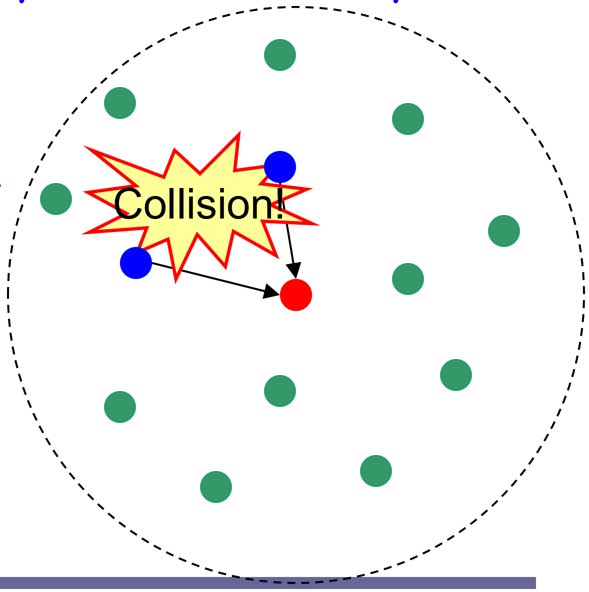
Lecture 6. Distributed MAC

- Random Access
- WiFi Networks

Distributed MAC I: Random Access

Random Access

- Each node determines whether to access the channel independently.
  - Time-slotted and packet-based transmissions
- Lack of coordination among nodes:
  - Transmissions may fail if multiple users transmit simultaneously.
  - Nodes may need multiple attempts before they can successfully access the channel.
- Key questions to be answered for design of a random access protocol:
  - When to start a transmission?
  - When to end the transmission?
  - What if the transmission fails?



Question 1: When to Start a Transmission?

- Aloha -- the first random access protocol
  - Transmit if packets are awaiting in the queue.

A more "polite" solution

- Carrier Sense Multiple Access (CSMA)
  - Transmit if packets are awaiting in the queue and the channel is sensed idle.

Question 2: When to End the Transmission?

- Stop when the packet transmission is completed.
- Any "smarter" solution? Stop when the transmission is deemed a failure.
  - Full-duplex (i.e., able to receive signals during transmissions): Stop when other on-going transmissions are sensed.
  - Half-duplex (i.e., unable to receive signals during transmissions): Send a short request to reserve the channel first before the packet transmission.

Collision Detection

Connection (Grant)-based access

Question 3: What if the Transmission Fails?

- The definition of transmission failure depends on what type of receivers is adopted:
  - ✓ Collision model: When multiple nodes transmit their packets simultaneously, a collision occurs and none of them can be successfully decoded. A packet transmission is successful only if there are no concurrent transmissions.
  - ✓ Capture model: Each node's packet is decoded independently by treating others' as background noise. A packet can be successfully decoded as long as its received signal-to-interference-plus-noise ratio (SINR) is above a certain threshold.

Question 3: What if the Transmission Fails?

- Resolving transmission failures: Backoff
  - Probability-based: Retransmit with a certain probability.
  - Window-based: Choose a random value and count down. Retransmit when the counter is zero.
- How to set the transmission probability?
  - Adjust the transmission probability according to the number of transmission failures k that the packet has experienced, i.e., $q_k = q_0 \cdot Q(k)$, where Q(k) is an arbitrary monotonic non-increasing function of the number of transmission failures k , $k = 0, 1, \ldots$.
  - Constant (Uniform) Backoff: $Q(k) = 1$.

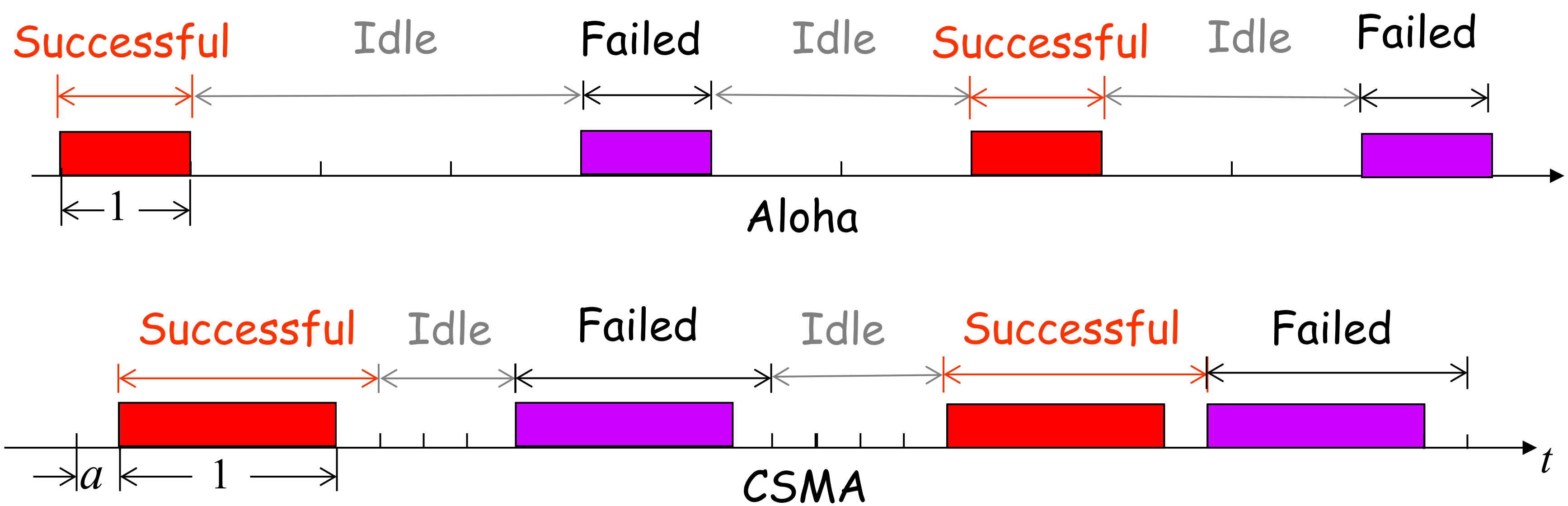
    Binary Exponential Backoff (BEB): $Q(k) = 2^{-k}$.

Performance Metrics

- Network Throughput: the average number of successfully decoded packets of the network per time slot.
- Delay of a Packet:
  - Access delay: the time interval from the instant that the packet becomes the head-of-line (HOL) packet to its successful transmission
  - Queueing delay: the time interval from the packet's arrival to its successful transmission
- Network Sum Rate: the average number of successfully decoded information bits of the network per time slot.
  - Depends on both the network throughput and the information-encoding rate of each packet.

Network Throughput Analysis

- Network Throughput: the average number of **successfully** decoded packets of the network per time slot.



- The throughput performance depends on nodes' transmission probabilities.
- For CSMA, it further depends on the ratio of sensing time to packet transmission time.

Network Throughput Analysis

- Example: Aloha with collision model and constant backoff over a noiseless channel
  - ✓ Each node always has packets to transmit.
  - ✓ In each time slot, each node transmits its packet with probability q.
  - ✓ A packet transmission is successful if and only if there are no concurrent transmissions.

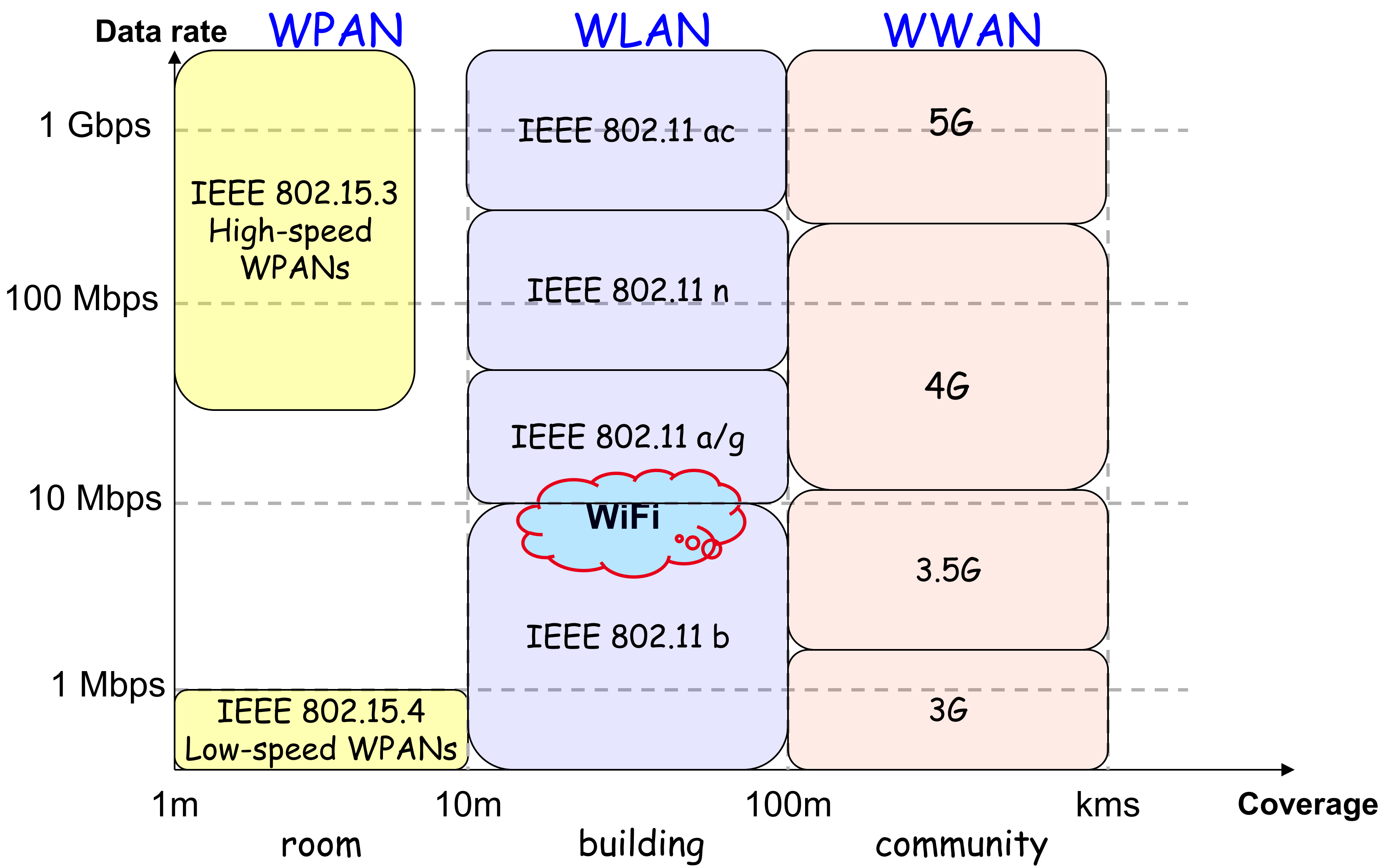
  - Given that one node transmits, the probability that its transmission is successful is: $p = (1-q)^{n-1}$
  - In each time slot, the probability that there is a successful transmission is: $npq = nq(1-q)^{n-1}$
  - Network throughput: $\hat{\lambda}_{out} = nq(1-q)^{n-1} \approx nq \cdot \exp\{-nq\}$ with a large n
  - Maximum network throughput: $\max_{q} \hat{\lambda}_{out} \approx e^{-1}$ achieved when $q=1/n$

Summary I: Random Access

- Design of a random access protocol
  - ✓ To sense (CSMA) or not to sense (Aloha)
  - ✓ Connection (Grant)-free or Connection (Grant)-based
  - ✓ Backoff: Constant (Uniform), Exponential, ...
- Performance evaluation of a random access protocol
  - ✓ Network throughput
  - ✓ Packet delay (access delay and queueing delay)
  - ✓ Network sum rate

Distributed MAC II: WiFi Networks

Wireless Networks



WiFi and IEEE 802.11

- WiFi
  - a class of WLAN devices based on the IEEE 802.11 standards.

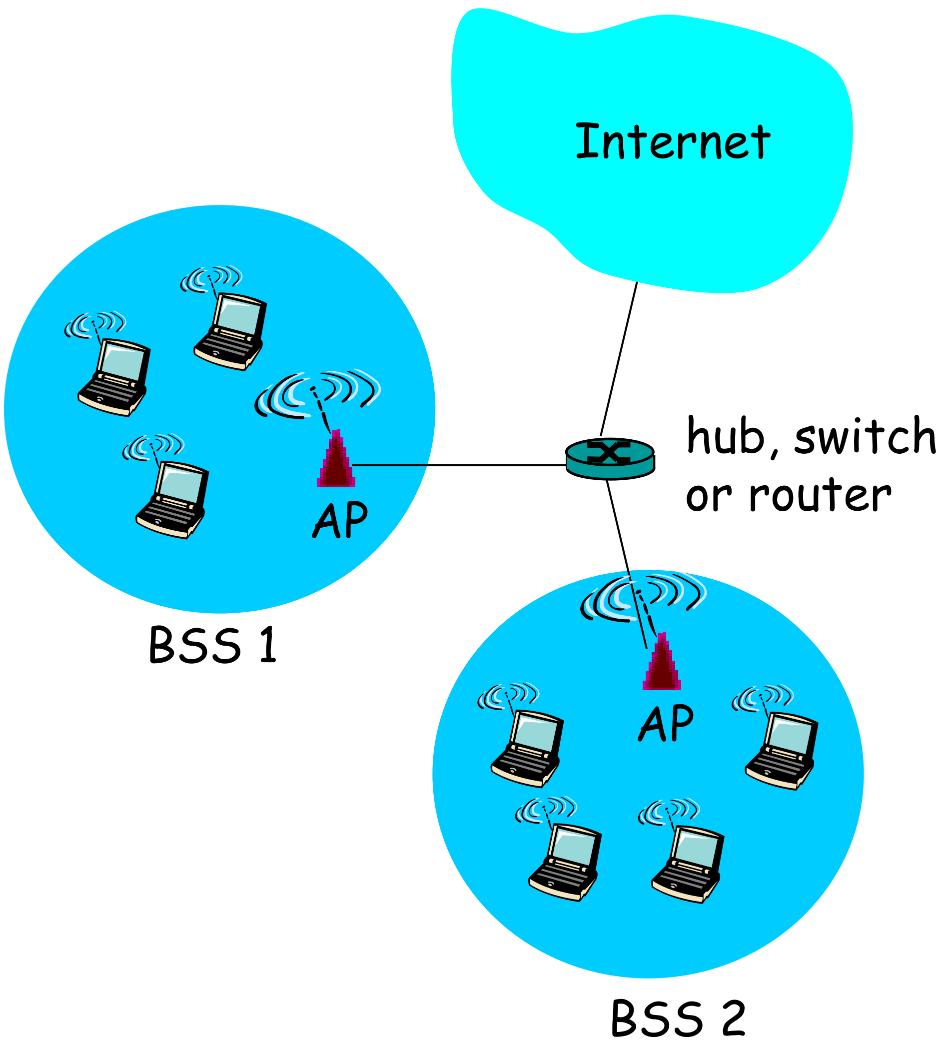
- IEEE 802.11
  - a set of standards carrying out WLAN computer communication in the 2.4, 3.6 and 5 GHz frequency bands. They are implemented by the IEEE LAN/MAN Standards Committee (IEEE 802).

IEEE 802.11 Standards

- 802.11a
  - 5 GHz
  - up to 54 Mbps
  - OFDM in physical layer
- 802.11g
  - 2.4 GHz
  - up to 54 Mbps
  - OFDM in physical layer
- 802.11ac
  - 5 GHz
  - up to 1900 Mbps
  - OFDM, Multiple antennas (8)
- 802.11b
  - 2.4 GHz unlicensed spectrum
  - up to 11 Mbps
  - DSSS in physical layer
- 802.11n
  - 2.4 GHz
  - up to 600 Mbps
  - OFDM, Multiple antennas (4)

- all use CSMA for multiple access

LAN Architecture



AP: Access Point

BSS: Basic Service Set

Channels and Association

- 802.11b: 2.4GHz-2.485GHz spectrum divided into 11 channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!
- Wireless Station: must *associate* with an AP
  - scans channels, listening for *beacon frames* containing AP's name (SSID) and MAC address
  - selects AP to associate with
  - typically run DHCP to get IP address in AP's subnet

MAC Protocol: Distributed Coordination Function (DCF)

- Features of DCF
  - CSMA: Sense before transmit
  - Binary Exponential Backoff: The transmission probability of a packet is reduced in half every time when it experiences a transmission failure.
- DCF consists of two access mechanisms:
  - Basic Access Mechanism
  - Request-To-Send/Clear-to-Send (RTS/CTS) Access Mechanism: Reserve the channel before packet transmission.

Connection (Grant)-based access

DCF: Basic Access Mechanism

<u>A wireless Station with a fresh packet</u>

<u>Access Point</u>

* ✓ Choose a random backoff value from (0, CW_{min}-1) and count down whenever the channel is sensed idle. Transmit the packet when the counter reaches zero.

- If the packet is successfully decoded, then return ACK.

Received ACK

✓ Remove the packet from the data buffer. Go to Step *.

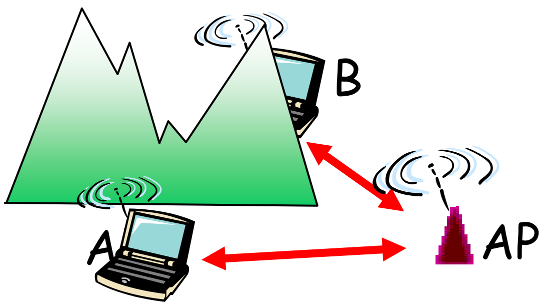
No ACK

✓ k=k+1: k is the number of transmission failures.

✓ If k reaches the maximum backoff stage, then drop the packet. Otherwise, choose a random backoff value from (0, $2^k CW_{min}$ -1). Count down whenever the channel is sensed idle. Transmit the packet when the counter reaches zero.

What if wireless stations cannot correctly sense the channel?

- Hidden Terminal Problem



  - ✓ Node A and AP hear each other.
  - ✓ Node B and AP hear each other.
  - ✓ Node A and Node B cannot hear each other, and so are unaware of each other's transmission.
  - ✓ But AP can hear both Node A and Node B!

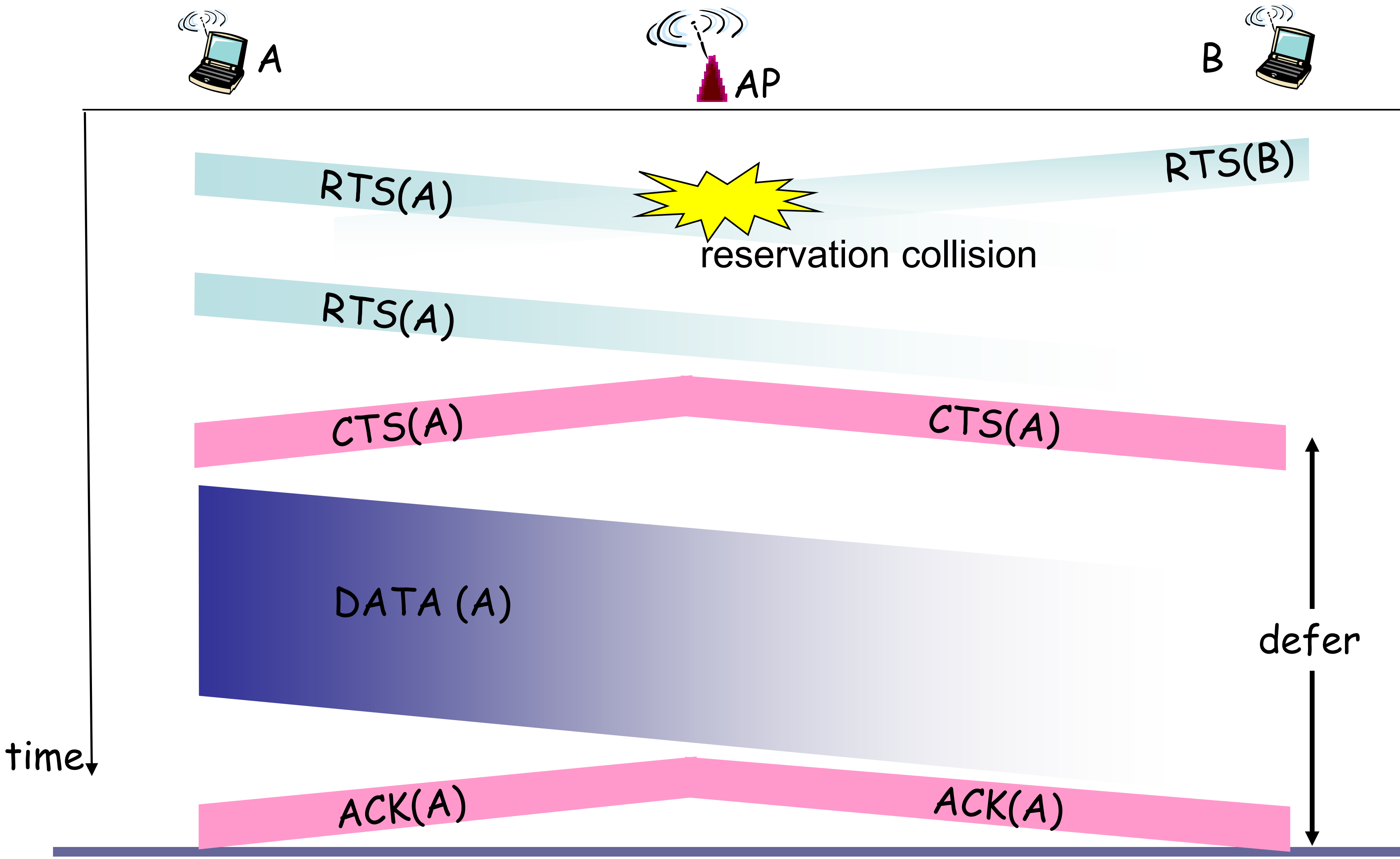
- Solution: "Ask" AP if the channel is idle.

DCF: RTS/CTS Access Mechanism

- Wireless stations transmit *short* request-to-send (RTS) messages to AP before their data packet transmissions.
  - RTS messages may still collide with each other (but they're short!)
- If an RTS message is successfully received, then AP broadcasts a clear-to-send (CTS) message, specifying which wireless station can start the data transmission.
  - The CTS message can be heard by all wireless stations!
- The wireless station which is authorized to transmit starts its data packet transmission. Others are notified that the channel is now occupied.

Avoid data packet collisions by using short reservation messages!

DCF: RTS/CTS Access Mechanism



Summary II: WiFi Networks

- Low cost, short-distance transmission
  - Free spectrum
  - High data rate
- Distributed MAC: DCF
  - CSMA+Binary Exponential Backoff
  - Connection-free access: Basic Access Mechanism
  - Connection-based access: RTS/CTS Mechanism