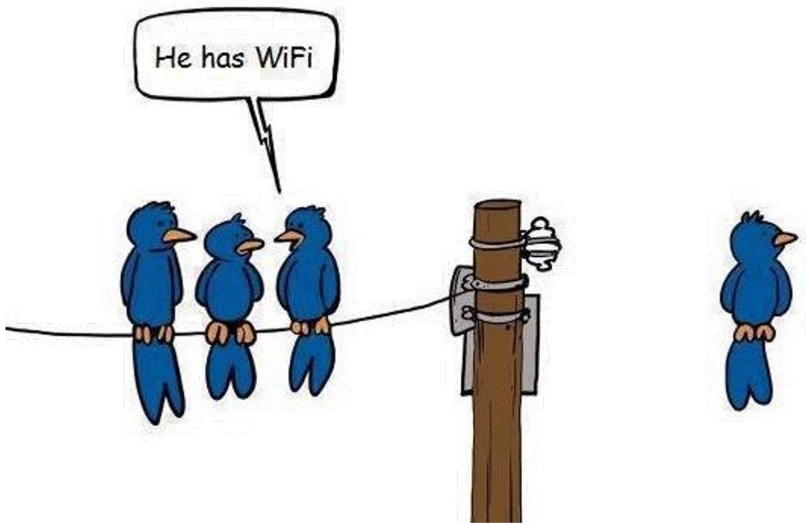
COM-405: Mobile Networks

Lecture 6.0: MAC
Haitham Hassanieh



EPFL

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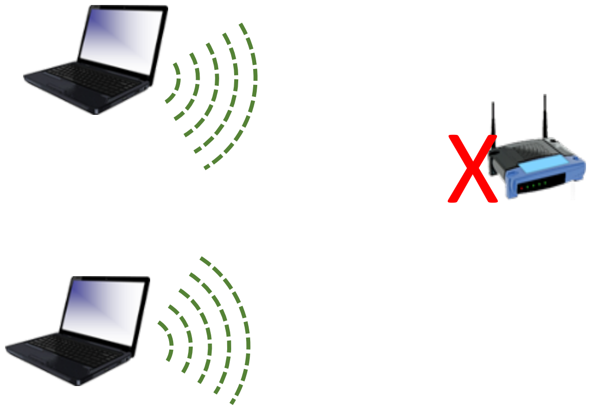
Wireless Is Shared Medium

- *interference from nodes in the network:*



- *interference from other sources:* standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices (motors, microwaves, baby monitors, …) interfere as well

Wireless Interference

SNR is no longer the main metric!

$$Interference\ to\ Noise\ Ratio:\ INR = \frac{Interference\ (I)}{Noise\ (N)}$$

- $INR > 1 \rightarrow$ Interference limited
- $INR < 1 \rightarrow$ Noise limited

$Signal - to - Interference\ \&\ Noise\ Ratio$:

$$SINR = \frac{Received\ Signal\ Power\ (P_{Rx})}{Interference\ (I) + Noise\ (N)}$$

Multiple Access Protocols

- Single shared broadcast channel
- Two or more simultaneous transmissions by nodes: 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

MAC Protocol Should be:

Efficient:

No idle channels, Maximize utilization, No Collisions

→ No wasted resources

Fair:

No starvation, Equal distribution of resources

→ based on what? Need?

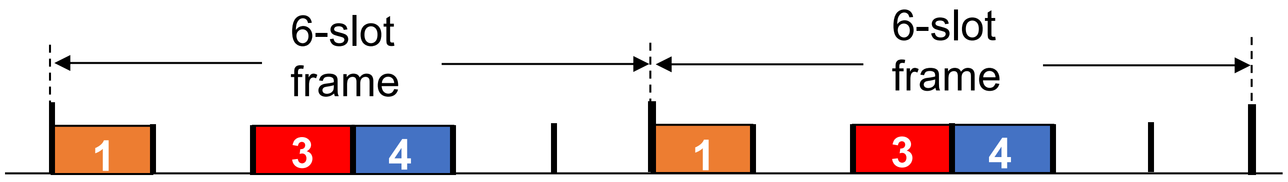
MAC Protocols

- *Reservation Based:*
  - divide channel into smaller "pieces" (time slots, frequency, code)
  - allocate piece to node for exclusive use

- *Contention Based: (random access)*
  - channel not divided, allow collisions
  - "recover" from collisions

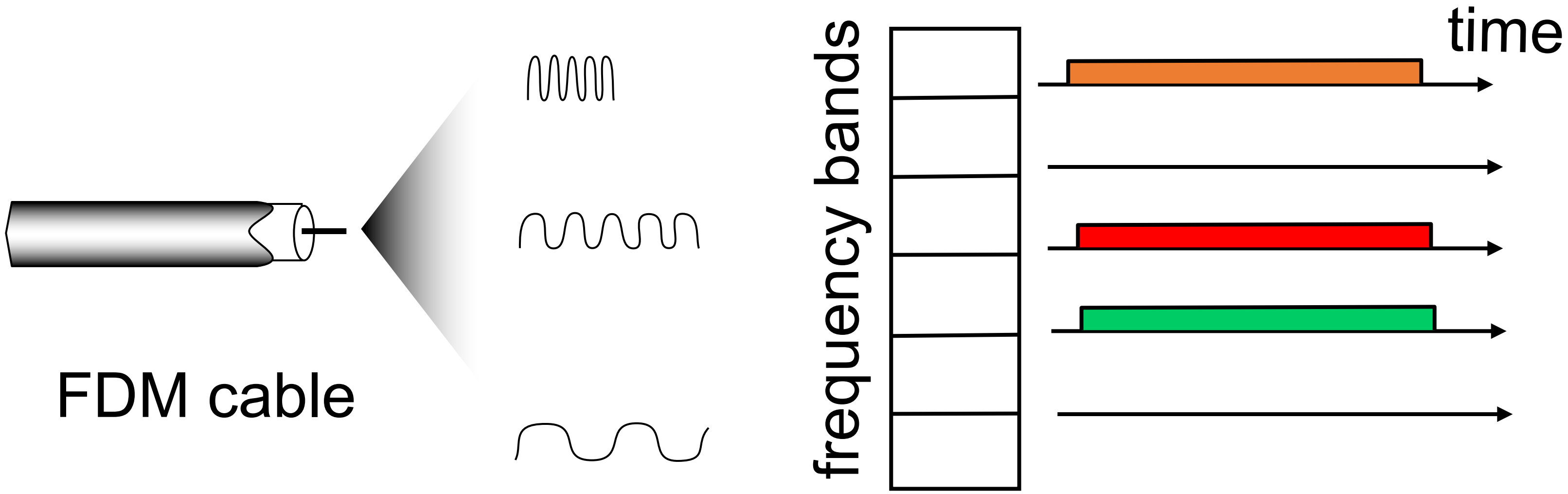
TDMA: Time Division Multiple Access

- access to channel in "rounds"
- each station gets fixed length slot (length = packet transmission time) in each round
- unused slots go idle
- Need some synchronization
- example: 6-station LAN, 1,3,4 have packets to send, slots 2,5,6 idle



FDMA: Frequency Division Multiple Access

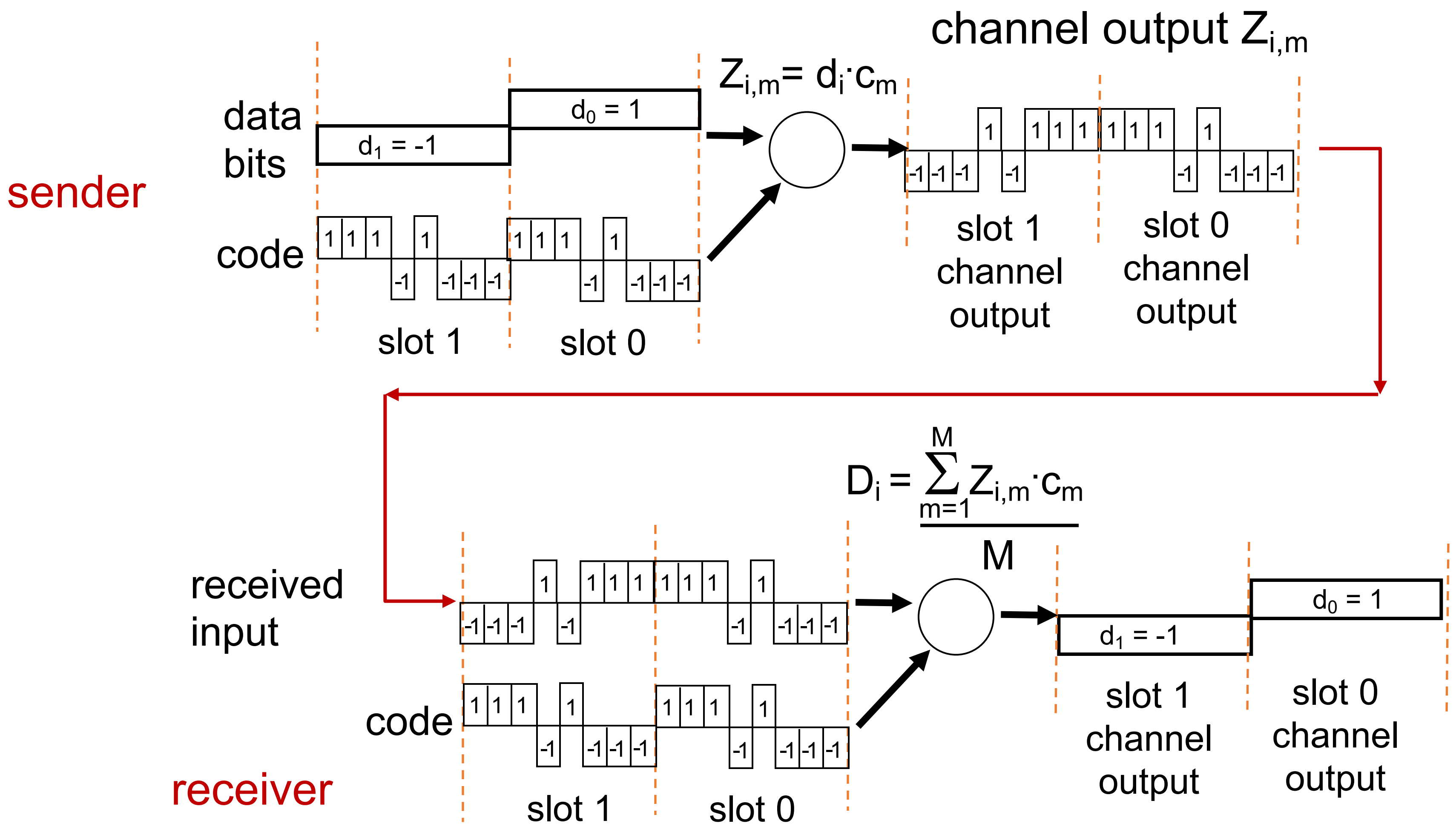
- channel spectrum divided into frequency bands
- each station assigned fixed frequency band
- unused transmission time in frequency bands go idle
- Need guard bands
- example: 6-station LAN, 1,3,4 have packet to send, frequency bands 2,5,6 idle



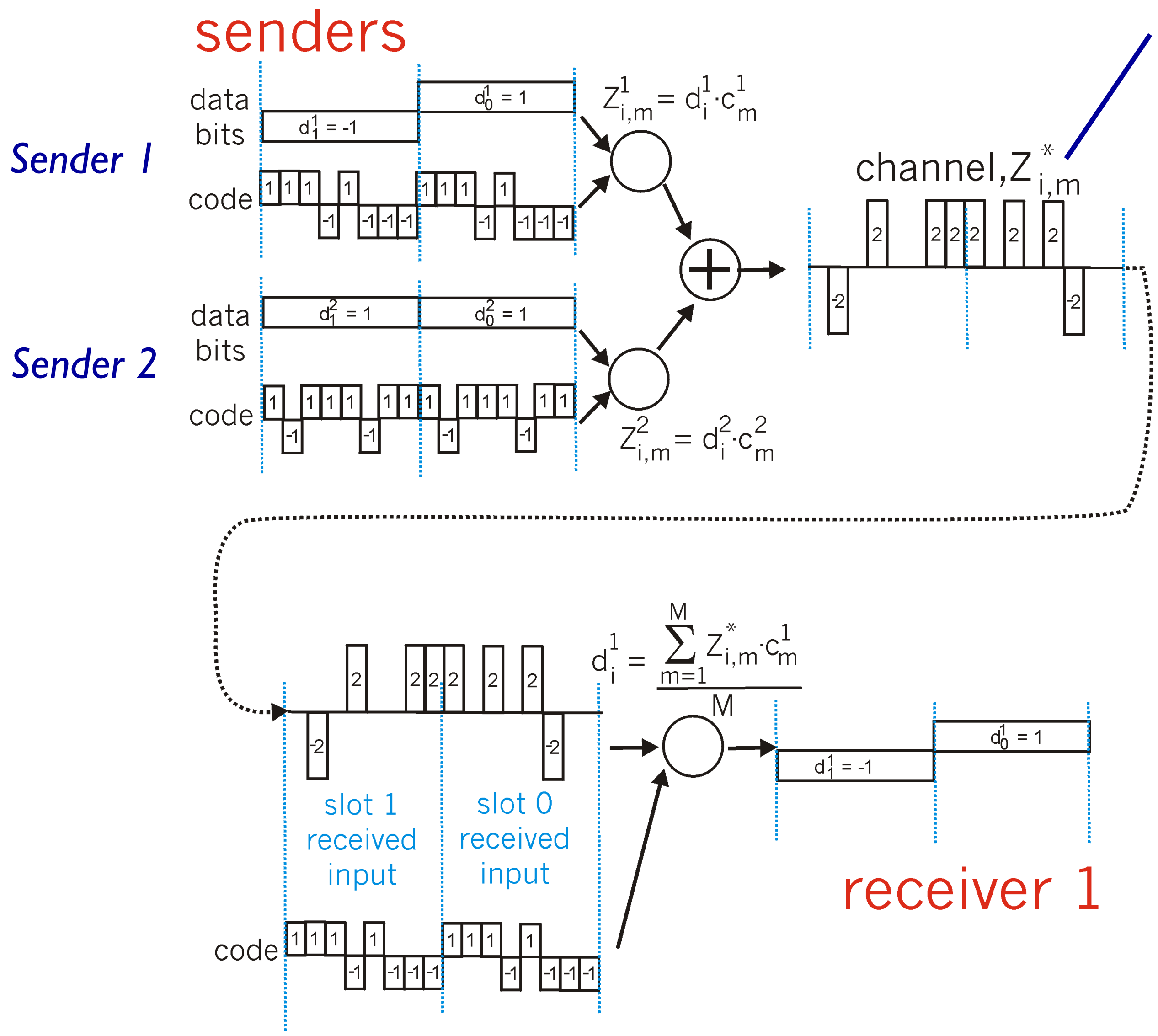
Code Division Multiple Access (CDMA)

- unique "code" assigned to each user; i.e., code set partitioning
  - all users share same frequency, but each user has own "chipping" sequence (i.e., code) to encode data
  - allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")
- *encoded signal* = (original data) X (chipping sequence)
- *decoding:* inner-product of encoded signal and chipping sequence
- Example codes: Gold Codes, Walsh Codes

CDMA encode/decode



CDMA: two-sender interference



channel sums together transmissions by sender 1 and 2

using same code as sender 1, receiver recovers sender 1's original data from summed channel data!

Code Division Multiple Access (CDMA)

- Ideally, need codes to have good:

Auto-correlation properties: $c_i(t) \cdot c_i(t) = 1$

Cross-correlation properties: $c_i(t) \cdot c_j(t) = 0 \text{ for } j \neq i$

$$\left(\sum_i h_i d_i(t)\, c_i(t)\right) \cdot c_i(t) = h_i d_i(t)$$

- Need orthogonal codes:

For N users, length of code is exponential in N → 2^{N-1}

- Near Far Effect Problem → need power management

Slotted ALOHA

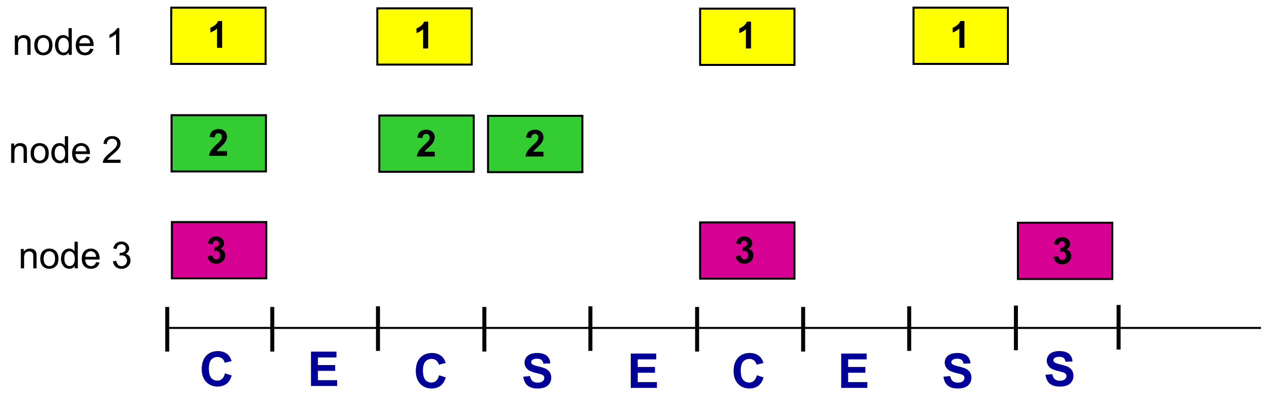
assumptions:

- all frames same size
- time divided into equal size slots (time to transmit 1 frame)
- nodes start to transmit only slot beginning
- nodes are synchronized
- if 2 or more nodes transmit in slot, these nodes detect collision

operation:

- when node obtains fresh frame, transmits in next slot
  - *if no collision:* node can send new frame in next slot
  - *if collision:* node retransmits frame in each subsequent slot with prob. p until success

Slotted ALOHA



Pros:

- single active node can continuously transmit at full rate of channel
- highly decentralized: only slots in nodes need to be in sync
- simple

Cons:

- collisions, wasting slots
- idle slots
- nodes may be able to detect collision in less than time to transmit packet
- clock synchronization

Slotted ALOHA: efficiency

- N nodes
- Each node picks a slot uniformly at random to transmit in.

Probability that a node transmits in a give slot: p

Probability that any node transmits without collision:

$$E = N \cdot p \cdot (1-p)^{N-1}$$

To maximize E, set $\frac{dE}{dp} = 0$

$\rightarrow N(1-p)^{N-1} - Np(N-1)(1-p)^{N-2} = 0$

$\rightarrow 1 - p - pN + p = 0$

$\rightarrow p = \frac{1}{N}$

Slotted ALOHA: efficiency

- N nodes
- Each node picks a slot uniformly at random to transmit in.

Probability that a node transmits in a give slot: p

Probability that any node transmits without collision:

$$E = N \cdot p \cdot (1-p)^{N-1}$$

To maximize E, set $p = 1/N$

$$Efficiency = E = \left(1 - \frac{1}{N}\right)^{N-1}$$

$$Efficiency \leq \lim_{N\to\infty} E = \lim_{n\to\infty} \left(1 - \frac{1}{N}\right)^{N-1} = \frac{1}{e} = 0.37$$

Slotted ALOHA: efficiency

efficiency: long-run fraction of successful slots (many nodes, all with many frames to send)

- *suppose: N* nodes with many frames to send, each transmits in slot with probability *p*
- prob that given node has success in a slot = $p(1-p)^{N-1}$
- prob that *any* node has a success = $Np(1-p)^{N-1}$

- max efficiency: find *p** that maximizes $Np(1-p)^{N-1}$
- for many nodes, take limit of $Np^*(1-p^*)^{N-1}$ as *N* goes to infinity, gives:

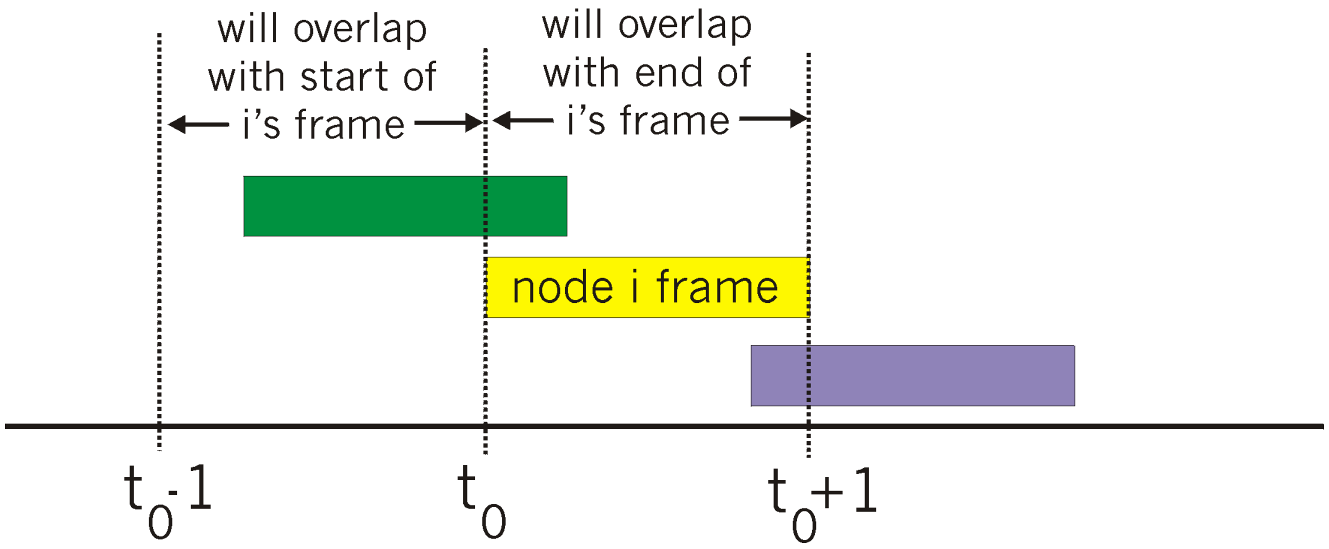
max efficiency = 1/e = .37

at best: channel used for useful transmissions 37% of time!

!

Pure (unslotted) ALOHA

- unslotted Aloha: simpler, no synchronization
- when frame first arrives
  - transmit immediately
- collision probability increases:
  - frame sent at t_0 collides with other frames sent in $[t_0-1, t_0+1]$



Pure ALOHA efficiency

P(success by given node) = P(node transmits) ·

P(no other node transmits in $[t_0\text{-}1, t_0]$ ·

P(no other node transmits in $[t_0, t_0\text{+}1]$

$$= p \cdot (1-p)^{N-1} \cdot (1-p)^{N-1}$$

$$= p \cdot (1-p)^{2(N-1)}$$

… choosing optimum p and then letting $n \longrightarrow \infty$

$$= 1/(2e) = .18$$

even *worse* than slotted Aloha!

CSMA/CA: Carrier Sense Multiple Access with Collision Avoidance

CSMA: listen before transmit:

if channel sensed idle: transmit entire frame

- if channel sensed busy, defer transmission

CSMA/CA: Carrier Sense Multiple Access with Collision Avoidance

Contention Window (CW):

- Sense, if channel idle, wait $DIFS \approx 50\mu s$
- Pick random number m between 0— CW_{max}
- Wait m slots ($\approx 10\mu s$), then sense & transmit
- Wait S$IFS \approx 10\mu s$ for an ACK
- If Collision: $CW_{max} = 2 \times CW_{max}$
- If Success: $CW_{max} = 2$

CSMA/CA: Carrier Sense Multiple Access with Collision Avoidance

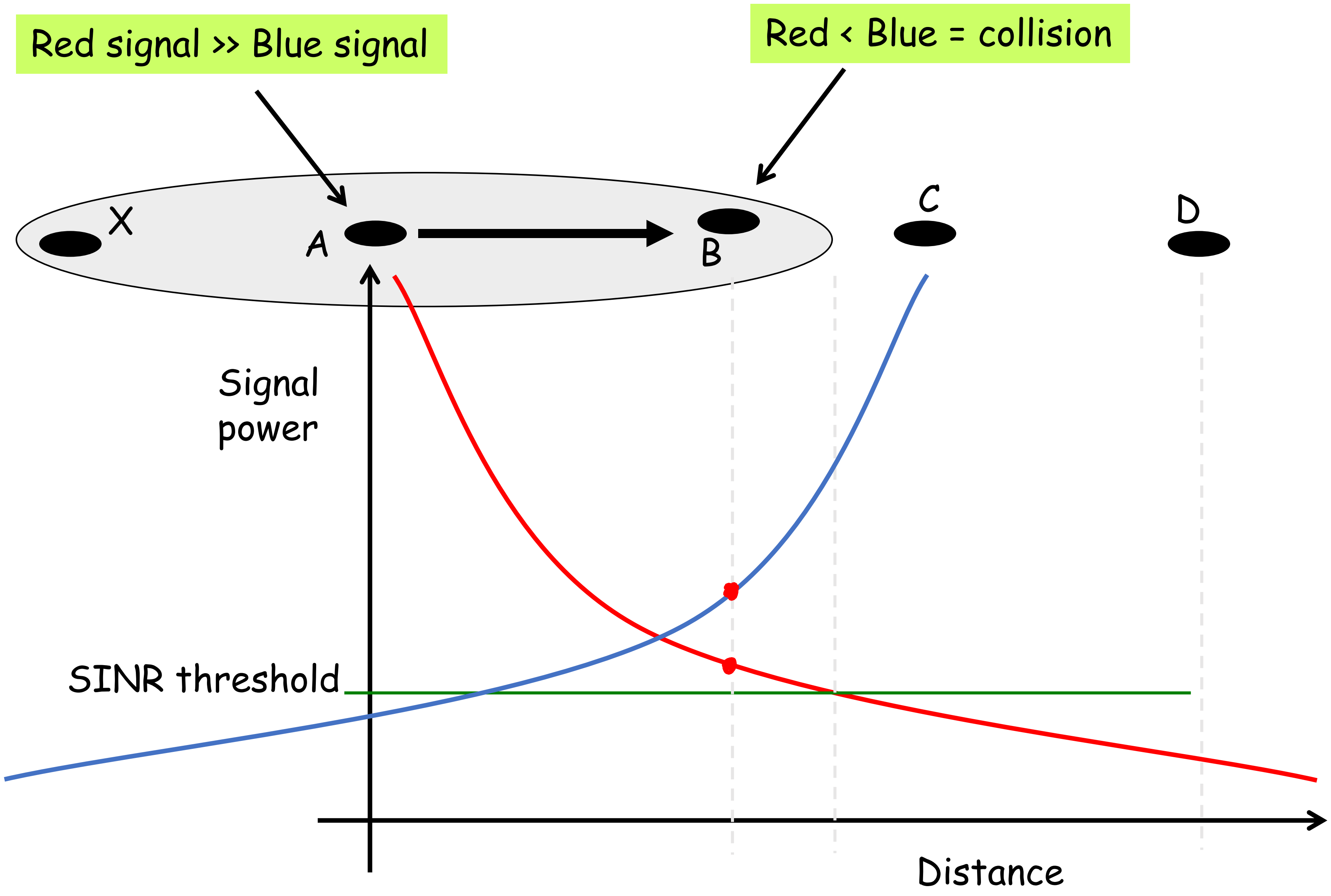
Throughput Efficiency

- Data: 1500 bytes = 12000 bits
- 802.11n advertised rate: 300 Mbps
- Data Packet Time = $12000/300Mbps = 40\mu s$

- Overhead:
$DIFS + SIFS + ACK + m\times slot = 50 + 10 + 30 + 7\times 10 = 160\mu s$

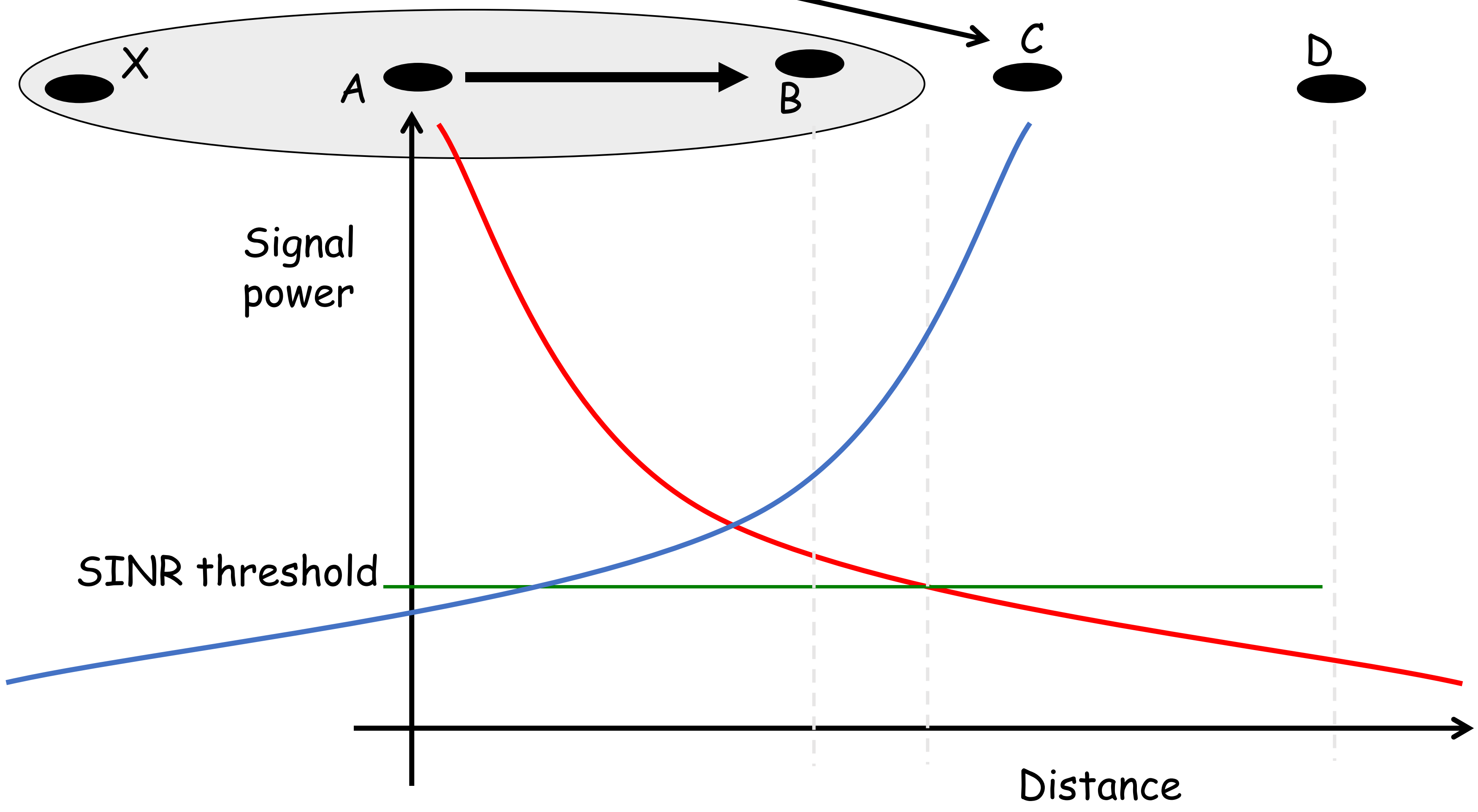
- Actual Throughput: $12000/(40 + 160) = 60Mbps$

- **80% Reduction in Throughput!!**


Red signal >> Blue signal
Red < Blue = collision
X
A
B
C
D
Signal power
SINR threshold
Distance

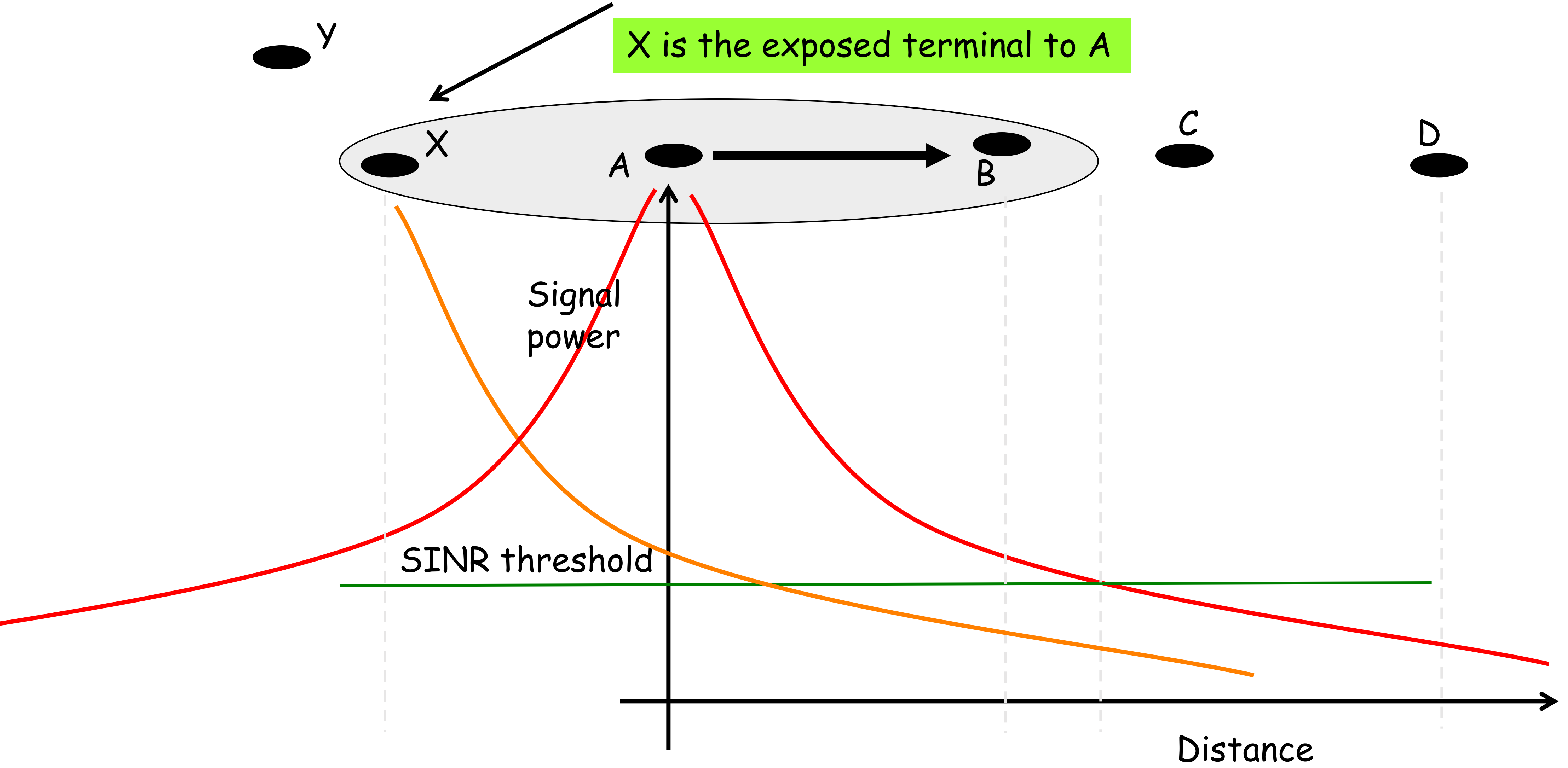
Important: C has not heard A, but can interfere at receiver B

C is the hidden terminal to A



Important: X has heard A, but should not defer transmission to Y

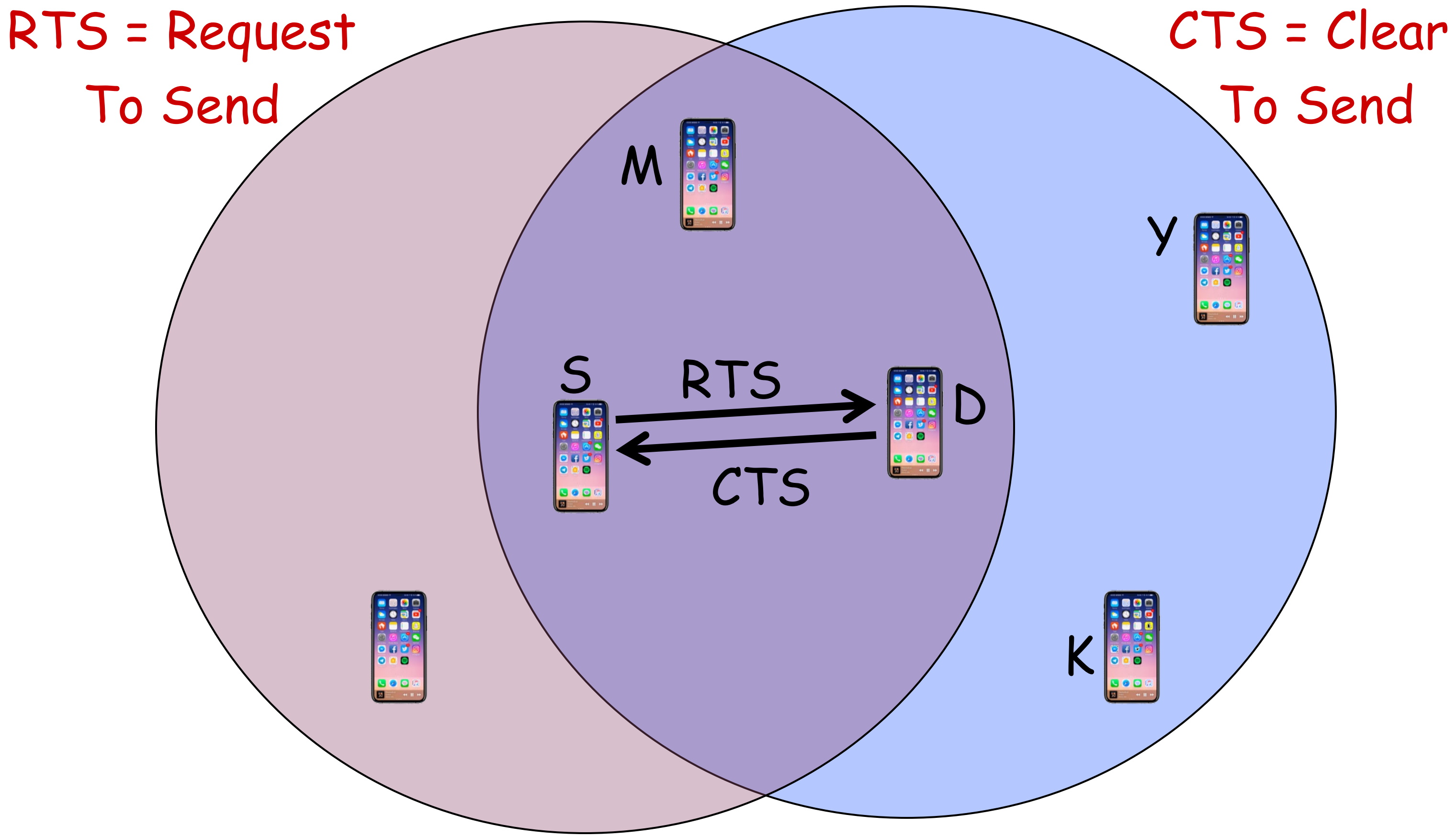
X is the exposed terminal to A



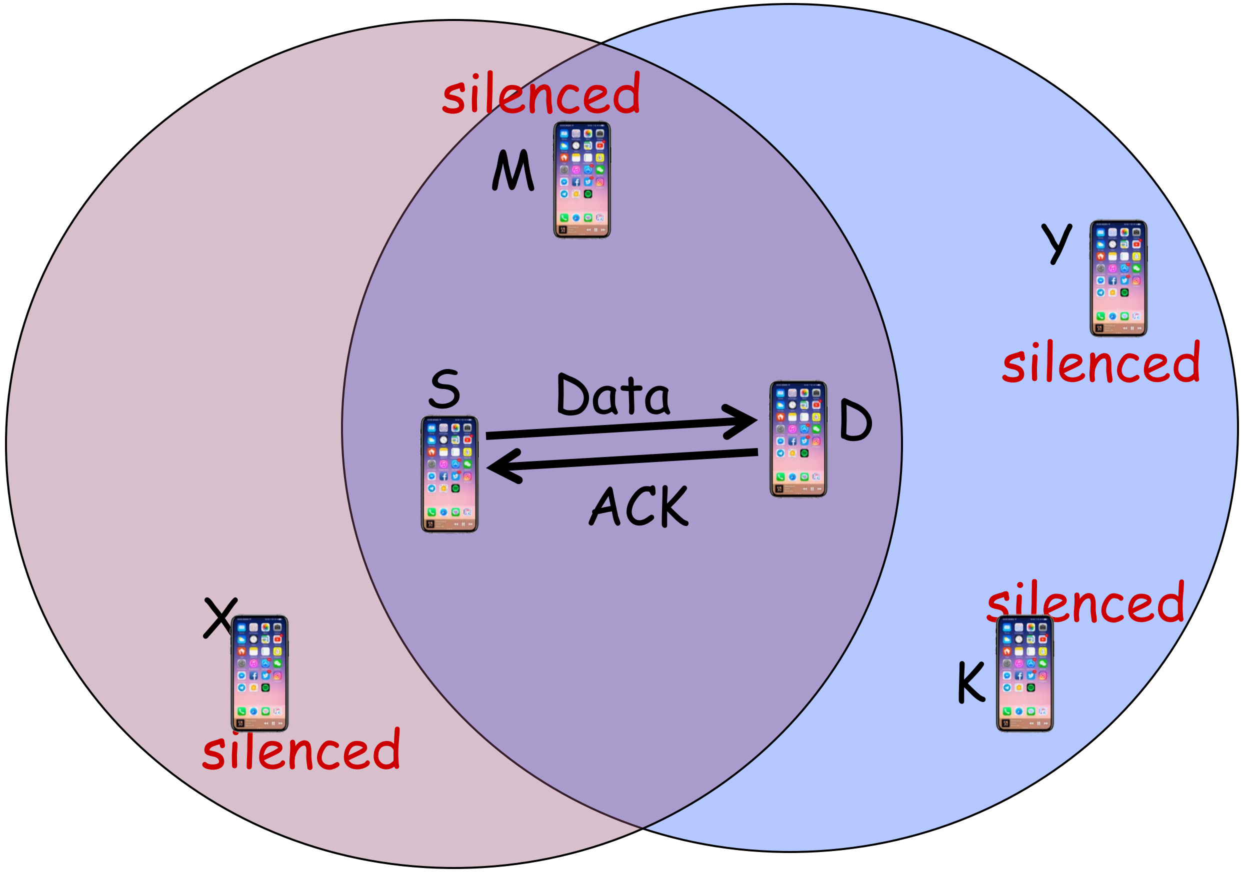
Hidden and Exposed Terminal Problems

Critical to wireless networks even today

IEEE 802.11



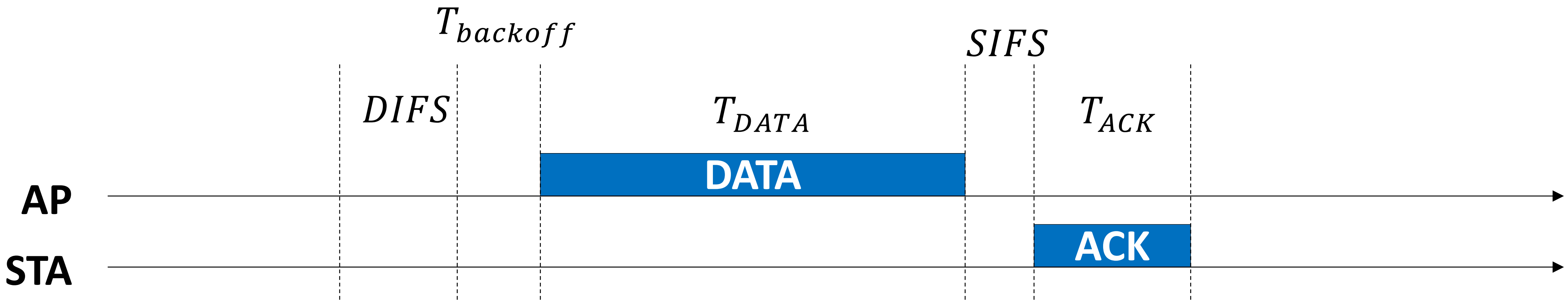
IEEE 802.11



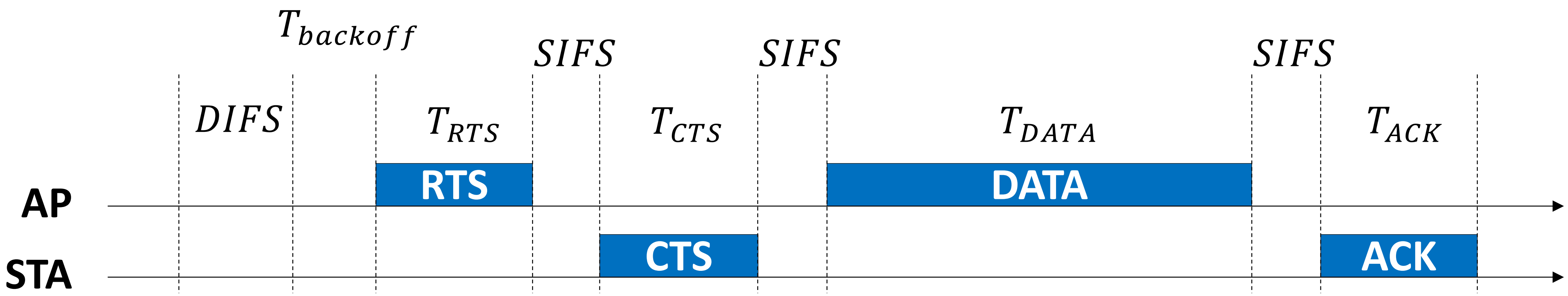
WiFi Standards Medium Access: CSMA/CA

- Carrier Sense Multiple Access with Collision Avoidance
- 802.11b, 802.11g, 802.11n, 802.11ac
- Contention based with exponential backoff
- RTS and CTS to avoid collisions

WiFi Standards Medium Access: CSMA/CA

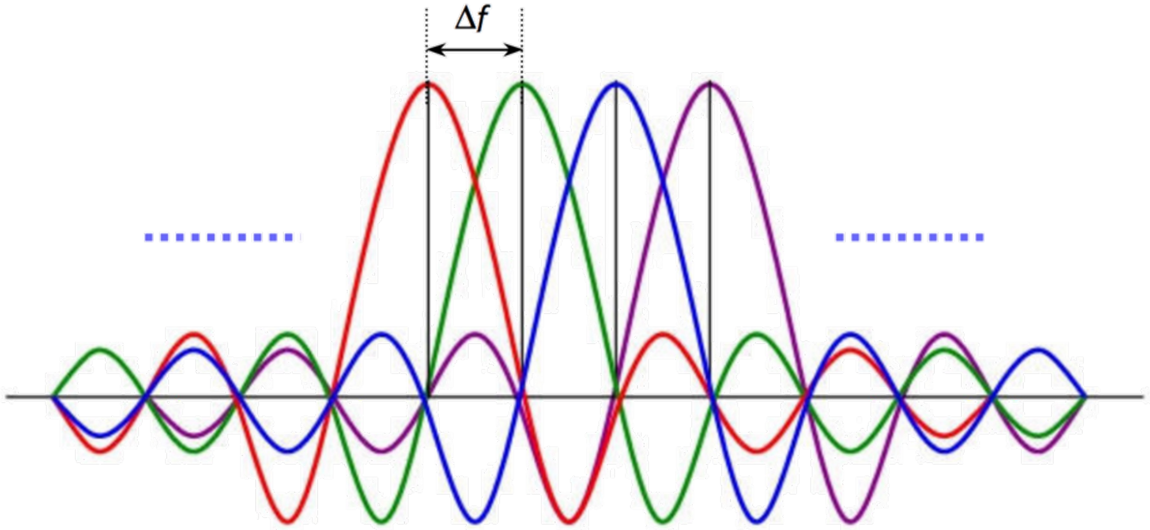


WiFi Standards Medium Access: CSMA/CA



WiFi 6 802.11ax Medium Access: OFDMA

- Orthogonal Frequency Division Multiple Access
- Use OFDM: Assign different subcarriers to different users.
- More efficient than FDMA since no guard bands are needed
- Requires Time Synchronization



WiFi 6 802.11ax Medium Access: OFDMA

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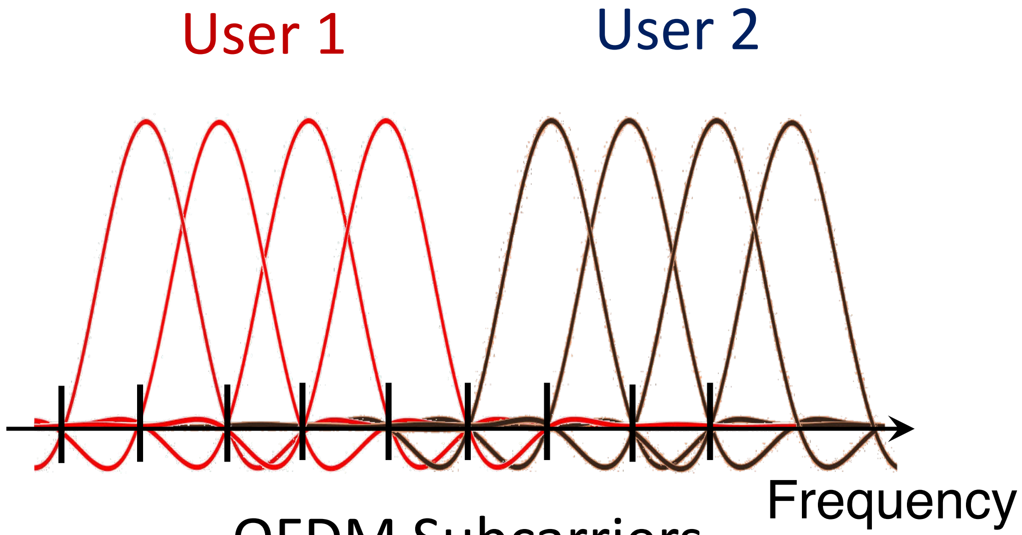
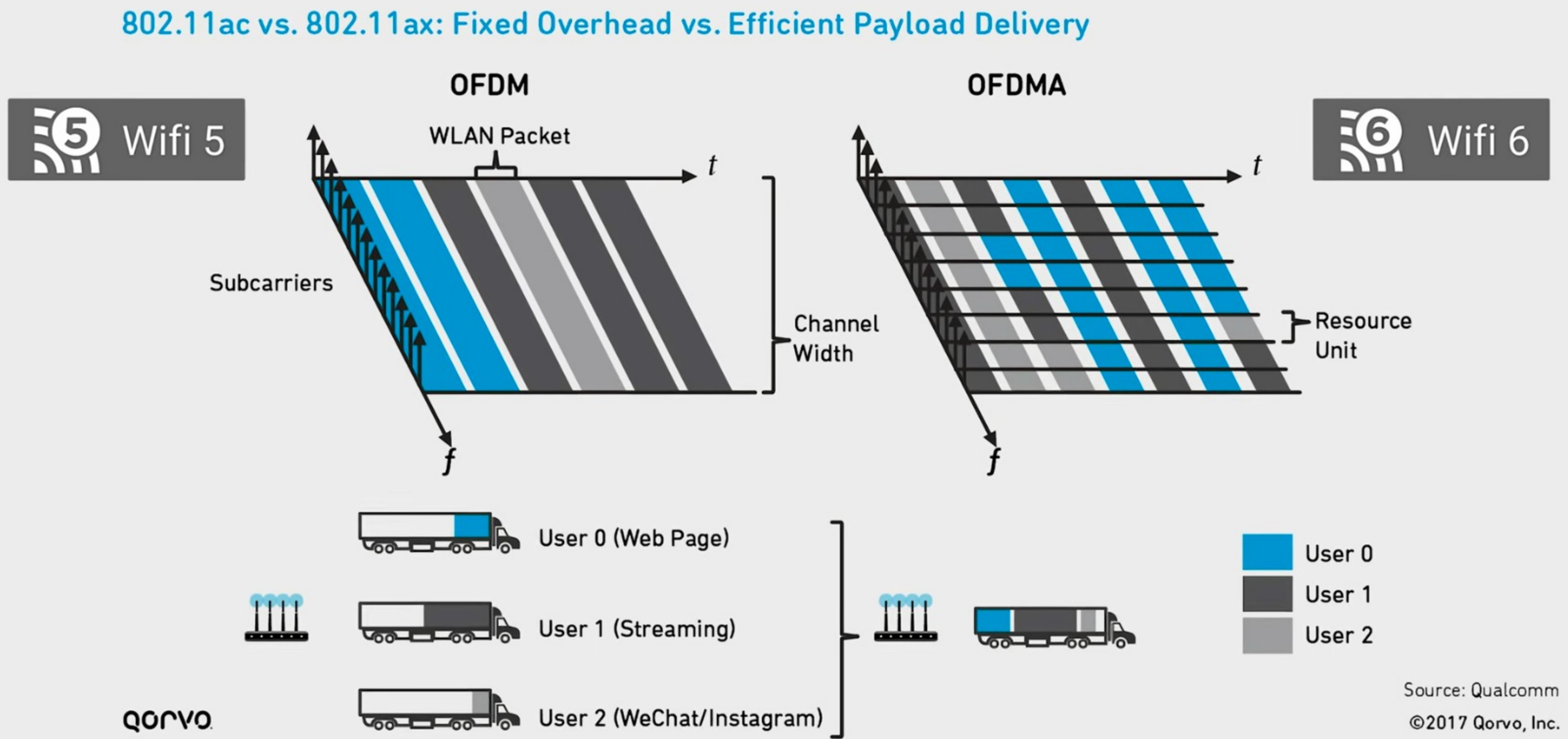
CSMA/CA (802.11a/bg/n/ac)

OFDMA (802.11ax)

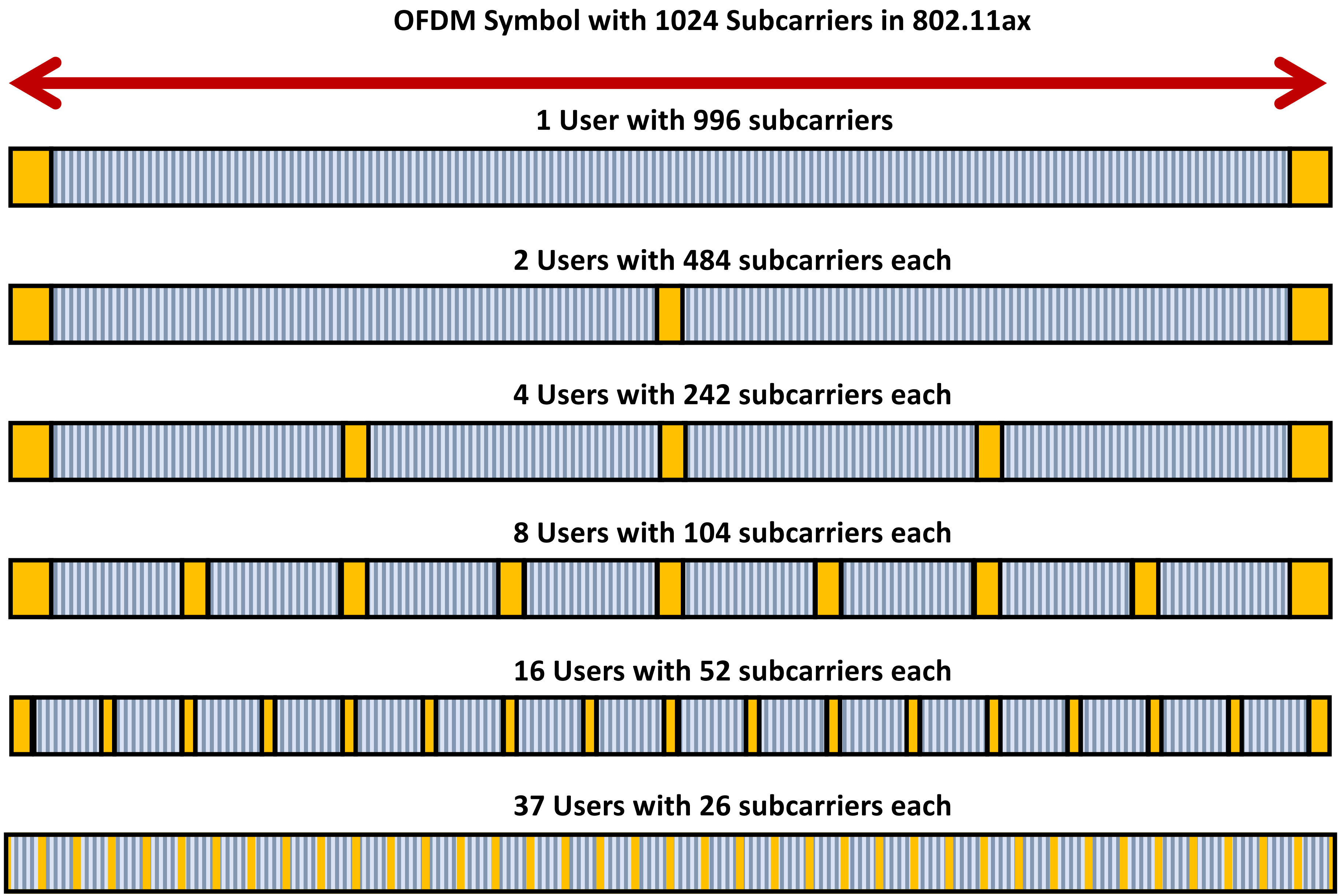


OFDM Subcarriers

WiFi 6 802.11ax Medium Access: OFDMA

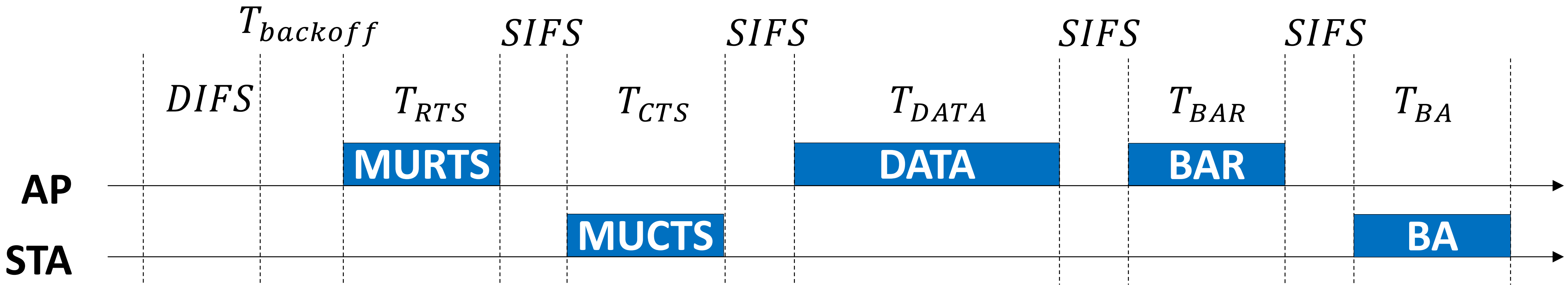


WiFi 6 802.11ax Medium Access: OFDMA



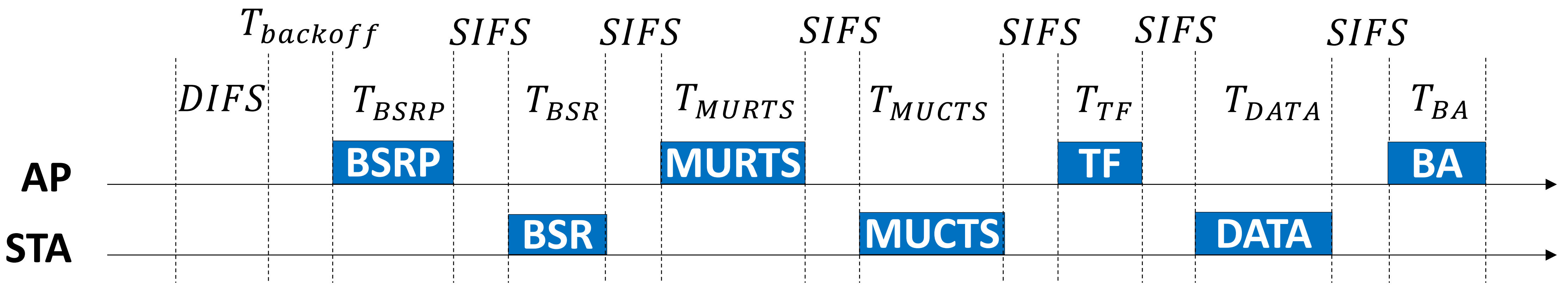
WiFi 6 802.11ax Medium Access: OFDMA+ CSMA/CA

Downlink: AP → Clients



WiFi 6 802.11ax Medium Access: OFDMA+ CSMA/CA

Uplink: AP → Clients



MAC Protocols: Pros and Cons

- ***Reservation Based:***
  - + No Interference
  - + Fair
  - Centralized
  - Wasted resources

TDMA
FDMA
CDMA
OFDMA

Token Passing
Polling

WiFi 6: OFDMA & CSMA

- ***Contention Based: (random access)***
  - + Distributed
  - + Good for bursty traffic
  - Collisions
  - Overhead

CSMA
Alloha
Slotter Aloha