Medium Access Control (MAC) Protocols for Ad hoc Wireless Networks - I

CS: 647
Advanced Topics in Wireless Networks

Drs. Baruch Awerbuch & Amitabh Mishra

Department of Computer Science

Johns Hopkins University

Reading

- C. K. Toh, Ad Hoc Mobile Wireless Networks, "Chapter 4 – Ad Hoc Wireless Media Protocols", Prentice Hall

- Bob O'Hara and Al Petrick, *IEEE 802.11 Handbook: A Designer's Companion*, IEEE Press, 1999.

- Jochen Schiller, *Mobile Communications*, Section 7.3, Addison-Wesley, 2000.

Further Readings

□ Lots of MAC protocols published in Mobicom, Infocom, Globecom, ICC, Mobihoc, WCNC, VTC, etc.

□ CSMA: L. Kleinrock and F. A. Tobagi, "Packet Switching in Radio Channels: Part I – Carrier Sense Multiple Access Modes and Their Throughput-Delay Characteristics, IEEE Trans. On Communications, Vol. COM-23, No. 12, Dec. 1975, pp. 1400-1416

□ MACA: P. Karn, "MACA – A New Channel Access Protocol for Packet Radio", ARRL/CRRL Amateur Radio 9th Computer Networking Conference, 1990, pp. 134-140.

Further Readings

☐ FAMA: C. L. Fullmer and J. J. Garcia-Luna_Aceves, "Floor Acquisition Multiple Acsess (FAMA) for Packet-Radio Networks", Proceedings of ACM Sigcomm'95, Cambridge, MA, Aug. 1995, pp. 262-273.

☐ MACAW: V. Bharghavan, A. Demers, S. Shenker, and L. Zhang, "MACAW: A Media Access Protocol for Wireless LANs", Proceedings of ACM Sigcomm'94, London, UK, Sept. 1994, pp. 212-225.

☐ IEEE Computer Society LAN/MAN Standards Committee, "Wireless LAN Medium Access Protocol (MAC) and Physical Layer (PHY) Specifications, "IEEE Std. 802.11"

Outline

- Wireless MAC Issues
  - Hidden terminal problem
  - Exposed terminal problem
  - Capture
- MAC Performance Metrics
- Wireless MAC Classification
- Distributed Wireless MAC Protocols
  - Aloha
  - Slotted Aloha
  - CSMA
  - CSMA/CA
  - 802.11 MAC
   - DCF
    - Backoff
  - Hiper Lan MAC

Introduction

□ Multiple access control channels
  ○ Each Mobile Station (MS) is attached to a transmitter / receiver which communicates via a channel shared by other nodes
  ○ Transmission from any MS is received by other MSs in the neighborhood

MS 3

MS 4

MS 2

Shared Multiple Access Medium

MS 1

Node N
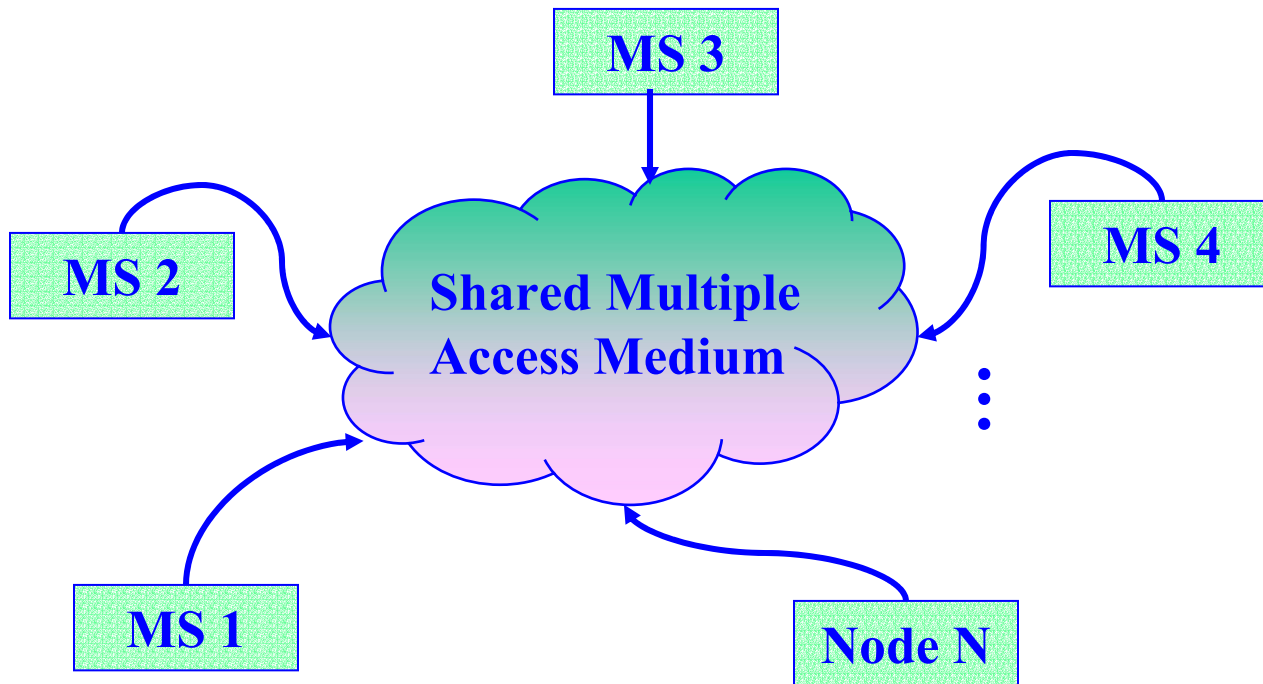
Introduction (Cont'd)

- Multiple access issues
  - Wireless Channel (Wireless medium) is shared among multiple neighboring nodes
  - If more than one MS transmit at a time on the shared media, a collision occurs
 - How to determine which MS can transmit?
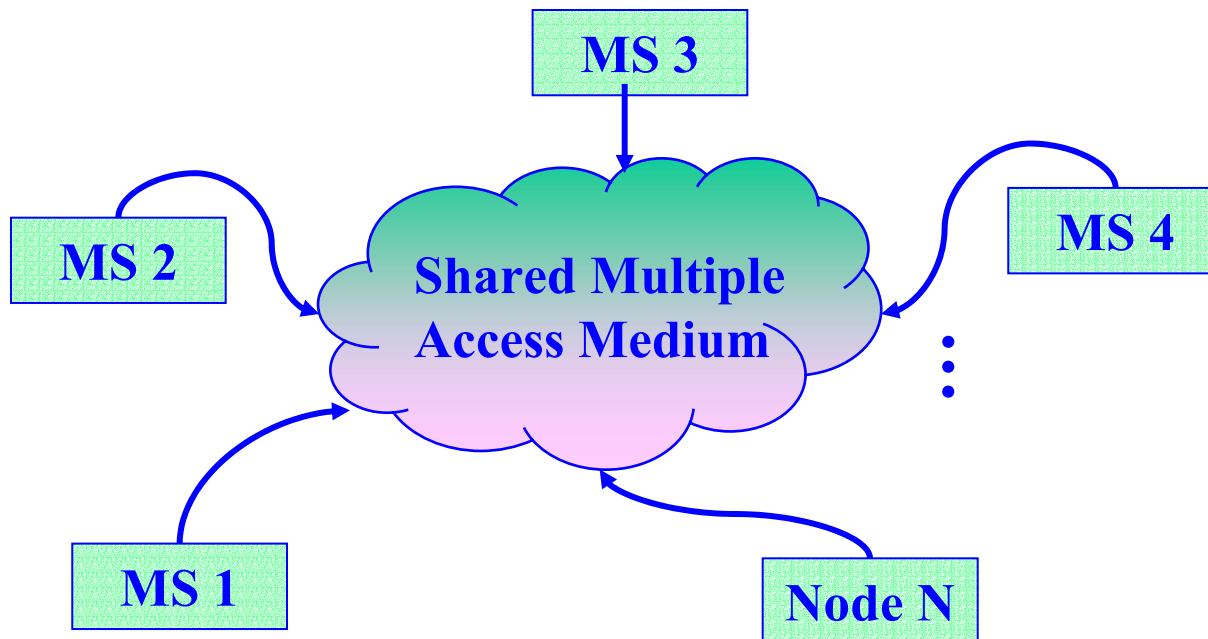
Wireless Medium Access Control – Why?

- Access Control protocols define rules for orderly access to the shared medium
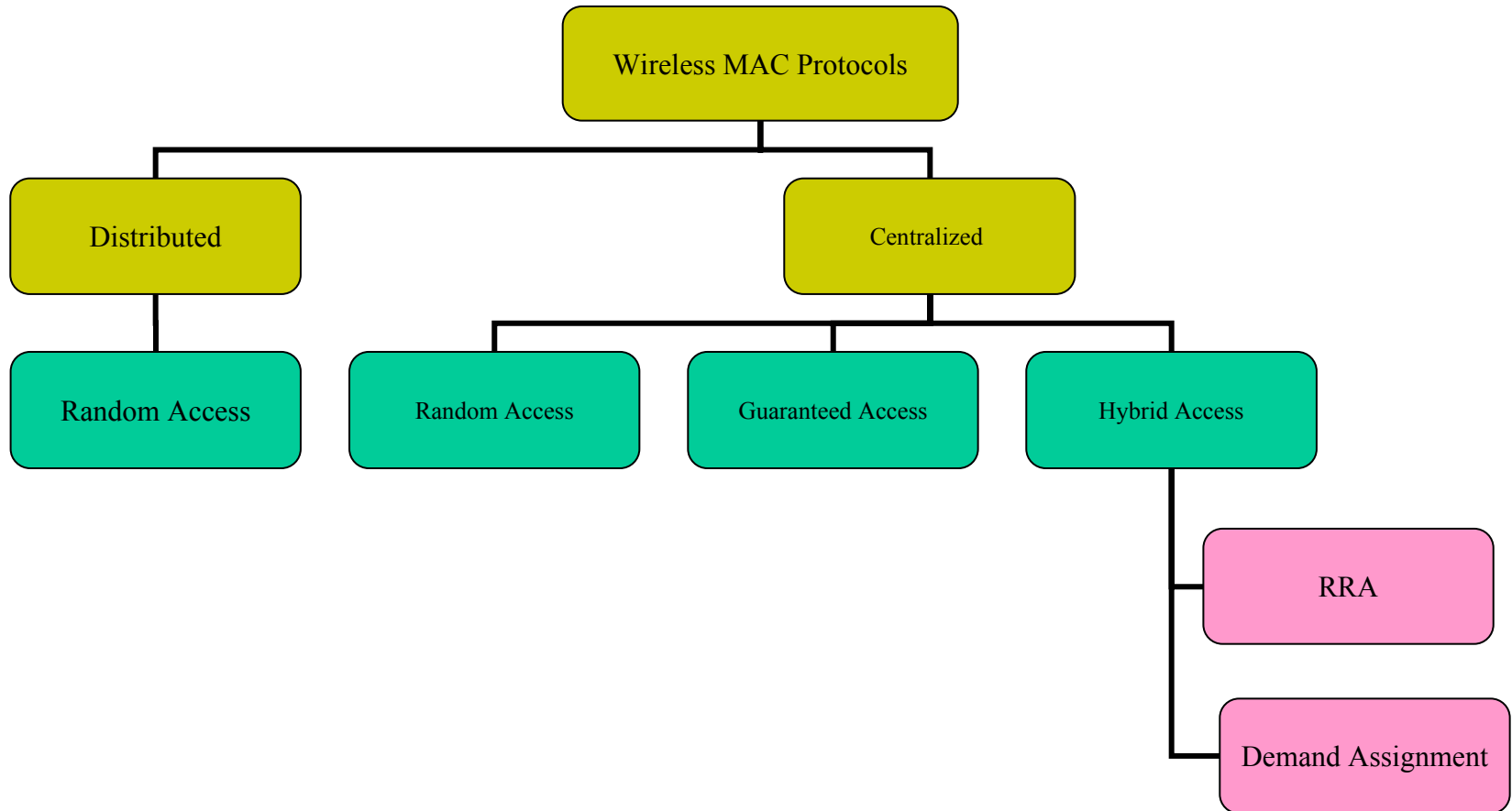 - Fairness in sharing
  - Efficient sharing of bandwidth

- Need to avoid packet collisions at the receiver due to interference
  - Different types:
    - Contention protocols resolve a collision after it occurs or try to avoid it. These protocols execute a collision resolution protocol after each collision
    - Conflict-free protocols (e.g., TDMA, FDMA, CDMA) ensure that a collision can never occur.

- Mobility
- Energy Constraints
- Wireless MACs have been studied heavily since 1970s

Channel Sharing Techniques
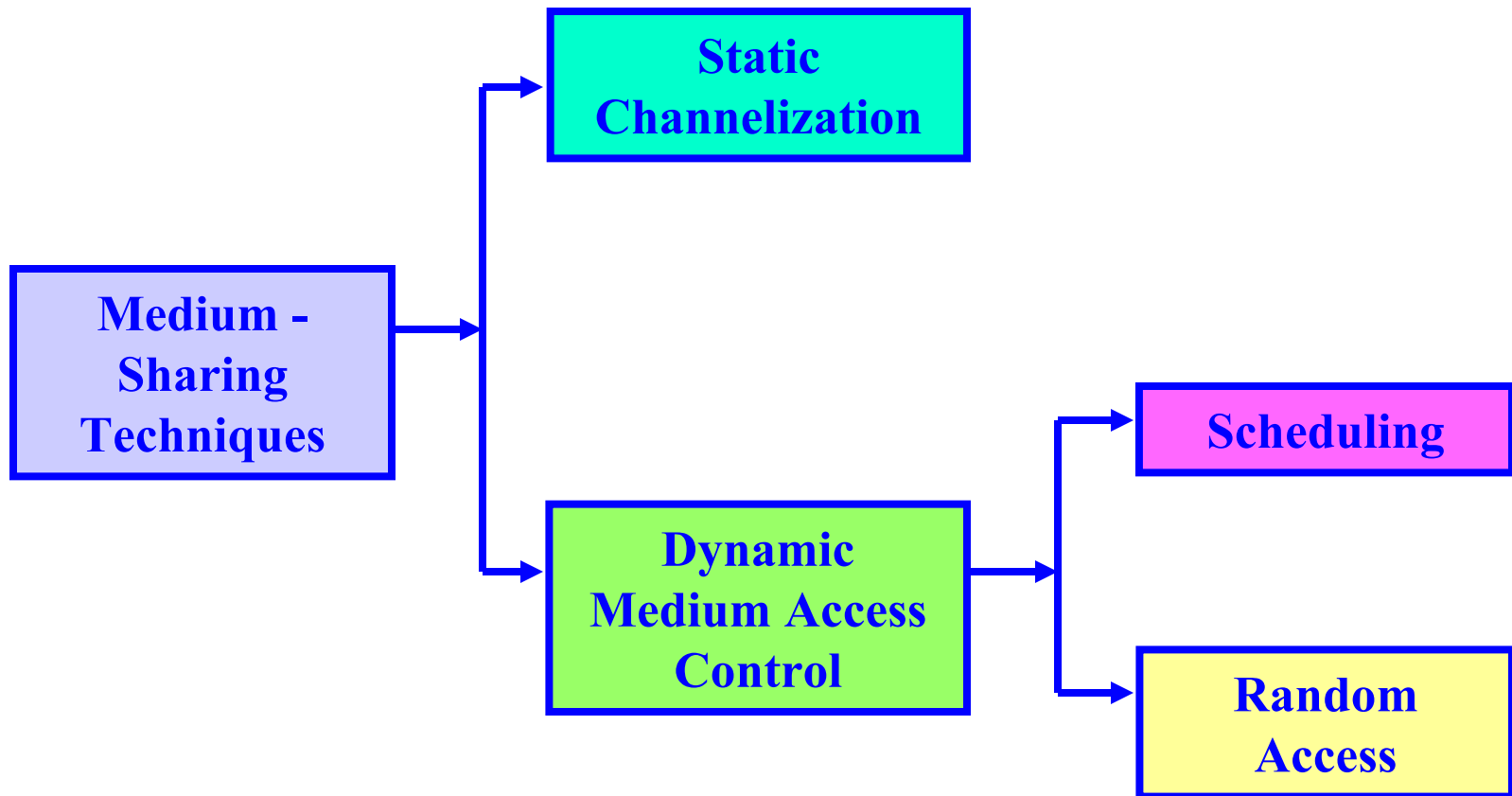
Classification of Wireless MAC Protocols

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                    ┌──────────────────────────┐
                    │  Wireless MAC Protocols  │
                    └──────────────────────────┘
                      │                      │
          ┌───────────────┐          ┌───────────────┐
          │  Distributed  │          │  Centralized  │
          └───────────────┘          └───────────────┘
                  │              ┌──────────┼──────────────┐
       ┌───────────────┐  ┌───────────────┐ ┌──────────────────┐ ┌───────────────┐
       │ Random Access │  │ Random Access │ │ Guaranteed Access│ │ Hybrid Access │
       └───────────────┘  └───────────────┘ └──────────────────┘ └───────────────┘
                                                                         │
                                                                 ┌──────────────┐
                                                                 │     RRA      │
                                                                 └──────────────┘
                                                                 ┌──────────────────┐
                                                                 │ Demand Assignment│
                                                                 └──────────────────┘
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Wireless MAC Issues (1)

□ Wireless medium makes the MAC design more challenging than the wireline networks.

□ The three important issues are:

1. Half Duplex operation –> Either send or receive but not both at a given time
2. Time varying channel
3. Burst channel errors

Wireless MAC Issues (2)

1. Half Duplex Operation

○ In wireless, Its difficult to receive data when the transmitter is sending the data, because:

❑ When node is transmitting, a large fraction of the signal energy leaks into the receiver path

❑ The transmitted and received power levels can differ by orders of magnitude

❑ The leakage signal typically has much higher power than the received signal -> "Impossible to detect a received signal, while transmitting data"

❑ Collision detection is not possible, while sending data

– CSMA/CD (Ethernet MAC) cannot be used as it is

Wireless MAC Issues (3)

□ Half Duplex Operation (Contd.)

   ○ As collision cannot be detected by the sender, all proposed protocols attempt to minimize the probability of collision -> Focus on collision avoidance

Wireless MAC Issues (4)

2. Time Varying Channel

- Three mechanisms for radio signal propagation (T. Rappaport's book)
  - Reflection – occurs when a propagating wave impinges upon an object that has very large dimensions than the wavelength of the radio wave e.g. reflection occurs from the surface of the earth and from buildings and walls
  - Diffraction – occurs when the radio path between the transmitter and the receiver is obstructed by a surface with sharp edges
  - Scattering – occurs when the medium through which the wave travels consists of objects with dimensions smaller than the wavelength of the wave

Wireless MAC Issues (5)

2. Time Varying Channel (Contd.)

- The received signal by a node is a superposition of time-shifted and attenuated versions of the transmitted signals → The received signal varies with time

- The time varying signals (time varying channel) phenomenon → also known as multipath propagation

- The rate of variation of channel is determined by the coherence time of the channel
  - Coherence time is defined as time within which the received signal strength changes by 3 dB

Wireless MAC Issues (6)

2. Time Varying Channel (Contd.)

- When a node's received signal strength drops below a certain threshold the node is said to be in fade

- Handshaking is widely used strategy to ensure the link quality is good enough for data communication

- A successful handshake between a sender and a receiver (small message) indicates a good communication link

Wireless MAC Issues (7)

3. Burst Channel Errors

- As a consequence of time varying channel and varying signals strengths → errors are introduced in the transmission (Very likely)
- For wireline networks the bit error rate (BER) is typically 10^{-6} i.e. the probability of packet error is small
- For wireline networks the errors are due to random noise
- For wireless networks the BER is as high as 10^{-3}
- For wireless networks the errors are due to node being in fade as a result errors occur in a long burst
- Packet loss due to burst errors - mitigation techniques
    - » Smaller packets
    - » Forward Error Correcting Codes
    - » Retransmissions (Acks)

Location Dependent Carrier Sensing

☐ In free space signal decays with the square of distance

- Implication is that the carrier sensing becomes a function of the position of the receiver relative to the transmitter

- In wireless medium due to multi-path propagation, the signal strength decays according to a power law with distance

  ❑ Only nodes within a specific radius of the transmitter can detect the carrier on the channel
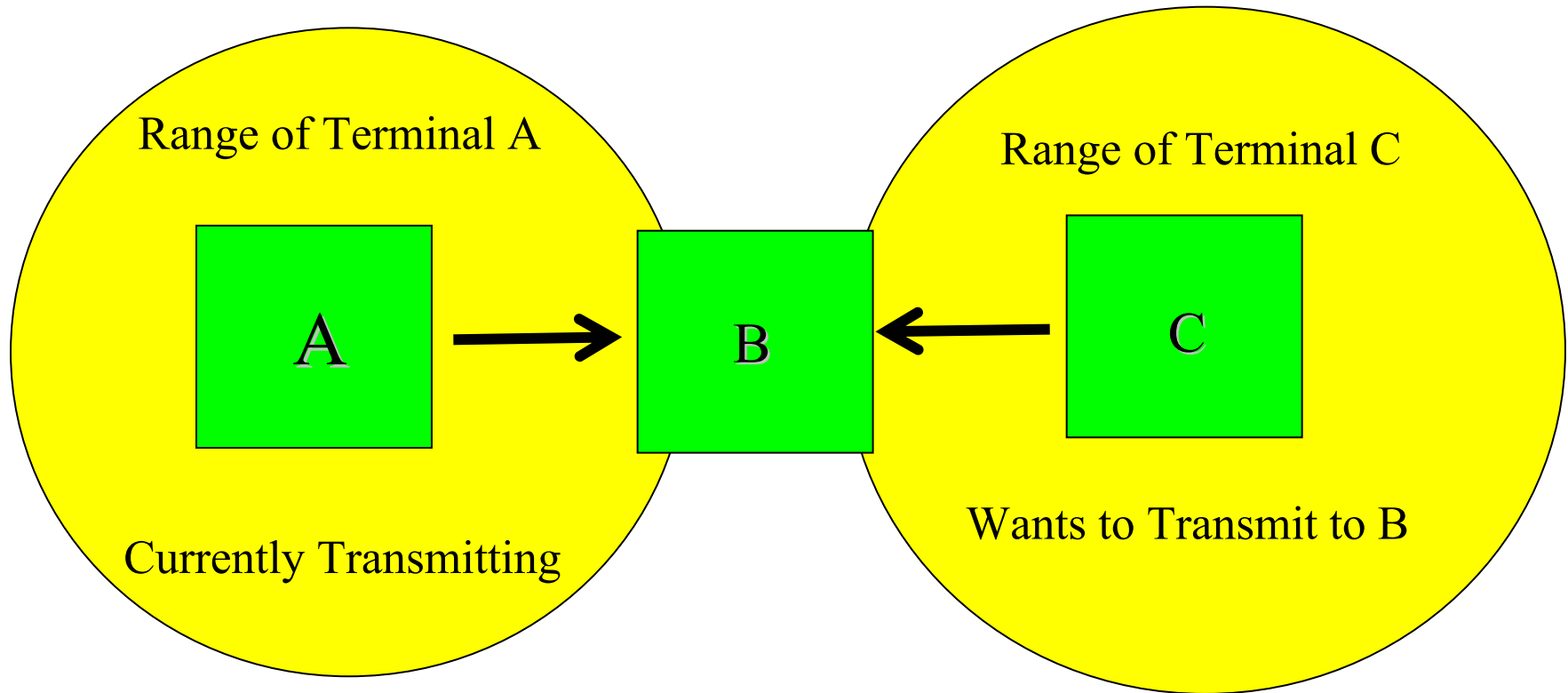
Location Dependent Carrier Sensing

☐ Location Dependent Carrier Sensing results in three types of nodes that protocols need to deal with:

☐ Hidden Nodes

   ○ Even if the medium is free near the transmitter, it may not be free near the intended receiver

☐ Exposed Nodes

   ○ Even if the medium is busy near the transmitter, it may be free near the intended receiver

☐ Capture

   ○ Capture occurs when a receiver can cleanly receive a transmission from one of two simultaneous transmissions

Hidden Node/Terminal Problem

- A hidden node is one that is within the range of the intended destination but out of range of sender
- Node B can communicate with A and C both
- A and C cannot hear each other
- When A transmits to B, C cannot detect the transmission using the *carrier sense* mechanism → C falsely thinks that the channel is idle
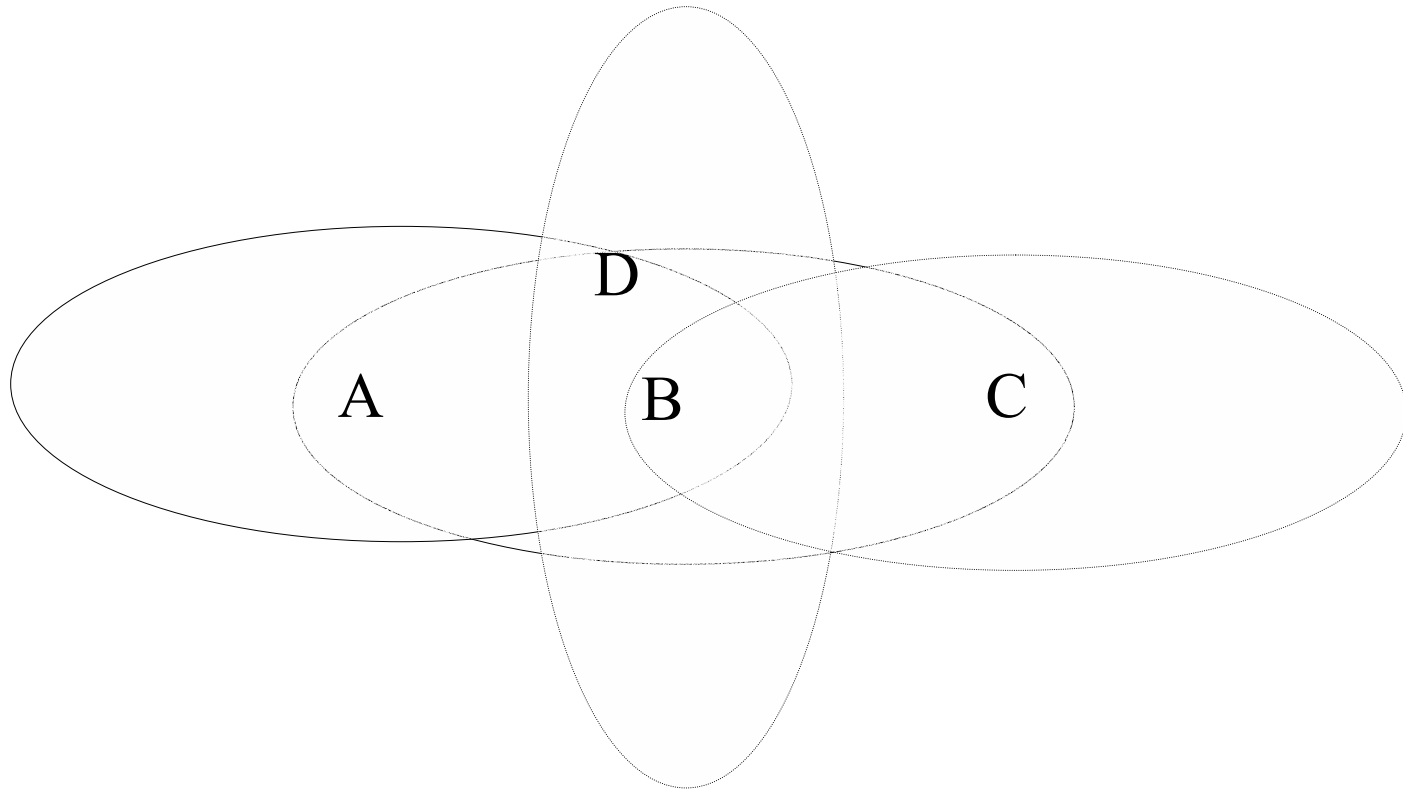- If C transmits, collision will occur at node B

A —— B —— C

Hidden Node Problem

Range of Terminal A

Range of Terminal C

A → B ← C

Currently Transmitting
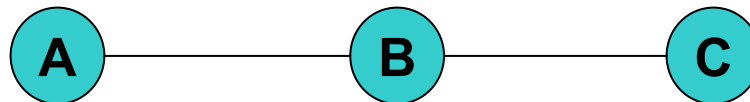
Wants to Transmit to B

Will collide with Transmission from A at B

Exposed Nodes

• An exposed node is one that is within the range of the sender but out of range of destination
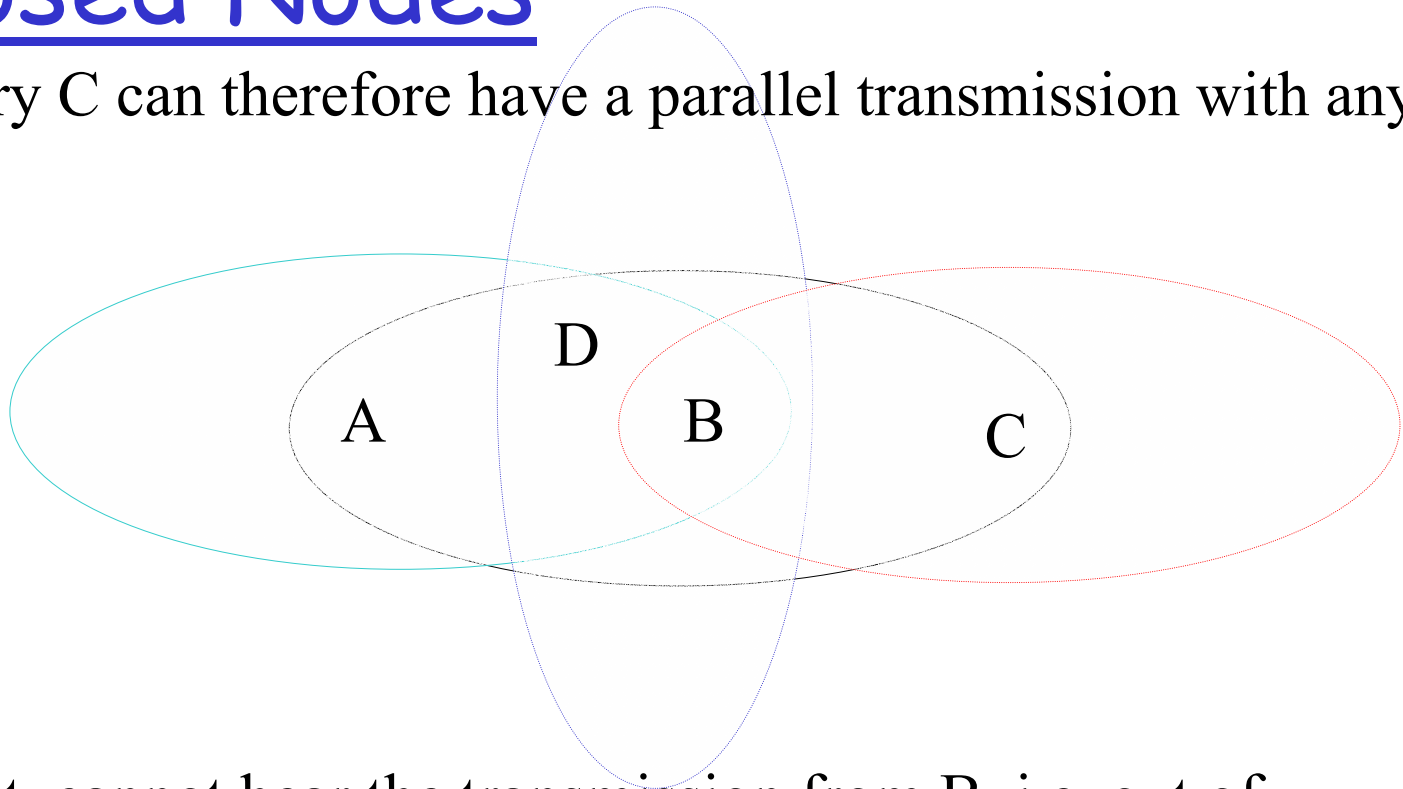
Exposed Nodes

1. Consider the case that node B is attempting to transmit to A
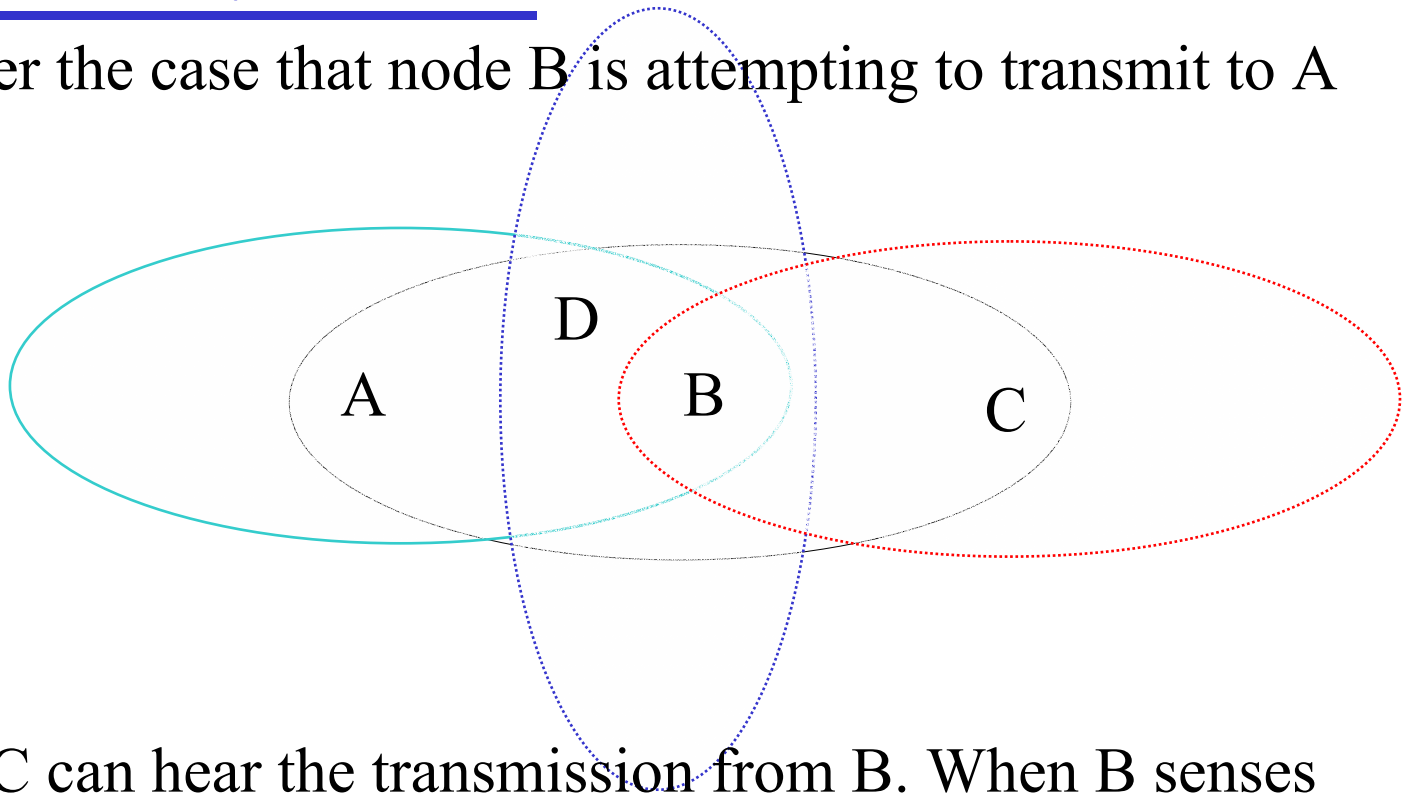
2. Node C can hear the transmission from B. When B senses the channel it finds the channel to be busy.

3. However, any transmission by C cannot reach A (not in range), hence does not interfere with any reception at A.
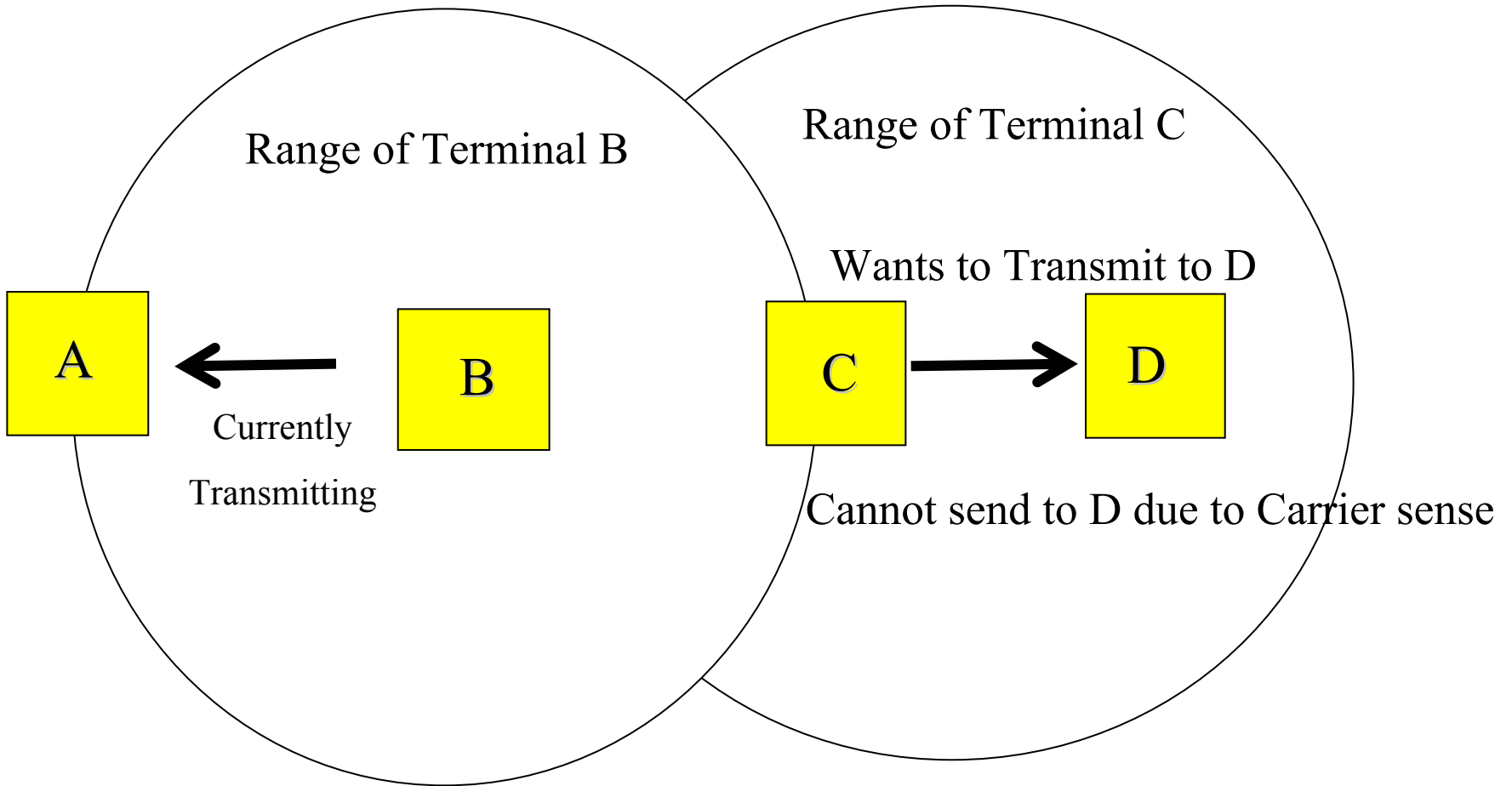
Exposed Nodes

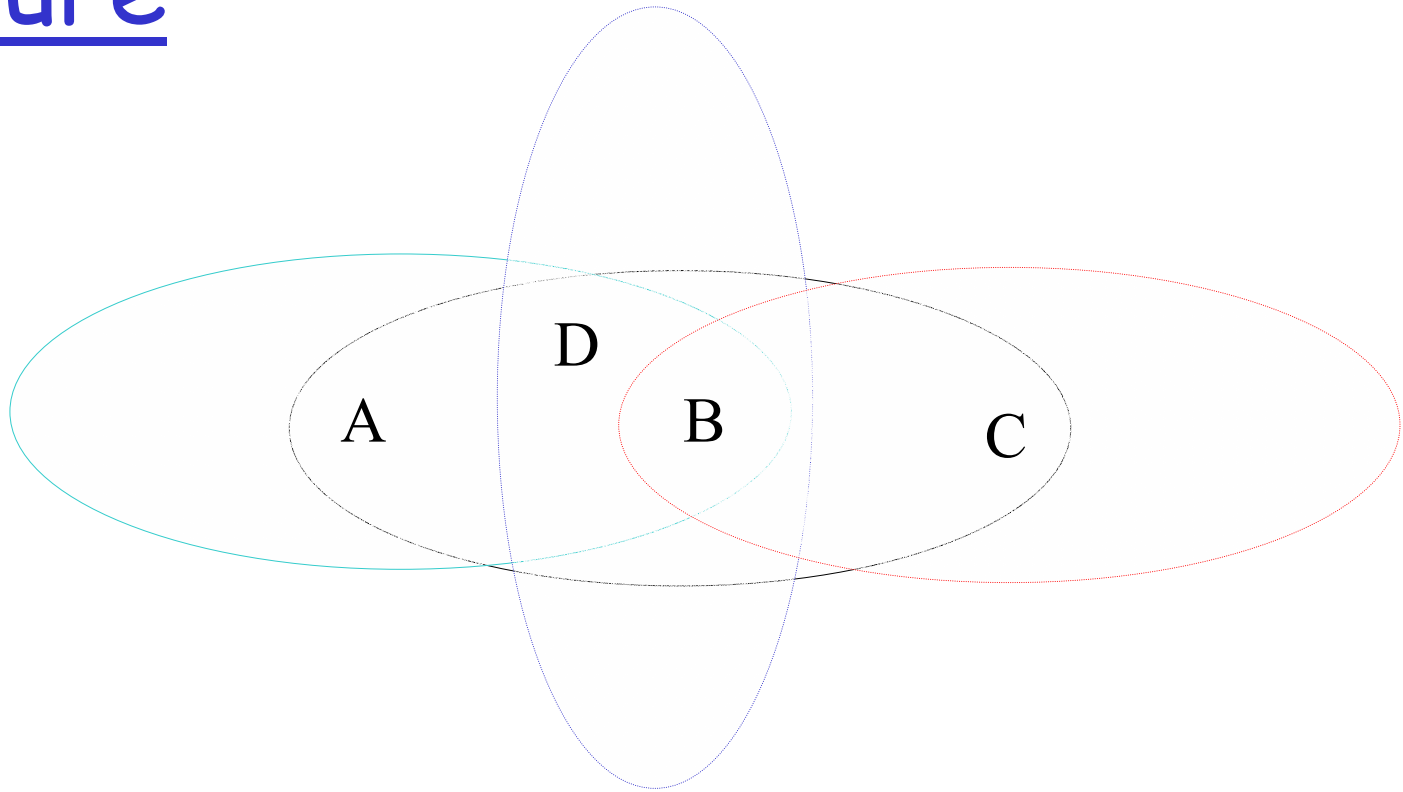4. In theory C can therefore have a parallel transmission with any

node that cannot hear the transmission from B, i.e. out of range of B.

5. But C will not transmit to any node because its an exposed node. Exposed nodes waste bandwidth.

Exposed Terminal Problem

Range of Terminal B

Range of Terminal C

Wants to Transmit to D

| A | ← | B | | C | → | D |

Currently

Transmitting
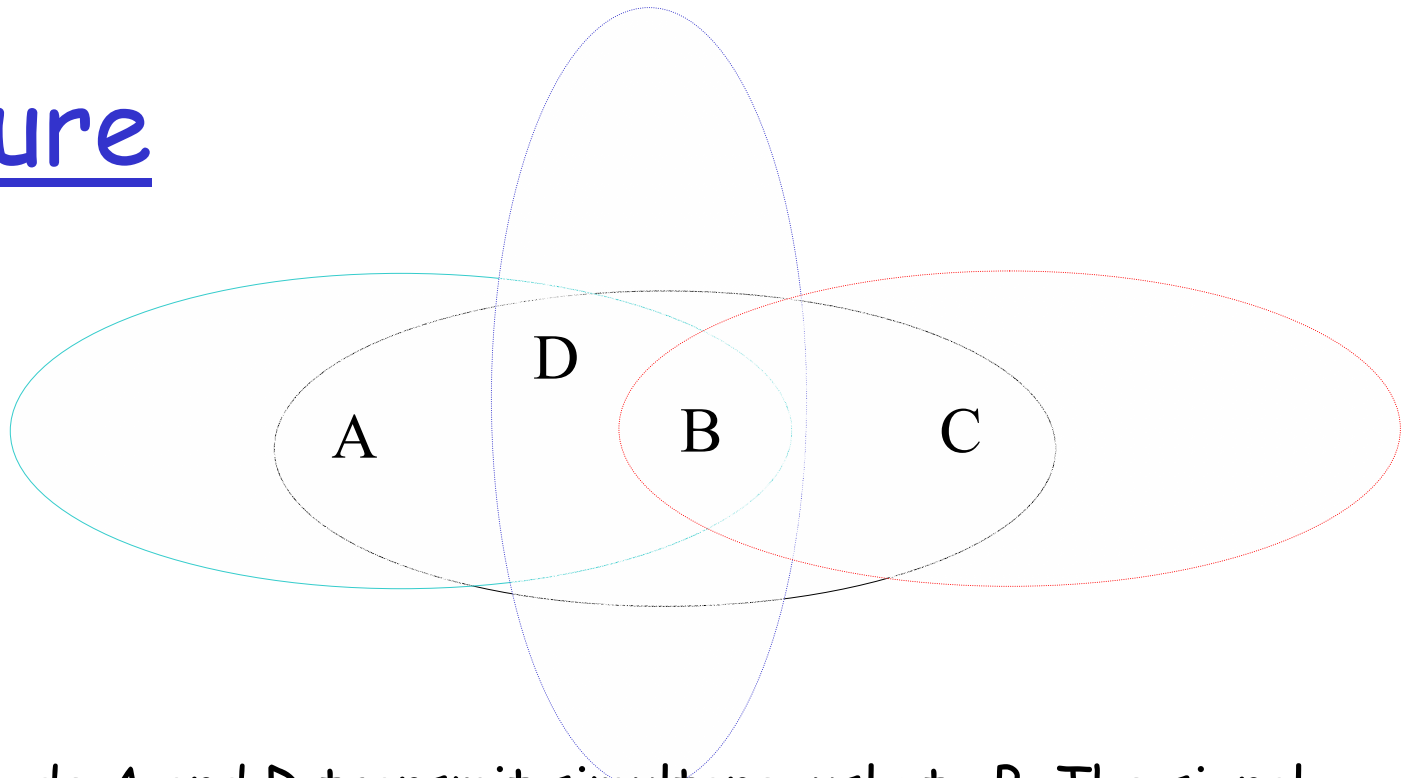
Cannot send to D due to Carrier sense

Capture

□ Capture is said to occur when a receiver can cleanly receive a transmission from one of two simultaneous transmissions both within its range

Capture

D

A B C

❒ Assume node A and D transmit simultaneously to B. The signal strength received from D is much higher than that from A, and D's transmission can be decoded without errors in presence of transmissions from A.

❒ D has captured A

❒ Capture is unfair because it gives preference to nodes that are closer to the receiver

❒ It may improve protocol performance

Capture - Example
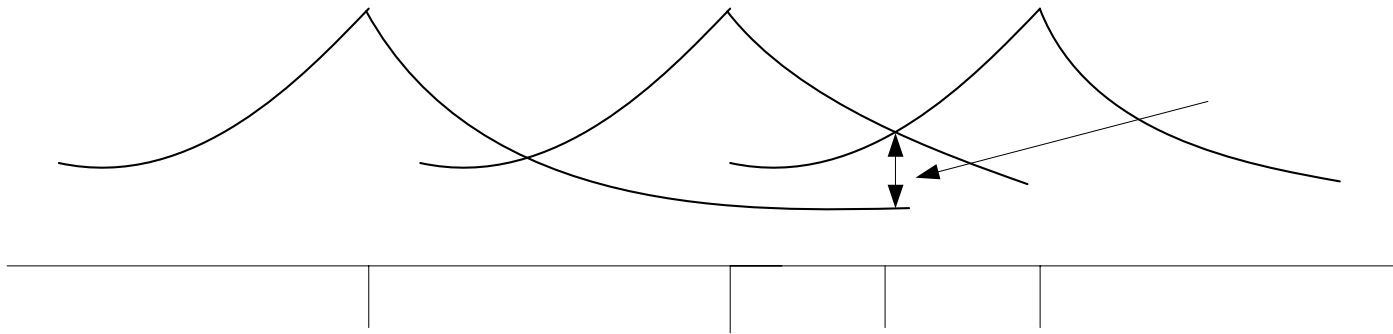
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MAC Performance Metrics

□ There are hundreds of MAC protocols proposed for wireless networks.

□ We need performance metrics so that we can compare one protocol from the other

□ The key metrics are:
  ○ Delay
  ○ Throughput
  ○ Fairness
  ○ Stability
  ○ Robustness against channel fading
  ○ Power Consumption
  ○ Support for multimedia

MAC Performance Metrics

□ **Delay**

  ○ Defined as the average time spent by a packet in the MAC queue, i.e. from the instant it is en-queued till its transmission is complete

  ○ Sensitive to traffic characteristics, so two MAC protocols should be compared under identical traffic conditions

□ **Throughput**

  ○ Fraction of channel capacity used for data transmissions

  ○ MAC need to maximize throughput while keeping the access delay to minimum

MAC Performance Metrics

□ For a P bits message size, on a channel of capacity C bits/sec, T seconds are elapsed,

□ So throughput of the channel is

$$\eta = \frac{P}{TC}$$

□ **Fairness**

○ When all nodes are treated equally, and no node is given preference
  ❑ Leads to fair sharing of bandwidth
  ❑ Traffic with different priorities can bias this definition

○ For multimedia traffic, usually the MAC is considered fair when (voice, data, video) get their allocated bandwidth

MAC Performance Metrics

□ **Stability**
- System need to be stable if instantaneously high load is seen by the MAC

□ **Robustness against channel fading**
- Wireless channel is time varying and error prone
- Fading may make channel unusable for short durations
- MAC needs to work reliably while channel in fade

□ **Power Consumption**
- Wireless nodes have limited battery power -> MAC should conserve energy

MAC Performance Metrics

□ **Support for multimedia**

   ○ MAC should support multimedia applications (voice, video, data)

   ○ Multimedia data implies data with real-time constraints

   ○ By using priorities and scheduling – delay can be controlled and/or guaranteed