無線網路概論
Intro. to Wireless Internet

Lecture 04 – Multiple Access

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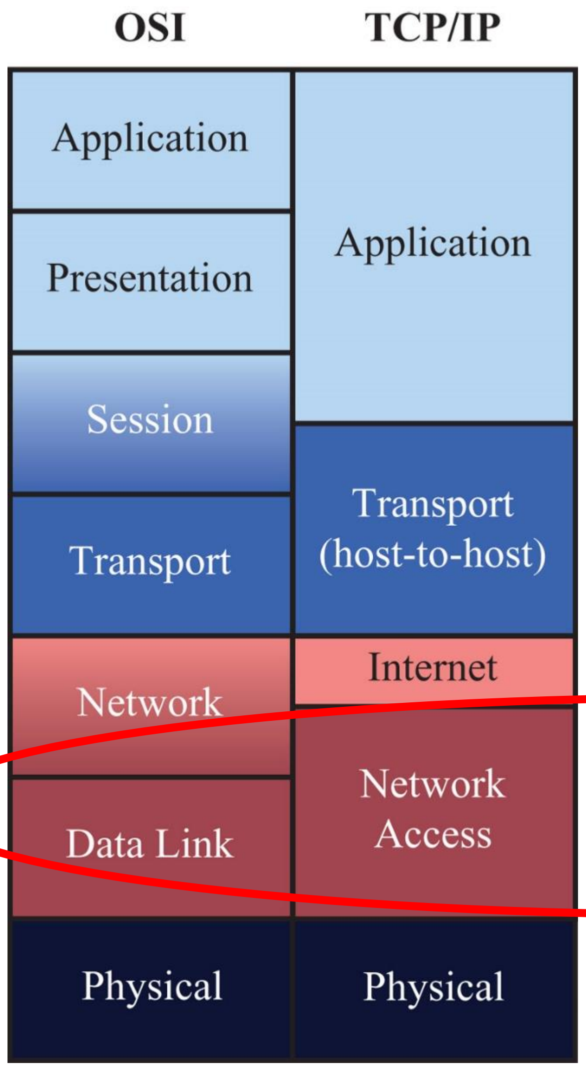
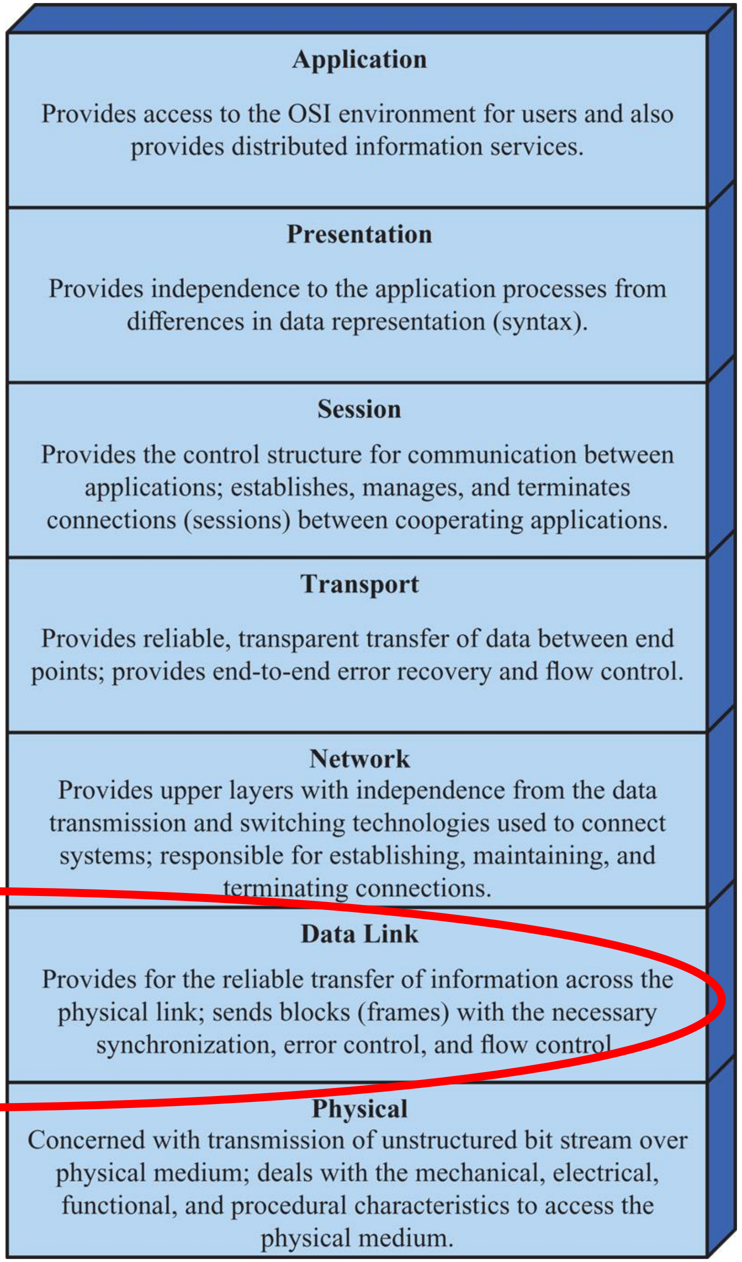
YZU CSE

Lecture Material

- "Introduction to Wireless & Mobile Systems", 4th edition, Dharma P. Agrawal, Qing-An Zeng, 2016.
  - Ch. 6 and Ch.7
- "Wireless Communication Networks and Systems", Corry Beard and William Stallings, 2016.
  - Ch 5. Overview of Wireless Communications
- Wireless Internet
  - Prof. You-Chiun Wang
  - National Sun Yat-sen University
- Wireless Networks and Applications
  - Prof. Peter Steenkiste
  - Carnegie Mellon University

Network Layers





Outline

- Data link fundamentals
- Channel reservation protocols
- Random access protocols
- Uplink & downlink
- Issues of wireless MAC

Datalink Functions

- Framing: encapsulating a packet into a bit stream.
  - Add header, mark and detect frame boundaries, …
- Logical link control: managing the transfer between the sender and receiver, e.g.
  - Error detection and correction to deal with bit errors
  - Flow control: avoid that the sender outruns the receiver
- Media access: controlling which device gets to send a frame next over a link
  - Easy for point-to-point links; half versus full duplex
  - Harder for multi-access links: who gets to send?

Framing

- Typical structure of a "wired" packet:
  - Preamble: synchronize clocks sender and receiver
  - Header: addresses, type field, length, etc.
  - The data to be send, e.g., an IP packet
  - Trailer: padding, CRC, ..

7 byte	1 byte	6 byte	6 byte	2 byte	46 to 1500 byte	4 byte
Preamble	Start Frame Delimiter	Destination Address	Source Address	Length	Data	Frame Check Sequence (CRC)

- How does wireless differ?
  - Explicit multi-hop support
  - Control information for physical layer
  - Ensure robustness of the header

Error Control

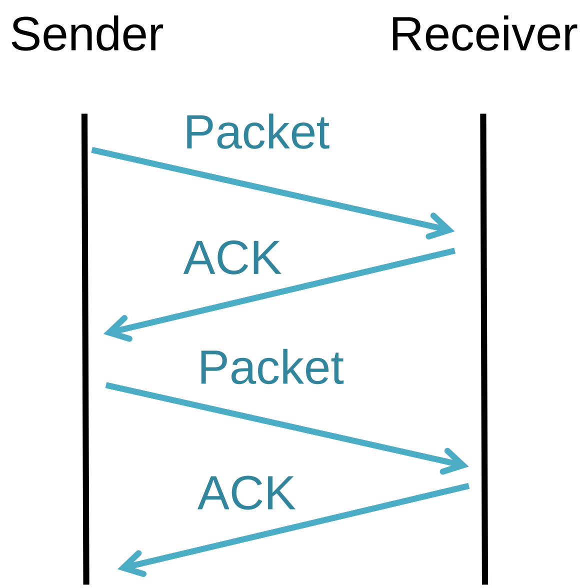
- Error Detection and Error Recovery
- Detection: only detect errors
  - Make sure corrupted packets get thrown away, e.g. Ethernet.
  - Use of error detection codes, e.g. CRC
- Recovery: also try to recover from lost or corrupted packets
  - Option 1: forward error correction (redundancy)
  - Option 2: retransmissions
- How does wireless differ?
  - Uses CRC to detect errors, similar to wired
  - Error recovery is much more important because errors are more common and error behavior is very dynamic.

Error Recovery in Wireless

- Use of redundancy:
  - Very common at physical layer
  - Spread spectrum, OFDM, etc.
- Use of Automatic Repeat Request (ARQ)
  - Use timeouts to detect loss and retransmit
- Many variants:
  - Stop and wait: one packet at a time
  - Go Back N: sender keeps sending and retransmits, starting with the unacknowledged packet.
  - Selective Repeat: only packets that are not acknowledged are retransmitted.

Stop and Wait

- Simplest ARQ protocol
- Send a packet, stop and wait until acknowledgement arrives.



Media Access Control

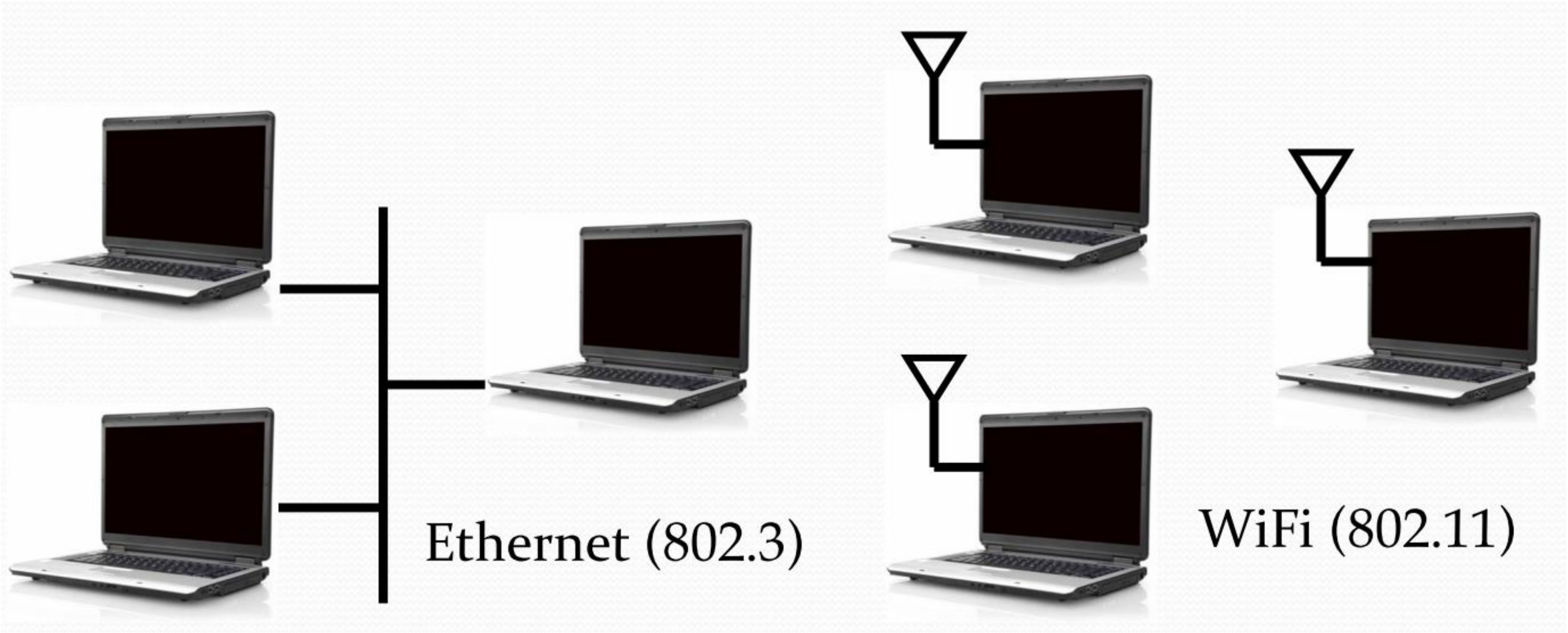
- How do we transfer packets between two hosts connected to the same network?
- Using point-to-point “links” with “switches” – store-and-forward
  - Very common in wired networks, at multiple layers
- Multiple access networks
  - Multiple hosts are sharing the same transmission medium
  - Need to control access to the medium
  - Taking turn versus contention based protocols
- What is different in wireless?
  - Is store and forward used?
  - Is multiple access used?

Broadcasting Networks

- Broadcasting (or shared-medium) network:
  - N senders and receivers are connected by a shared medium.
    - Ex: copper wire or air
  - They need to share local access to the same medium.

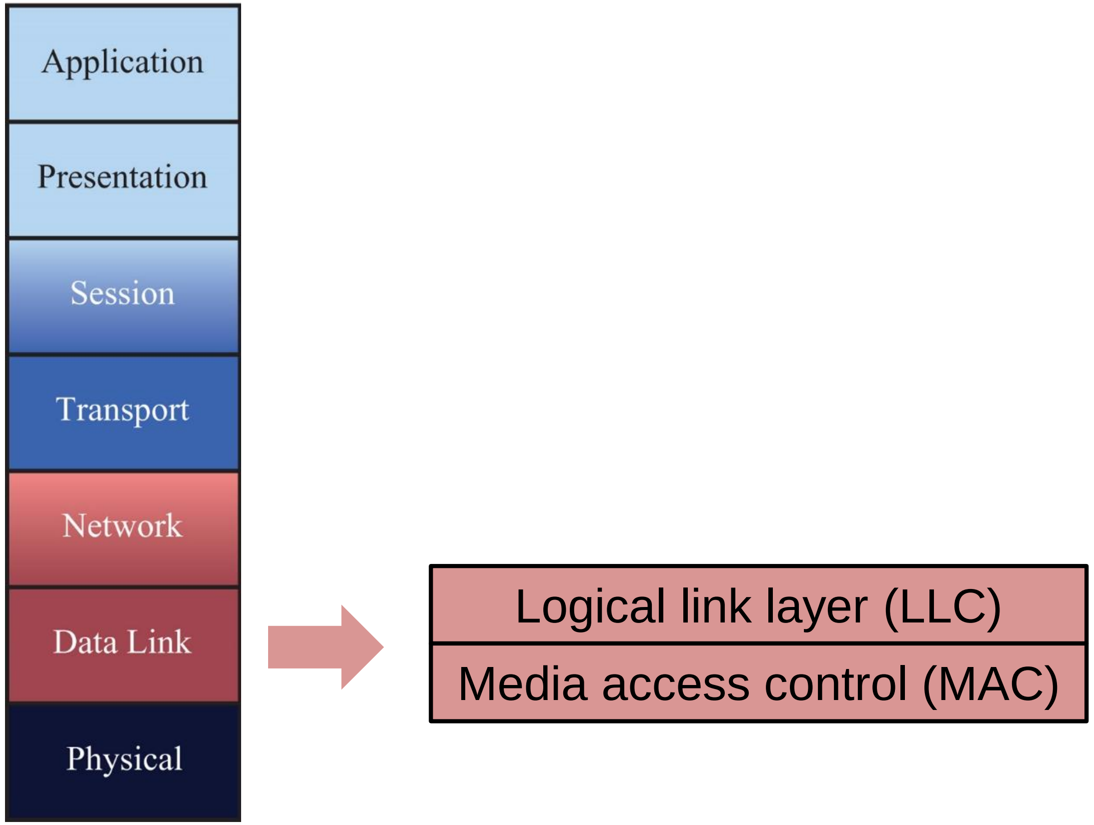
Example of Broadcasting Networks

- Local area network (LAN):
  - Wired network - Ethernet (IEEE 802.3)
  - Wireless network - WiFi (IEEE 802.11)



Multiple Access

- Before network-layer packets can be transmitted, the sender has to gain the access to the medium.
  - This is done by the media access control (MAC) layer, which is a sublayer of the data-link layer.



Multiple Access

- A multiple access protocol should determine the station which is allowed to transmit to the shared medium.
- There are two categories of multiple access protocols:
  - Channel reservation protocols:
    - FDMA
    - TDMA
    - CDMA
    - OFDMA
  - Random access protocols:
    - ALOHA
    - CSMA (including its variations)

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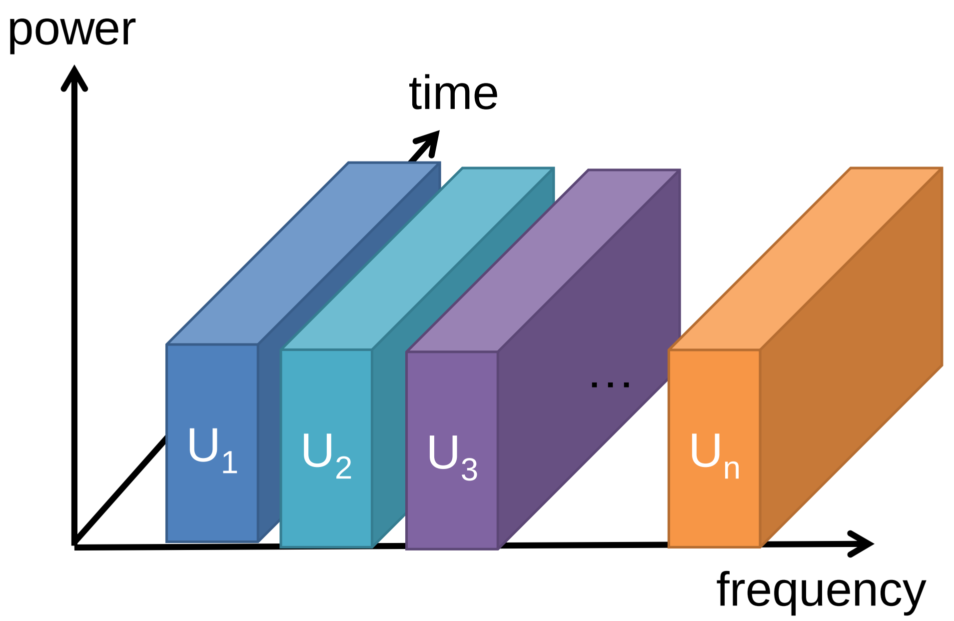
Channel Reservation Protocol

- In a channel reservation protocol, the "network resource" is divided in advance for communication.
  - Resource: Frequency, time, coding, …
- We will introduce the following protocols:
  - FDMA: Frequency division multiple access
  - TDMA: Time division multiple access
  - CDMA: Code division multiple access
  - OFDMA: Orthogonal frequency division multiple access

FDMA: Operation

- FDMA divides the spectrum into multiple frequency bands (called channels).
  - Each station transmits its data through a predetermined channel.



FDMA: Advantages (1/2)

- If the channel is not in use, it can stay idle.
- Channel bandwidth is relatively narrow (about 30kHz).
- FDMA is simple algorithmically, and from a hardware standpoint.
- FDMA is fairly efficient when the number of stations is small and the traffic is uniformly constant.

FDMA: Advantages (2/2)

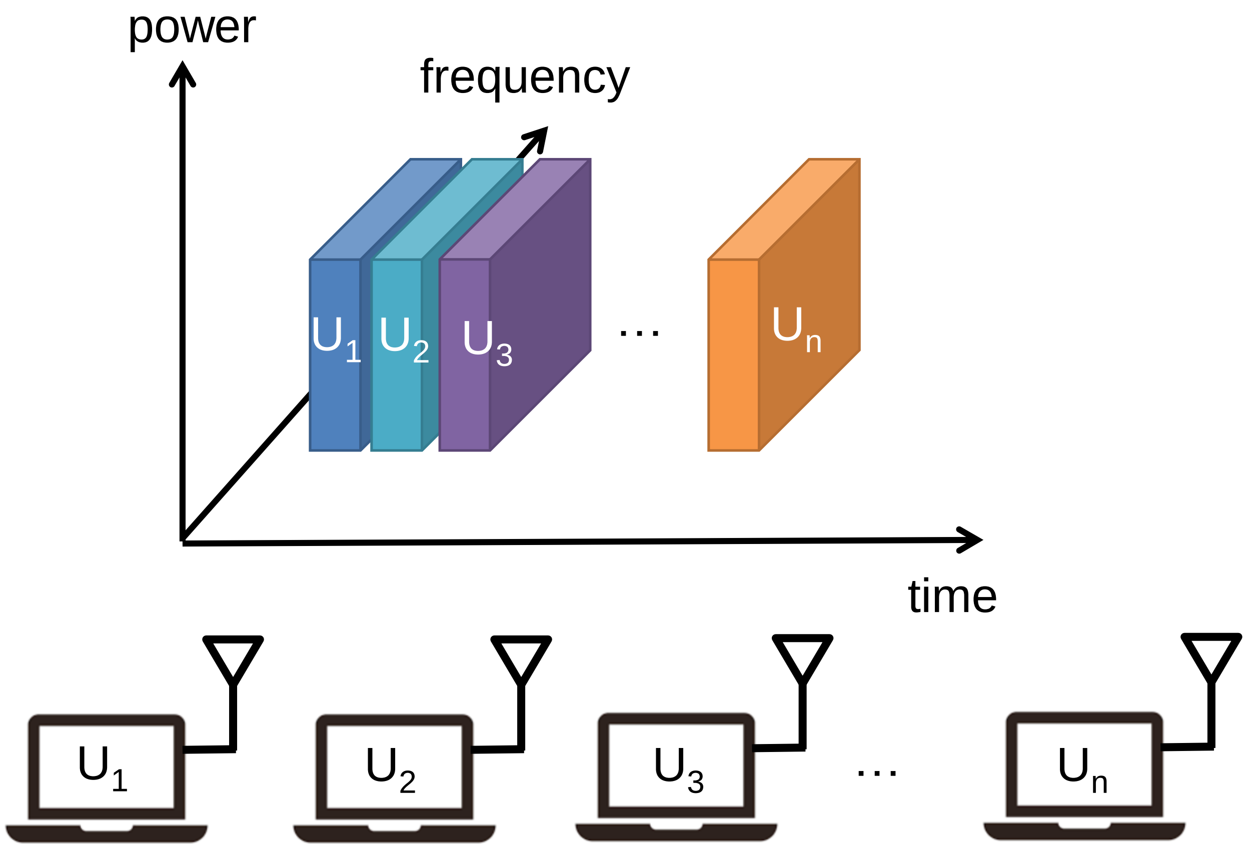
- FDMA can increase network capacity by reducing protocol overhead and using efficient digital code.
- FDMA does not need network timing.
- There is no restriction regarding the type of baseband or modulation in FDMA.

FDMA: Disadvantages

- FDMA must require guard bands.
- FDMA also requires RF filtering to minimize adjacent channel interference.
- The maximum bit rate per channel is fixed and small in FDMA.
- FDMA has inhibiting the flexibility in bit rate capability.
- FDMA does not differ significantly from analog systems.

TDMA: Operation

- TDMA divides time into multiple slots.
  - Each station transmits its data during pre-determined time slots.



TDMA: Advantages (1/2)

- TDMA can provide flexible bit rate.
- TDMA does not need frequency guard band.
- There is no need for precise narrowband filters in TDMA.
- TDMA is easy for mobile devices or base stations to initiate and execute handoff.

TDMA: Advantages (2/2)

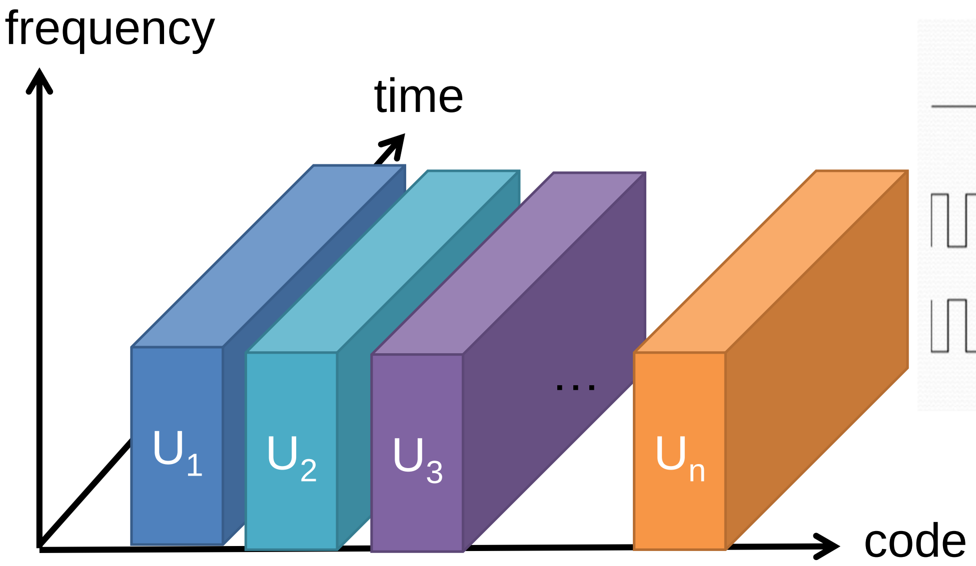
- TDMA can extend battery life because stations can turn off their transceivers at some slots.
- TDMA installations can offer savings in base station equipment, space, and maintenance.
- TDMA is the most cost-effective technology for upgrading a current analog system to digital.

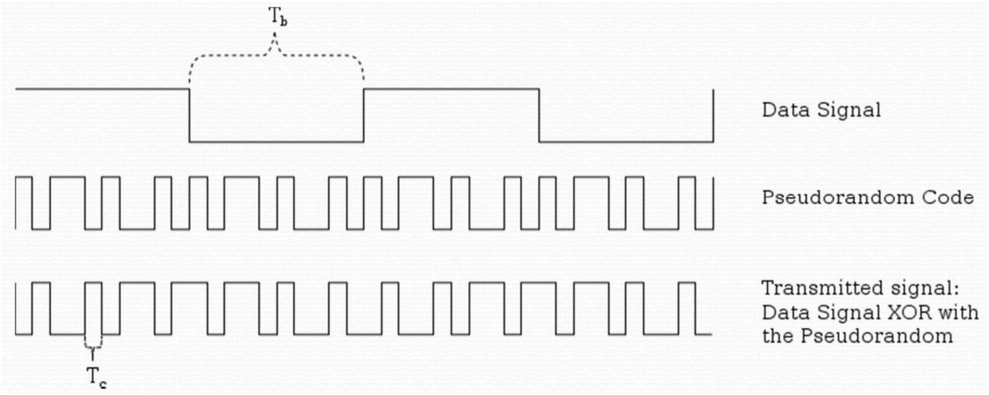
TDMA: Disadvantages

- TDMA requires network-wide timing synchronization.
- TDMA also requires signal processing for matched filtering and correlation detection.
- TDMA demands high peak power on uplink in transmit mode.
- TDMA may cause multipath distortion.

CDMA: Operation

- CDMA uses multiple orthogonal codes to partition a range of spectrum (including both time and frequency).
- Each station transmits its data by using a pre-determined code.





CDMA: Example

- Each station has a station code.
- Each bit is encoded by the station code:
  - Code 1 is mapped to '1'; Code 0 is mapped to '-1'.
  - Bit 1 is replaced by the station code; Bit 0 is replaced by the inverse of the station code.

Station codes	Transmissions	Decoding traffic of station:
C_A: 1 0 1 0	A: Bit 1 => 1 -1 1 -1	A: $S*C_A$=(-1 -1 3 -1)*(1 -1 1 -1)/4=1 => binary 1.
C_B: 1 0 0 1	B: Bit 0 => -1 1 1 -1	B: $S*C_B$=(-1 -1 3 -1)*(1 -1 -1 1)/4=-1 => binary 0.
C_C: 0 0 1 1	C: Bit 1 => -1 -1 1 1	C: $S*C_C$=(-1 -1 3 -1)*(-1 -1 1 1)/4=1 => binary 1.

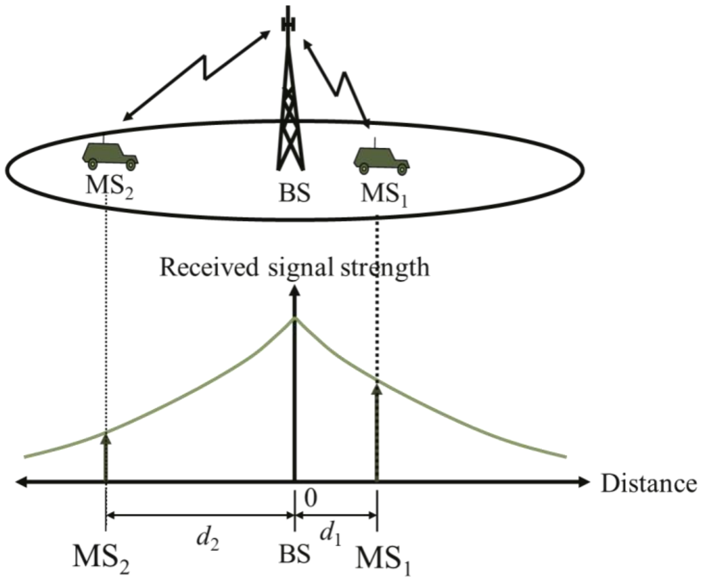
	S= -1 -1 3 -1	

CDMA: Advantages

- Many CDMA users can use the same frequency.
- Multipath fading may be substantially reduced in CDMA because of large signal bandwidth.
- There is no absolute limit on the number of users in CDMA.
- CDMA can easily add users.
- In CDMA, it is almost impossible for crackers to decipher the code sent.
- CDMA can provide better signal quality.

CDMA: Disadvantages

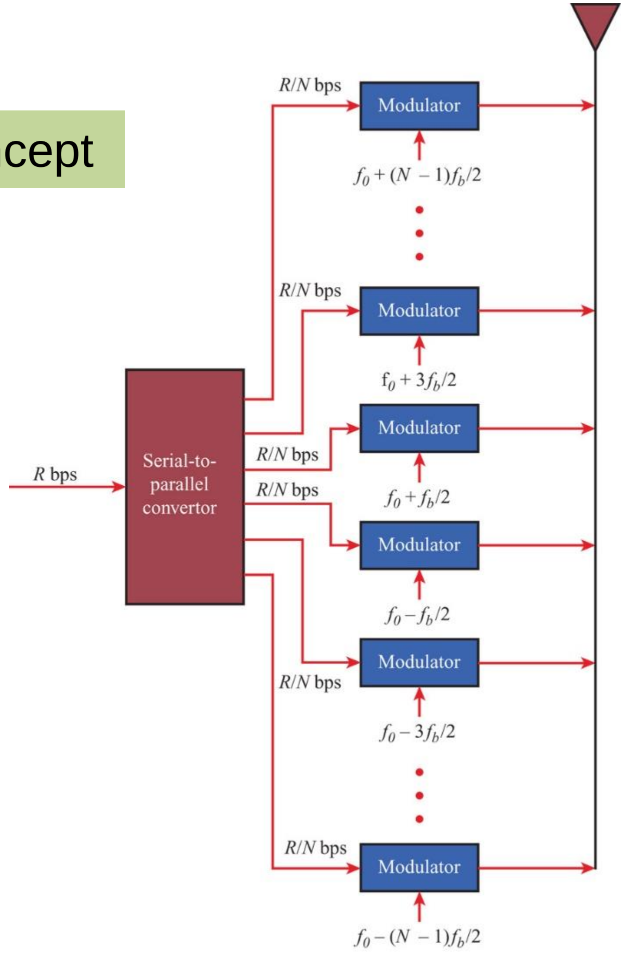
- When the number of users increases, the overall quality of service decreases in CDMA.
- CDMA may cause self-jamming.
- CDMA may also encounter near-far problem.
  - The near-far problem is a condition in which a receiver captures a strong signal and thereby makes it impossible for the receiver to detect a weaker signal.

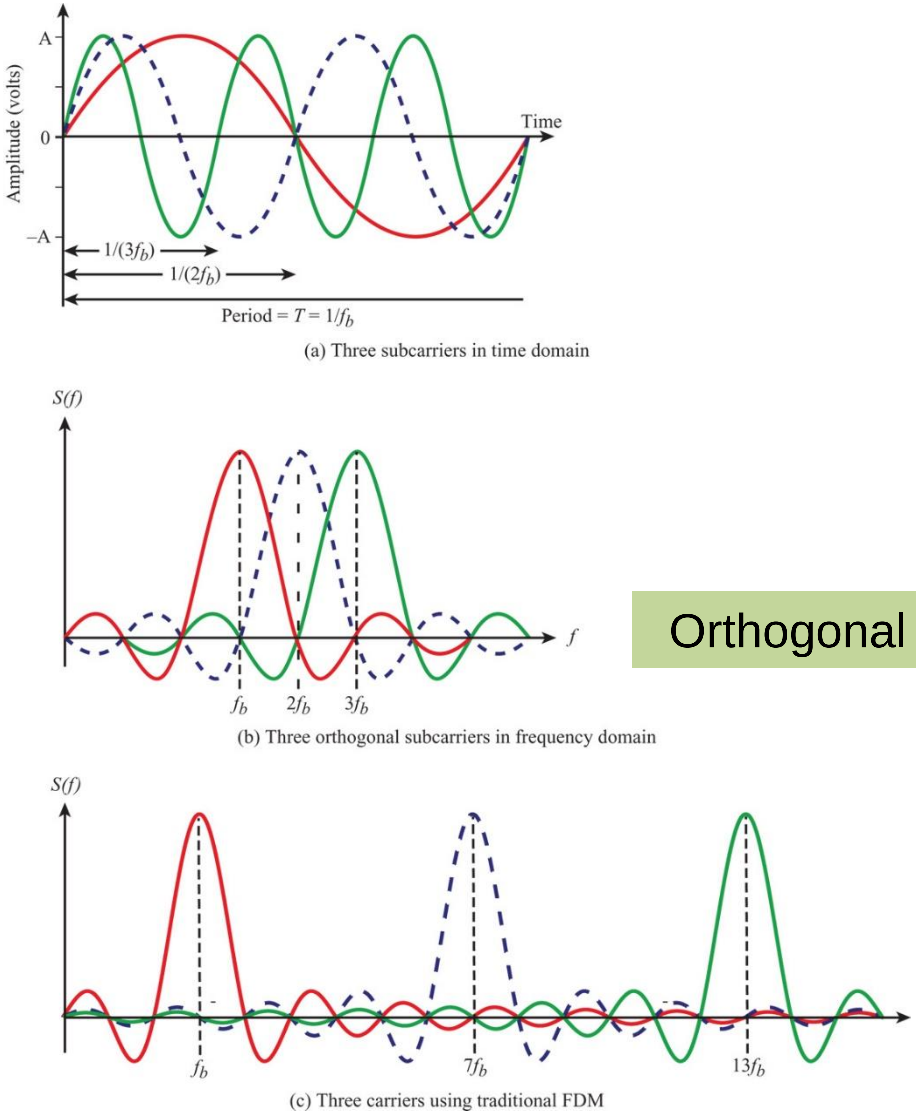


OFDMA

- Orthogonal Frequency Division Multiple Access (OFDMA)
- OFDM (orthogonal frequency division multiplexing

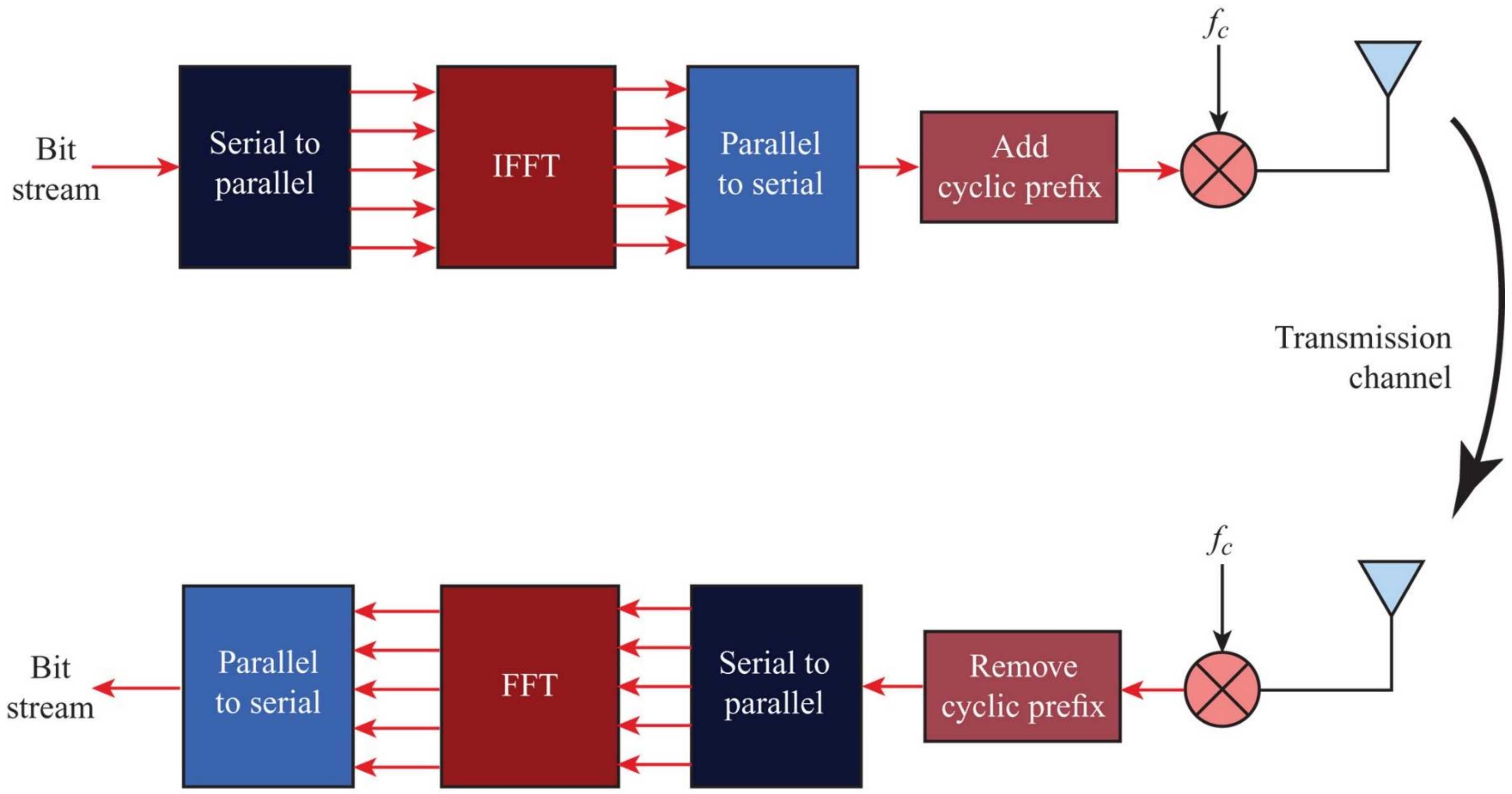
Concept





Orthogonal

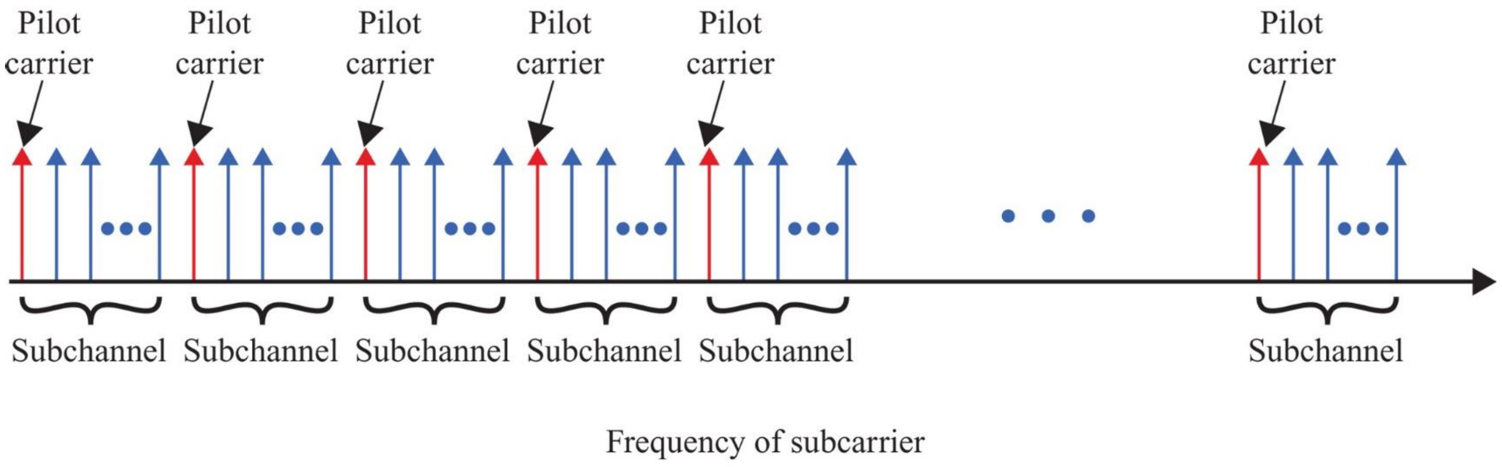
OFDM Implementation



FFT = fast Fourier transform
IFFT = inverse fast Fourier transform

OFDMA

- OFDMA uses OFDM to share the wireless channel
  - Different users can have different slices of time and different groups of subcarriers
  - Subcarriers are allocated in groups
    - Called subchannels or resource blocks
    - Too much computation to allocate every subcarrier separately



(b) OFDMA (adjacent subcarriers)

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Random Access Protocols (1/3)

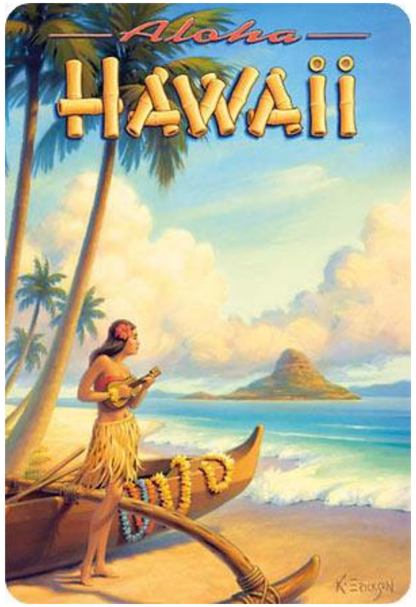
- In a channel reservation protocol, the network resource is divided in advance for communication.
- A random access protocol works when multiple users share the same resource (e.g., frequency band, time, code, space).
  - Analogy: speak in a conversation; grab the microphone to speak.

Random Access Protocols (2/3)

- What "protocol steps" will people use to talk in a conversation (i.e., shared media)?
  - Wait for silence
  - Then talk
  - Listen while talking.
  - What will people do if there are 2 talkers?
    - Backoff waiting
  - Repeat
- Protocols also add a random increasing timeout.

Random Access Protocols (3/3)

- There are two common random access protocols:
  - ALOHA
  - CSMA: Carrier sense multiple access
  - Each of them has many variations.



ALOHA Protocols

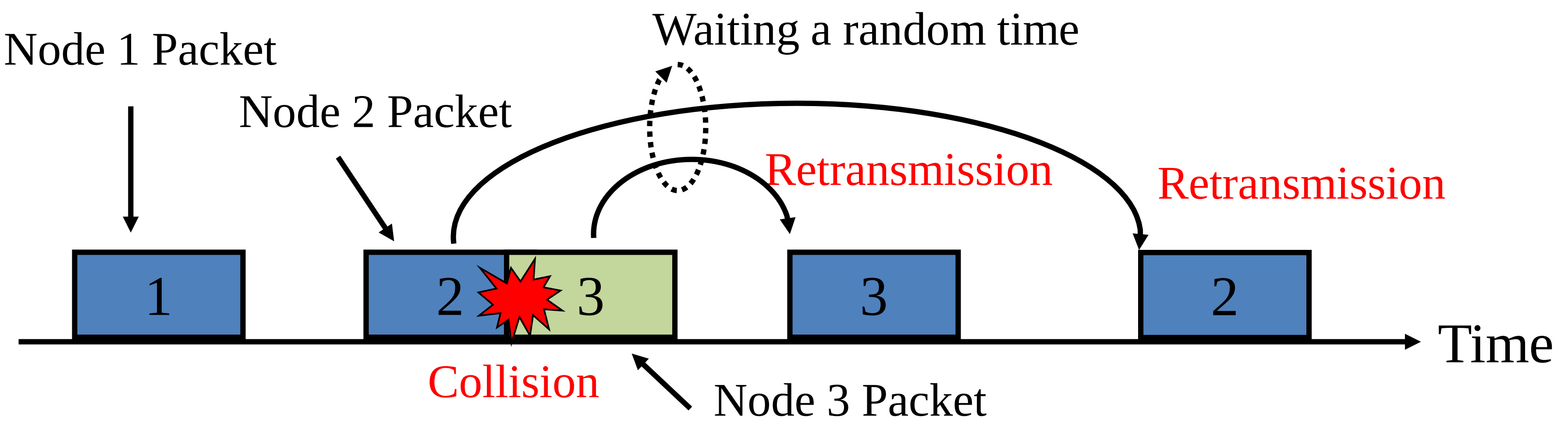
- ALOHAnet was developed for a packet radio network at University of Hawaii in 1971.
  - Ground-based ultra-high frequency (UHF) radios connect computers on several island campuses to the main university computer on the Oahu island.
  - It is the first well-known wireless network.
  - ALOHA is very simple, but not efficient!
- ALOHA variations:
  - Pure-ALOHA:
    Transmit the packet whenever desired.
  - Slotted-ALOHA:
    Further divide the time into slots.

Pure ALOHA (1/2)

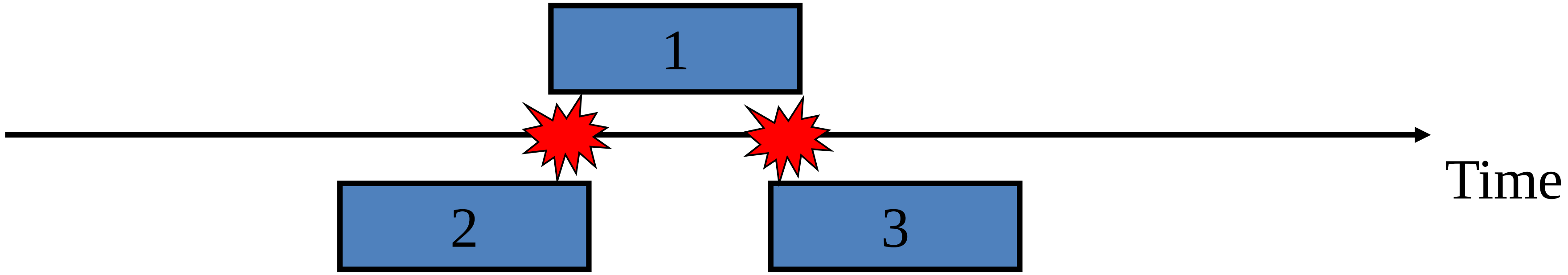
- In pure ALOHA, each station starts transmitting whenever they have data to send.
  - This is a basic form of random access.
- Collision will occur when two or more stations try to transmit packets at the same time.
- Each station will waits a timeout (= 1 round-trip time, or RTT) for an acknowledgement (ACK).
  - If there is no ACK received by timeout,
  - then the station waits a randomly selected delay to avoid repeated collisions, and then retransmits again.

Pure ALOHA (2/2)

- Collision mechanism

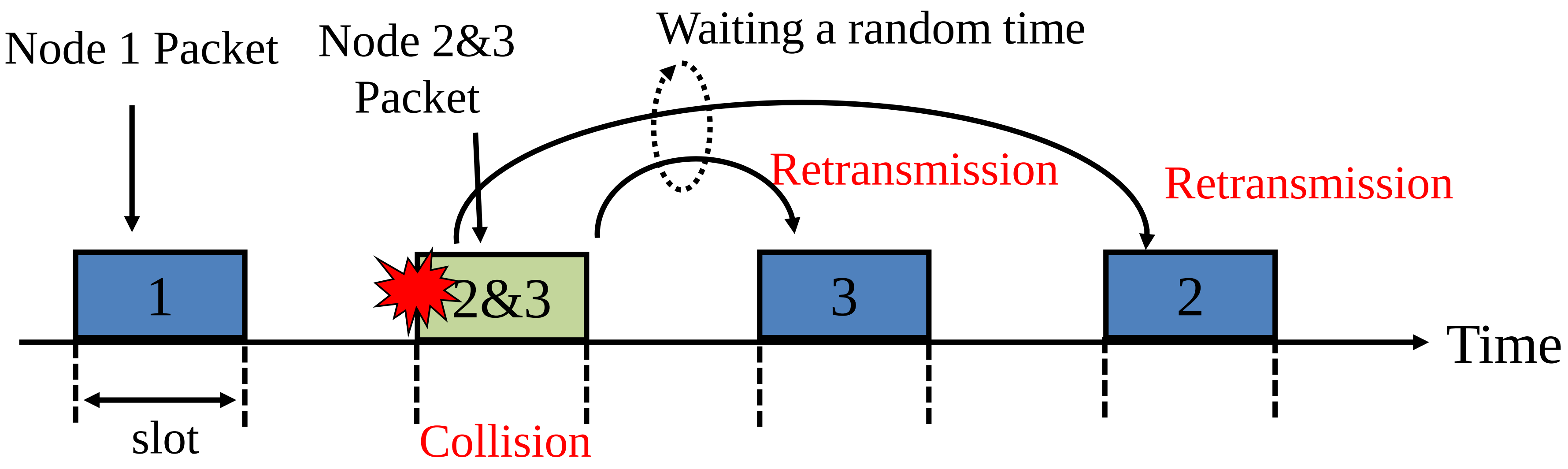


- More collisions (maximum throughput: ~18%)



Slotted ALOHA

- Instead of sending a packet at any time, slotted ALOHA allows a station to send the packet within a time slot.
  - Collisions are thus confined to one time slot.
  - Maximum throughput: ~36.8%

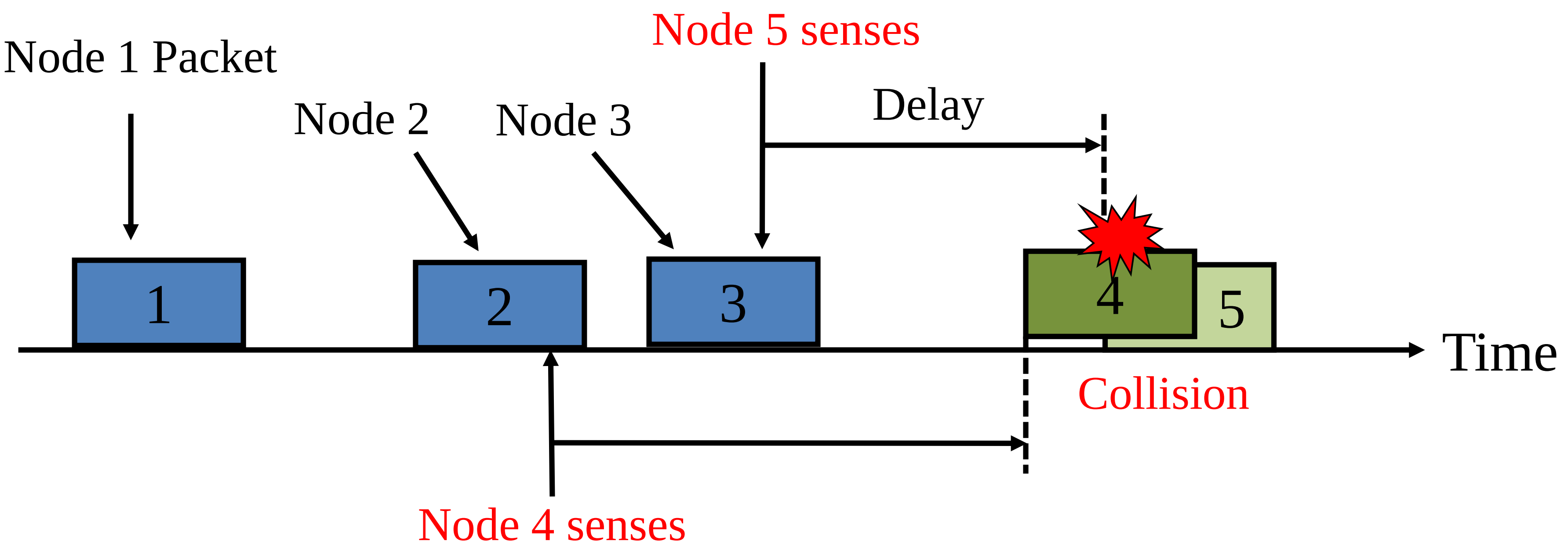


ALOHA Discussion

- ALOHA (and its slotted version) are inefficient because stations do not take into account what others are doing before they transmit.
- ALOHA is a talk-before-listen protocol.
- Ex: In a conversation, everyone speaks whenever they want to, regardless of whether another person is speaking.

CSMA Protocols

- Unlike ALOHA, CSMA (carrier sense multiple access) is a listen-before-talk protocol.
  - Each station senses the carrier (see if anyone else is transmitting) before it starts transmitting.



CSMA Variations (1/2)

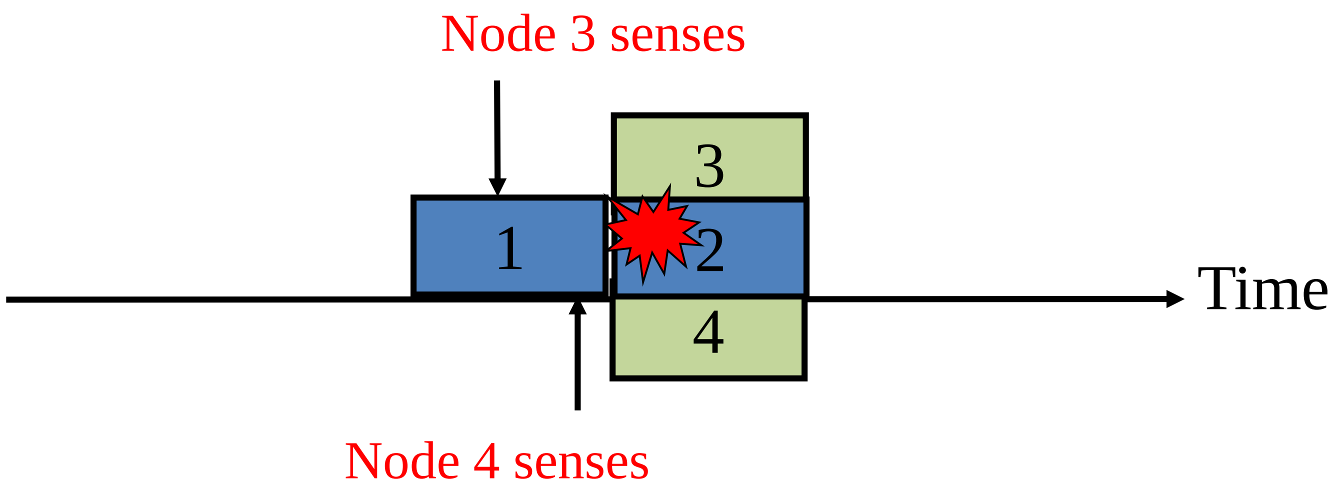
- Persistent CSMA
  - When the medium is busy, a station can persistently wait for the medium to become idle, and then starts sending with a probability.
    - 1-persistent CSMA
    - p-persistent CSMA
- Non-persistent CSMA
  - A station can stop monitoring the medium, and listen to it again after predefined time.

CSMA Variations (2/2)

- CSMA enhancements:
  - CSMA with collision detection (CSMA/CD): Used in wired networks such as Ethernet.
  - CSMA with collision avoidance (CSMA/CA): Used in wireless networks such as IEEE 802.11.

1-persistent CSMA (1/2)

- If the medium is busy, a station listens continuously.
- When the medium becomes free, the station starts transmitting its packet immediately (that is, with probability 1).
- Collision?



1-persistent CSMA (2/2)

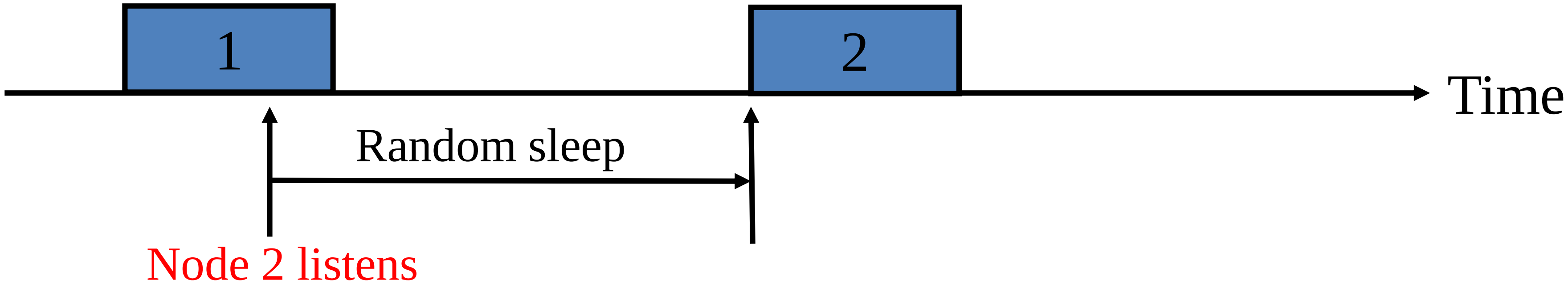
- Collision scenarios
  - Stations A and B are far apart from each other (i.e., long propagation delay). A's signal takes a long time to reach B. So, B thinks the medium is free, and thus starts transmitting.
  - Stations B and C transmit as soon as A finishes.

p-persistent CSMA

- p-persistent CSMA is a generalization of 1-persistent CSMA.
  - It is typically applied to slotted channels, where the slot length is chosen as the contention period (i.e., the round trip propagation time).
- A station senses the medium, and two cases may occur:
  - If the slot is idle, then the station starts transmitting with a probability p or defer with probability (1-p).
  - If the medium is busy, then the stations continuously sense the medium until it becomes free.

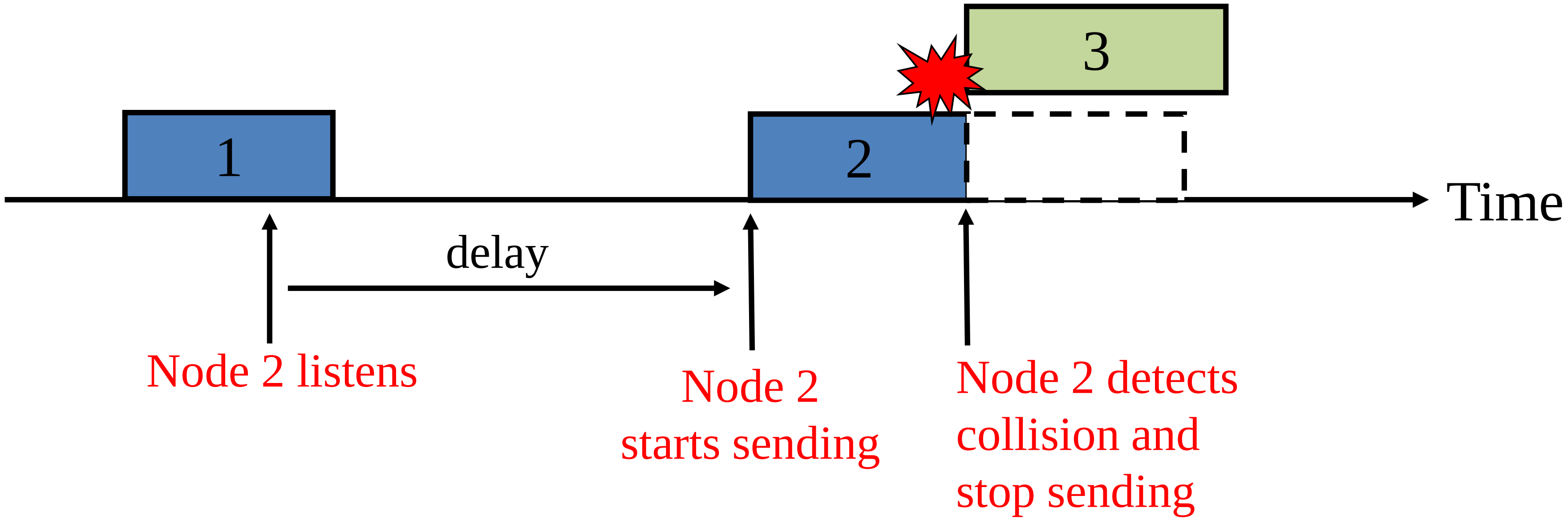
Non-persistent CSMA

- Stations do not sense the medium continuously.
- Instead, if the medium is busy, the station waits (or sleeps) by a random interval before sensing the medium again.
  - Like 1-persistent CSMA, as soon as the medium becomes idle, the station starts transmitting its packet.
  - Such an random interval reduces collisions. So, non-persistent CSMA achieves higher network throughput than 1-persistent CSMA when there are many senders in the network.



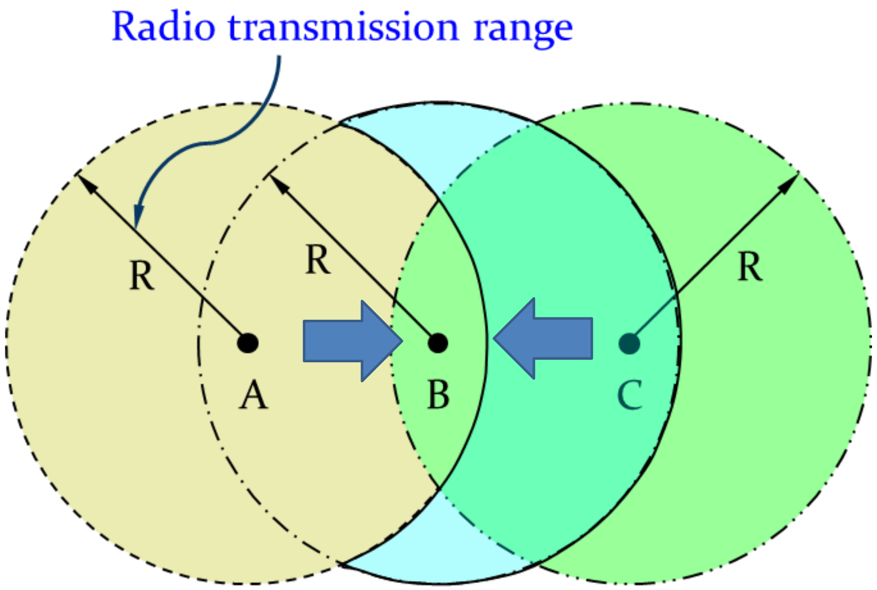
CSMA/CD

- Ethernet uses CSMA/CD, which is a listen-while-talk protocol.
  - A station listens even when it is transmitting.
  - If any collision is detected, then the station stops transmitting.



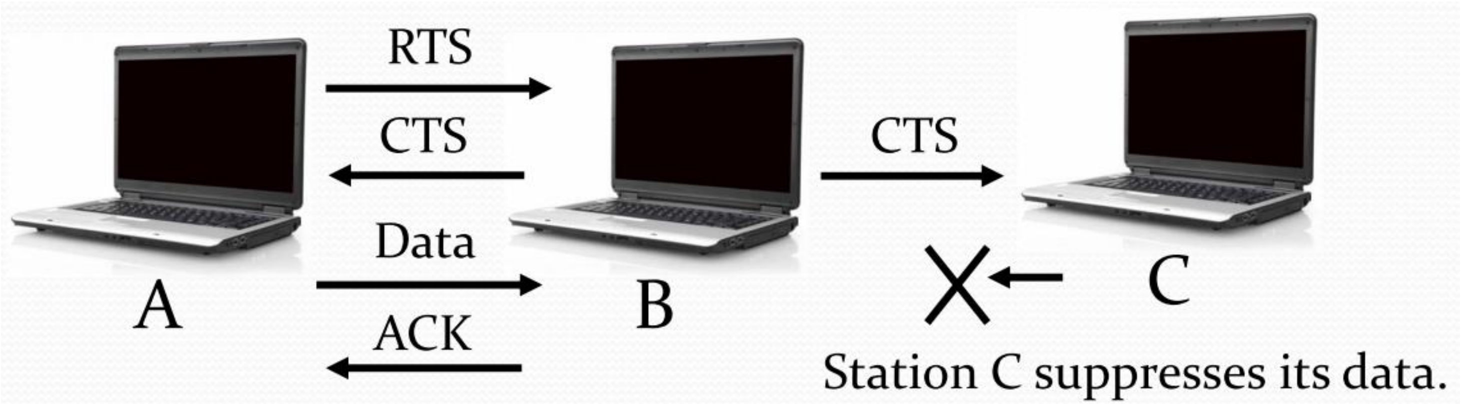
CSMA/CA (1/3)

- WiFi employs CSMA/CA for wireless transmission.
- Hidden terminal problem
  - B can hear A and C, but A and C cannot hear each other.
  - If A is sending data to B, C thinks the medium is clear and starts sending. -> Collision!
  - Ethernet does not have this problem because stations can hear each other.



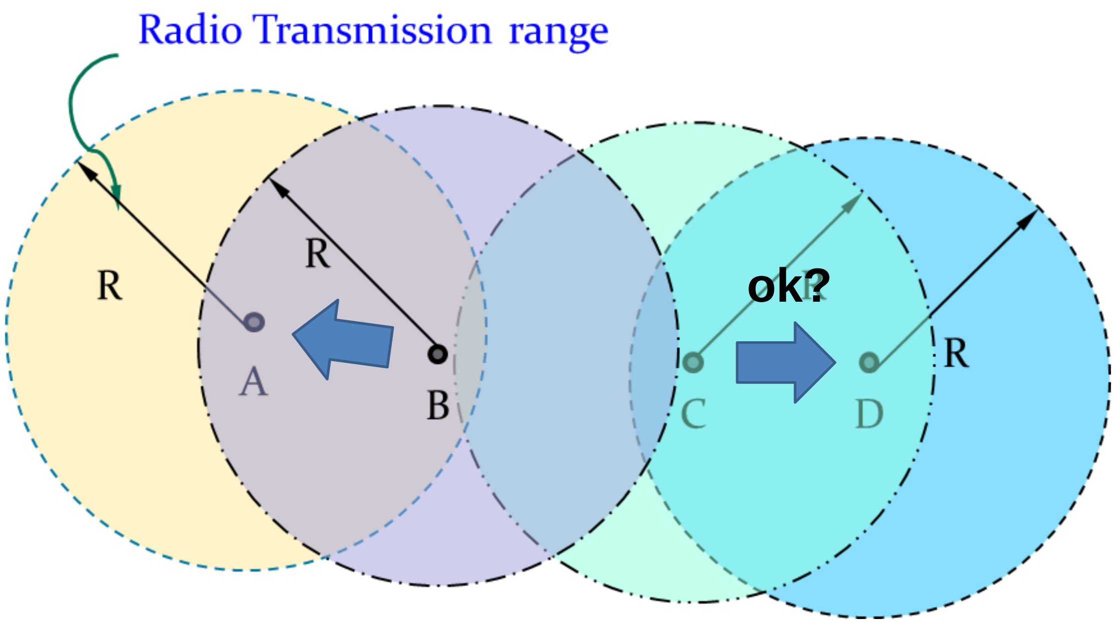
CSMA/CA (2/3)

- Deal with the hidden-terminal problem:
  - Station A sends a request-to-send (RTS) packet.
  - Station B sends a clear-to-send (CTS) packet.
  - Station C hears CTS, and thus does not interfere the transmission between A and B.
- This helps implement collision avoidance (CA).

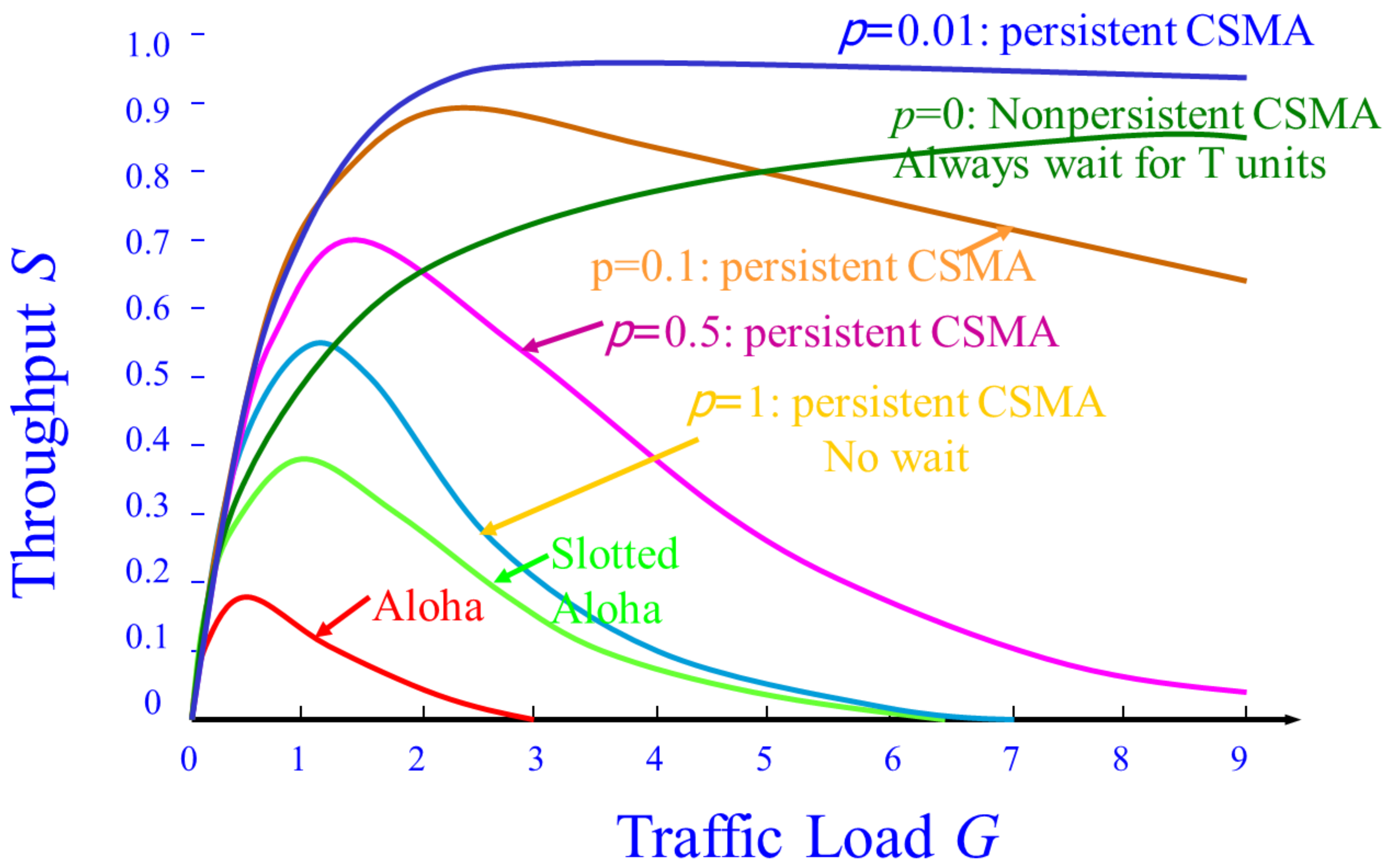


CSMA/CA (3/3)

- Exposed terminal problem
  - Caused by RTS/CTS mechanism
  - Lower network throughput.



Performance Comparison



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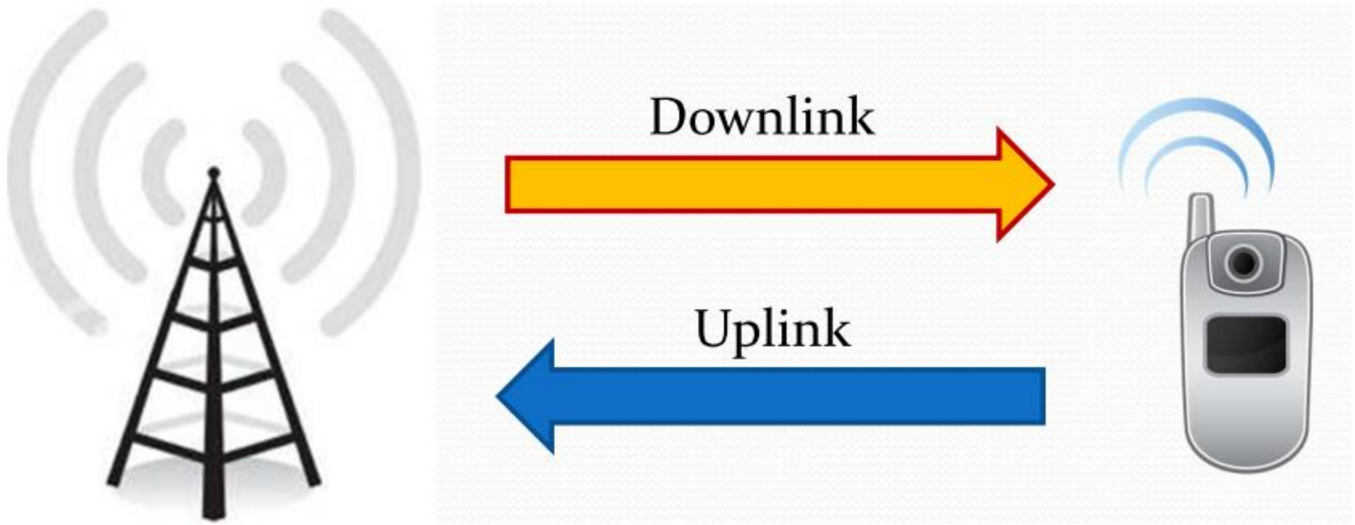
Downlink vs. Uplink

- In a wireless network with base stations (or access points), there will be two directions of traffics.
  - Such a network is called an infrastructure network.
  - Base station -> User station: Downlink
  - User station -> Base station: Uplink

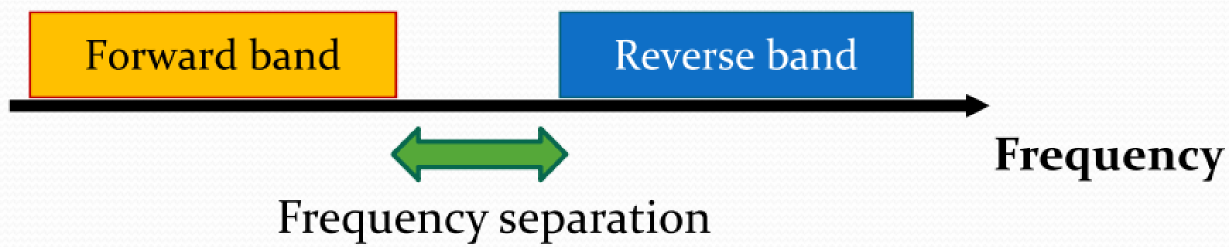


Duplexing Schemes

- To support both uplink and downlink traffics in the same network, we need duplexing schemes.
  - FDD: Frequency division duplexing
  - TDD: Time division duplexing

FDD

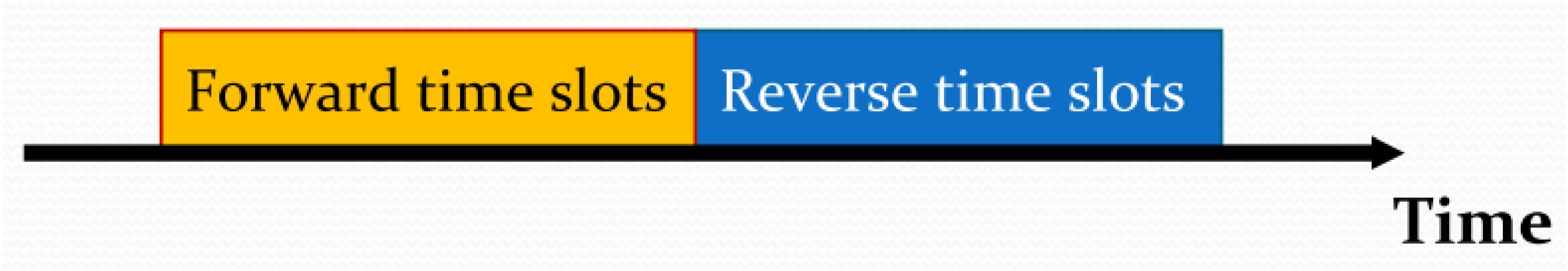
- FDD adopts two bands of frequencies for every station.
  - Forward band: Used to transmit downlink traffic
  - Reverse band: Used to transmit uplink traffic



- User stations req
  - Frequency separation between forward band and reverse band is constant.

TDD

- TDD allows multiple stations share a single radio channel.
- In TDD, time is divided into two parts:
  - Forward time slots: Used to transmit downlink traffic
  - Reverse time slots: Used to transmit uplink traffic



- Duplexer is not required in TDD.

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Issues in Wireless Networks

- Signal interference:
  Two signals simultaneously arriving at a receiver are usually treated as meaningless noises.
  - Intra-system interference
    - Ex: Interference between 802.11 stations
  - Inter-system interference
    - Ex: Interference of an 802.11 device from an external Bluetooth signal, which also operates on 2.4 GHz.

Issues in Wireless Networks

- Power management:
  - Electricity in battery is a limited resource.
  - Let the wireless network interface enter sleep or doze modes to save energy.
  - There is a tradeoff between network throughput and energy conservation.

Issues in Wireless Networks

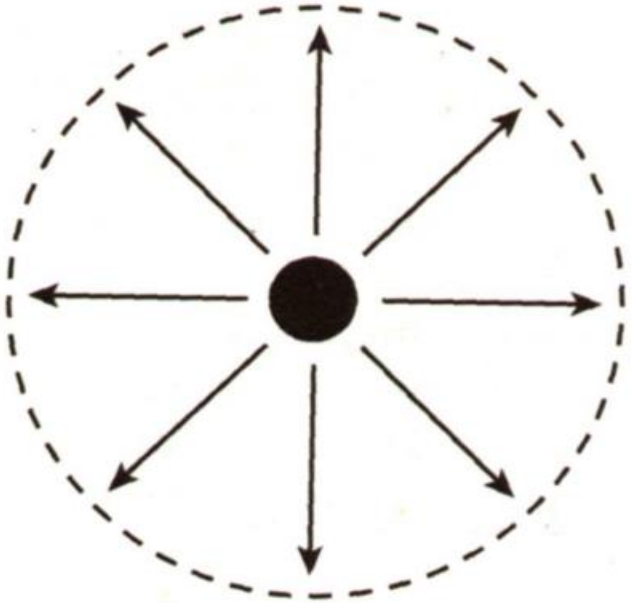
- System interoperability:
  - That is why we need standards for wireless networks.

Network	ETSI	IEEE
WWAN	3GPP (GSM, GPRS, EDGE)	802.20, 802.16e
WMAN	HiperMAN, HiperACCESS	802.16 (WiMAX)
WLAN	HiperLAN, HiperLAN2	802.11 (WiFi)
WPAN	HiperPAN	802.15 (Bluetooth, ZigBee)

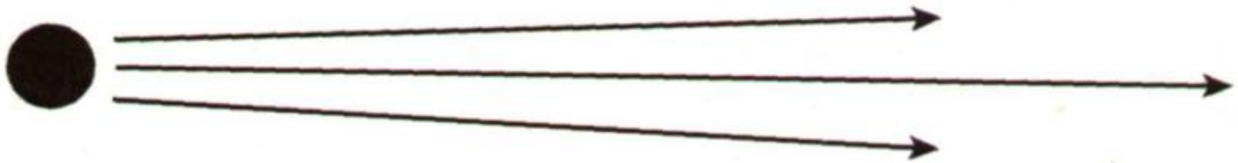
Antenna (1/2)

- Antenna’s propagation pattern:
  - Radiation power: Typically less than a few watts
  - Gain: The degree of amplification
    - Omnidirectional = 1
    - Directional > 1 (good for longer distance)
    - Example: Watering your lawn
- Directional radio propagation results in challenges on coverage and communication.

Antenna (2/2)



Omnidirectional radio propagation



Directional radio propagation

Security Threats

- Radio waves can easily penetrate walls, thus being tapped outside the building.
  - Eavesdrop: One passively retrieve your radio signal without being noticed.
  - Electronic sabotage: Someone maliciously jams your wireless network.

Cell Size

- Cell sizes vary from tens of meters to thousands of kilometers.
  - Bluetooth & ZigBee (for WPAN): 1 ~ 10 meters
  - WiFi (for WLAN): Around hundreds of meters
  - GSM, 3G, or LTE (for WMAN): Around several kilometers
  - Satellite: Thousands of kilometers
- Data rates may range from 0.1 Kbps to 50 Mbps (or higher).
  - Using various modulation schemes & communication frequency, the data rates can become more higher.

Improvement Methods

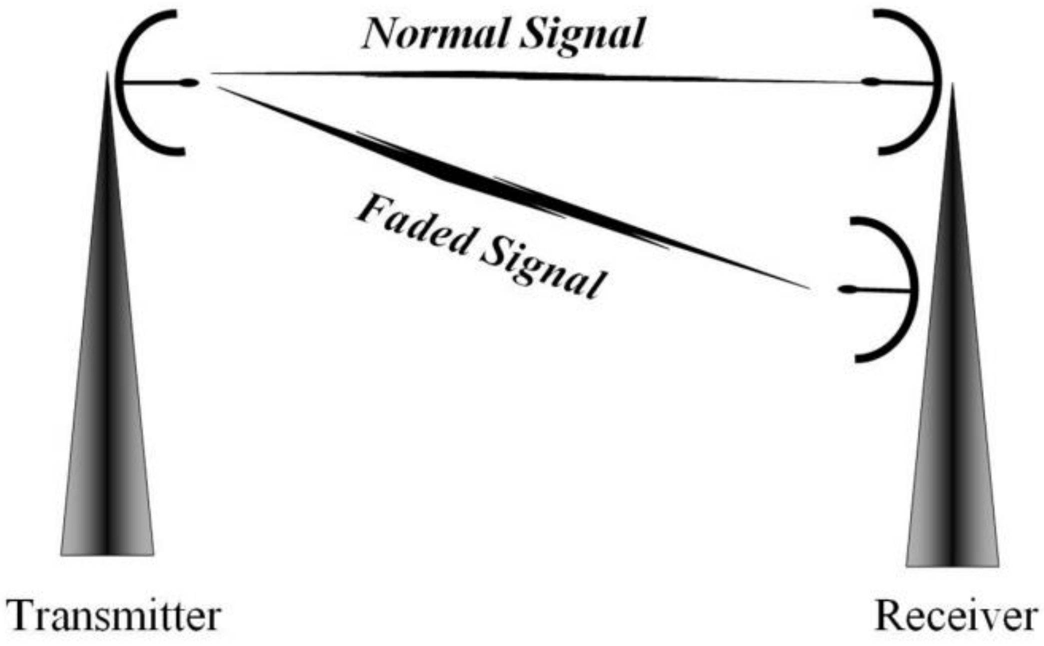
- There are several techniques to improve network performance for wireless networks:
  - Antenna diversity (or space diversity): Send multiple copies of the same information signal through several channels.
  - Smart antenna: Adjust the antenna to get a better receipt of the signal.
  - Power control: Shrink the communication range by reducing the transmission power.
  - Data integrity: Parity check, cyclic redundancy check (CRC), Hamming code, …

Antenna Diversity (1/2)

- Antenna diversity uses a set of array elements (sometimes called branches), which are spaced sufficiently apart from each other.
- Antenna diversity can combat multipath fading, because multipath fading is usually independent at distances in the order of the channel’s wavelength.

Antenna Diversity (2/2)

- Example: A two-branch diversity system
  - A number of algorithms have been proposed to reconstruct the original transmission.
  - Pick the strongest signal from one of the antennas.

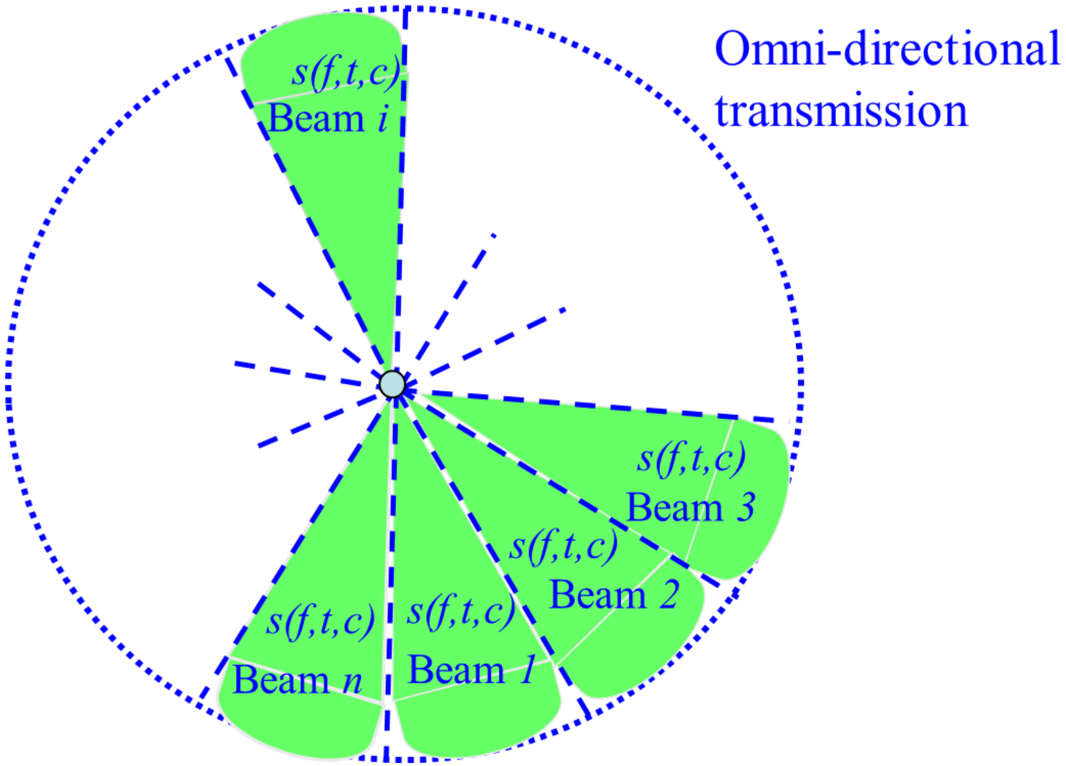


Smart Antenna

- Smart antennas are multi-antennas that can be adjusted in order to adapt to the conditions of wireless channels.
  - This scheme is also known as beam-forming.
- They can focus toward the receivers or transmitters.
- The technique of smart antenna is already available for decades, but it is not widely used due to the high cost.

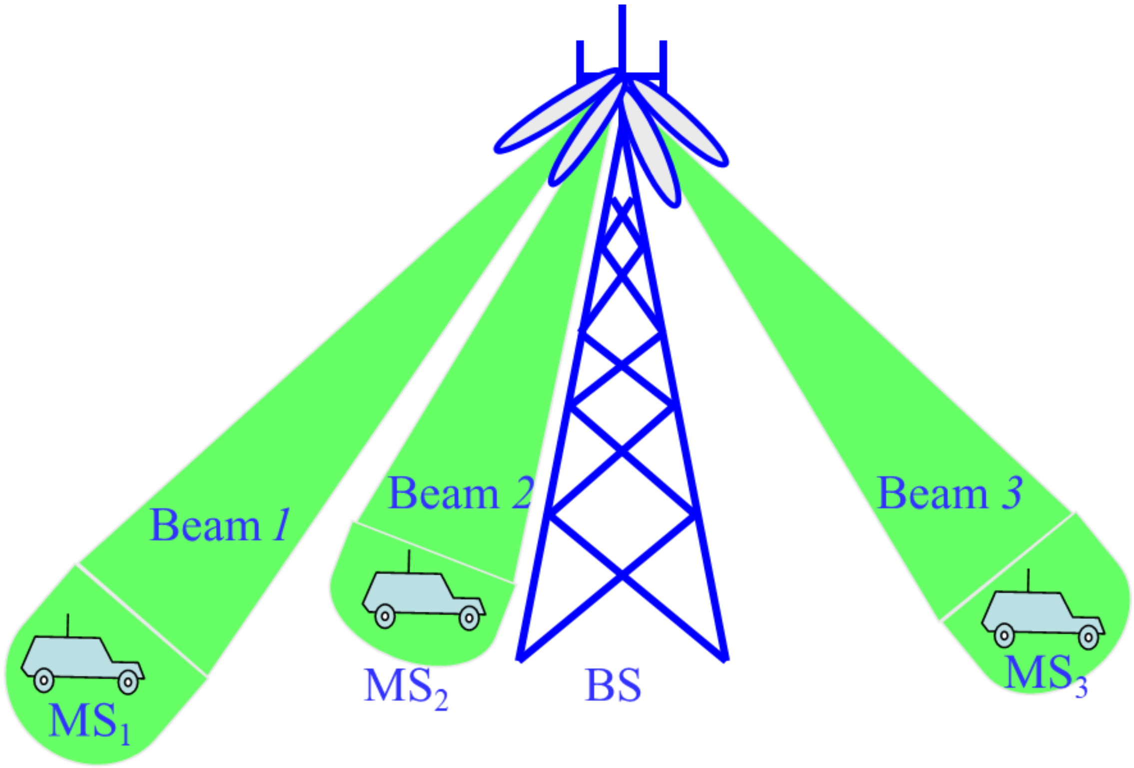
SDMA (1/2)

- Space division multiple access (SDMA)
  - Space divided into spatially separate sectors



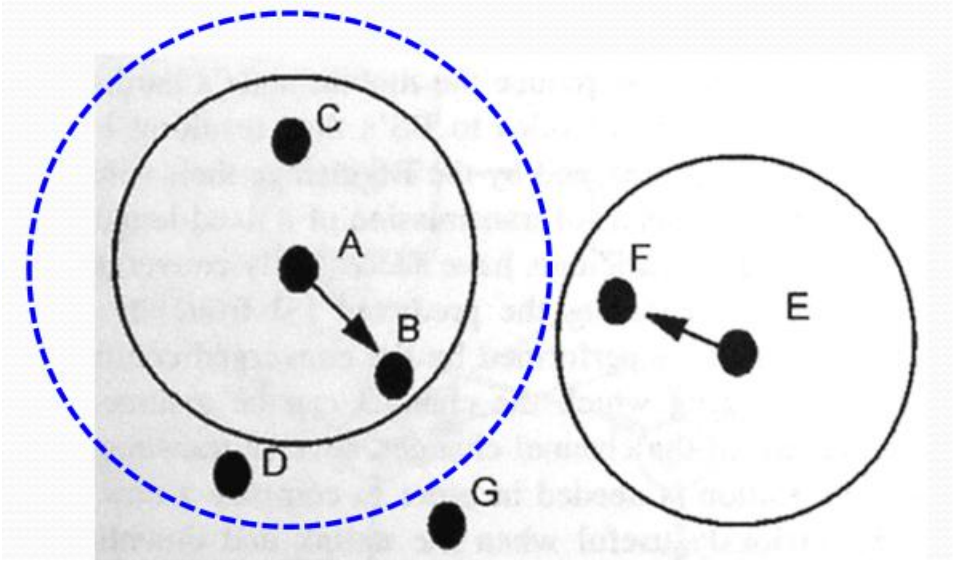
SDMA (2/2)

- A basic structure of a SDMA system



Power Control

- Power control schemes properly tune the transmission power of each station to reduce the transmission coverage and the potential interference.
  - They improve network throughput by allowing concurrent transmissions (i.e., increasing the spatial reuse).



Data Integrity

- Encoder and decoder for parity-check code:
- One-bit parity-check code: Add a parity bit so that the number of 1's will be even.

Datawords	*Codewords*	*Datawords*	*Codewords*
0000	00000	1000	10001
0001	00011	1001	10010
0010	00101	1010	10100
0011	00110	1011	10111
0100	01001	1100	11000
0101	01010	1101	11011
0110	01100	1110	11101
0111	01111	1111	11110

Summary

- In a broadcasting network, MAC layer should determine which station(s) can get the channel to send data.
- Channel reservation protocols include FDMA, TDMA, CDMA, and OFDMA.
- ALHOA and CDMA are two common random access protocols, which have many variations.
- Interference, power management, and system interoperability are critical concerns in wireless networks.
- Several techniques such as antenna diversity, smart antenna, power control, and data integrity can help improve network performance.