Next Up:** Naming and Addressing