Chapter 3:
Relay-Based Multi-Rate MAC Protocol

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Outline

- Background

- Related Work

- Motivation

- "rDCF: A Relay-enabled Medium Access Control Protocol for Wireless Ad Hoc Networks", IEEE Trans. on Mobile Computing, Sep. 06.

- "A Relay-Aided Media Access (RAMA) Protocol in Multirate Wireless Networks", IEEE Trans. On Vehicular Technology, Sep. 06.

- Conclusion

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Background

- The IEEE 802.11 standard supports multiple data rates at PHY layer.
  - 802.11a: 6, 9, 12, 18, 24, 36, 48, 54 Mbps
  - 802.11b: 1, 2, 5.5, 11 Mbps
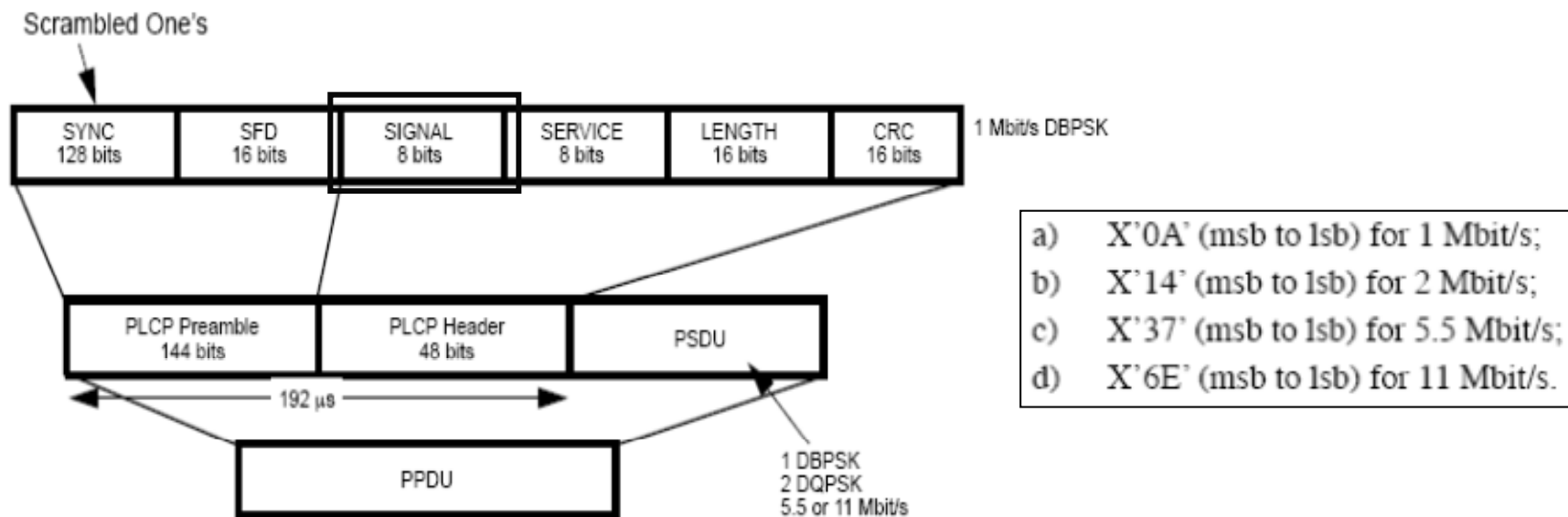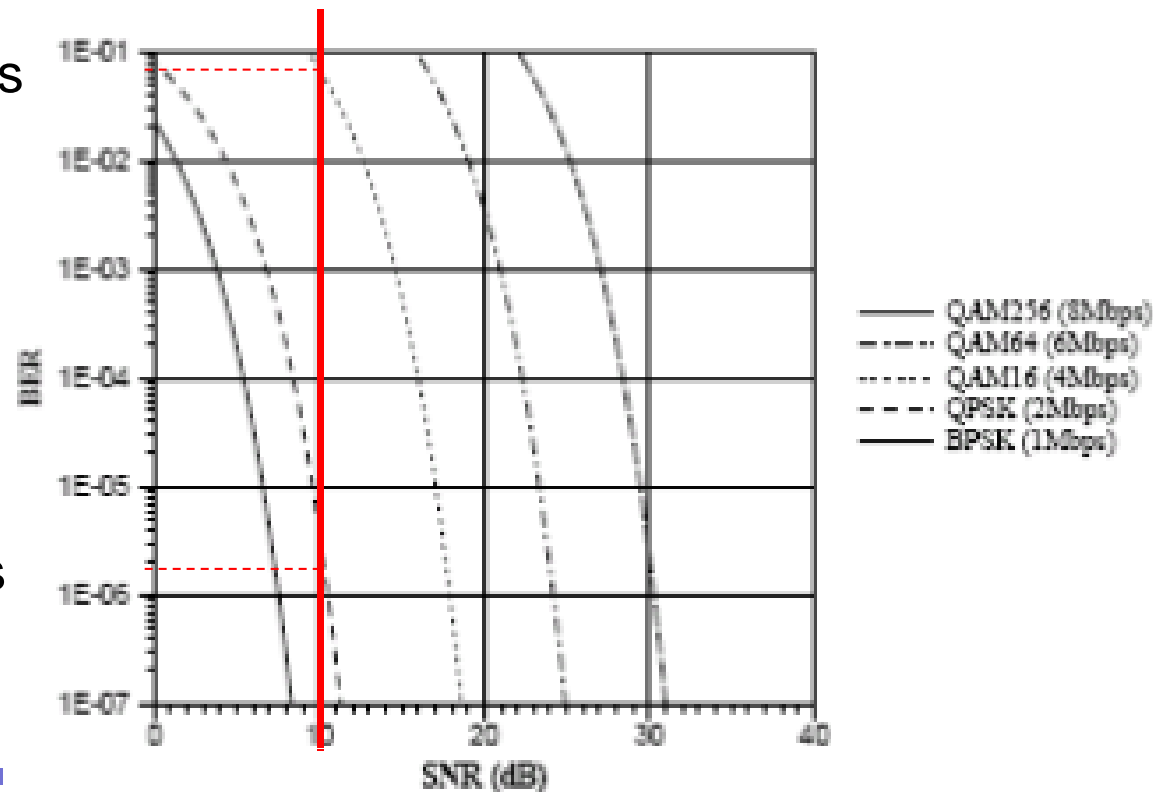 - 802.11g: 1, 2, 5.5, 6, 9, 11, 12, 18, 24, 33, 36, 48, 54 Mbps

Figure 127—Long PLCP PPDU format
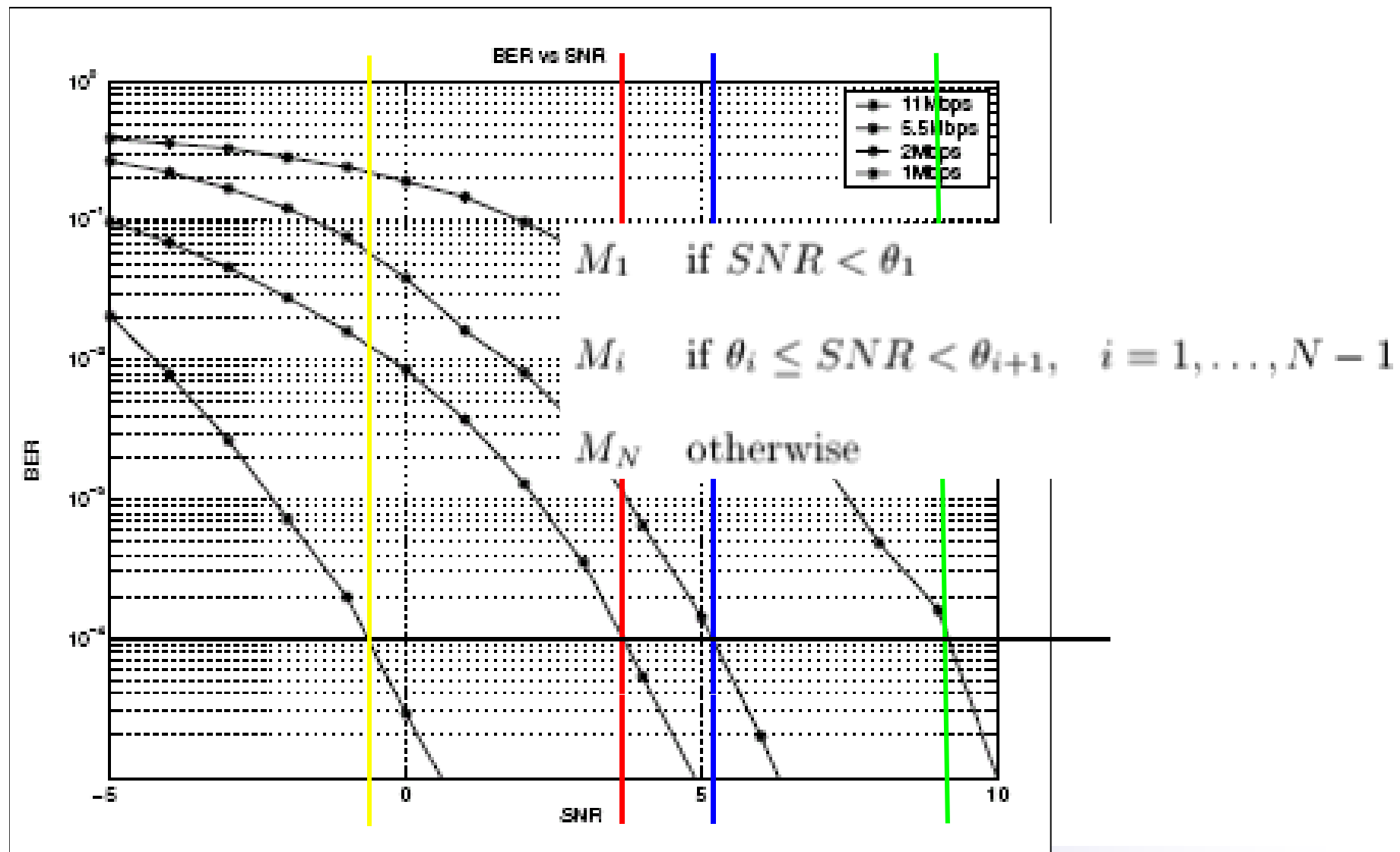
Modulation Scheme V.S. SNR and BER

- Path loss, fading, and interference cause variations in the received signal-to-noise (SNR) radio

- Fixed SNR
  - The higher bit rate modulation, the higher BER (bit error ratio)

QAM16 4Mbps

QPSK 2Mbps

How to Choose the Bit Rate

$$M_1 \quad \text{if } SNR < \theta_1$$

$$M_i \quad \text{if } \theta_i \leq SNR < \theta_{i+1}, \quad i = 1, \ldots, N-1$$

$$M_N \quad \text{otherwise}$$

Background

- A higher data rate modulation scheme requires higher signal-to-noise ratio (SNR)

- The relationship between transmission time and data rate modulation

  - Transmission time requires T if exploiting R data rate modulation
 - Transmission time requires T/2 if exploiting 2R data rate modulation

R data rate Modulation
T

A   DATA

B

2R data rate Modulation
T/2

A   DATA

B
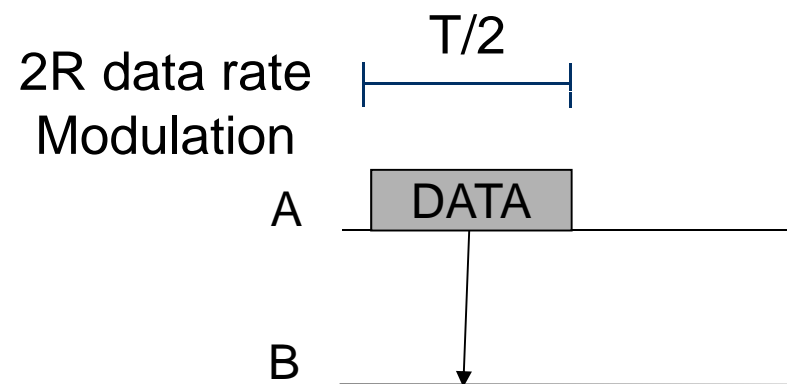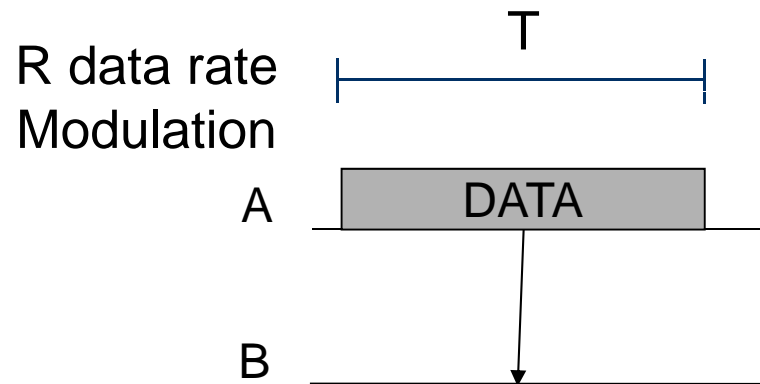
Background

- **Transmission range**
  - A node can receive and correctly decode packets.
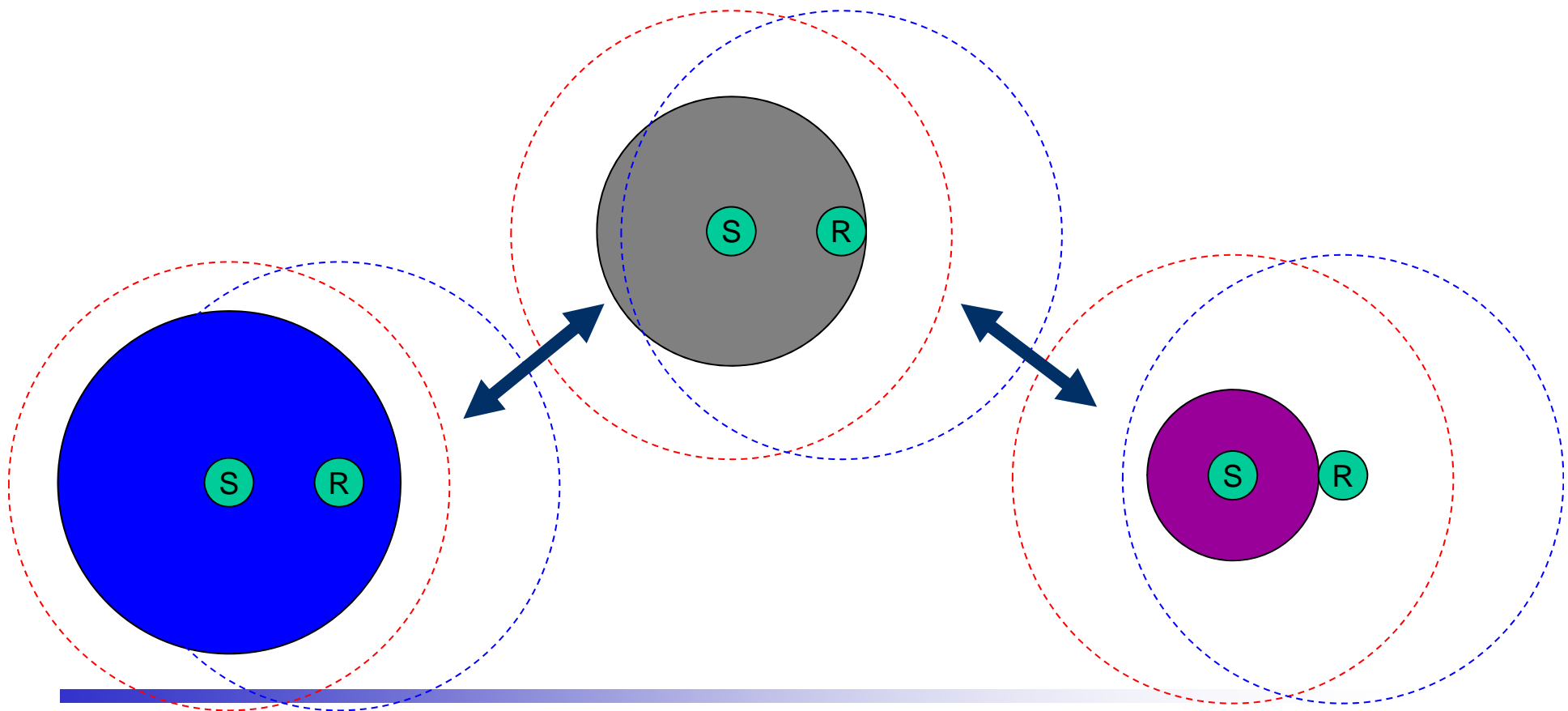 - Transmission range is in inverse proportion to data rate modulation.

- **Carrier sensing zone**
 - A node can sense the signal but cannot decode it correctly.

Transmission range

S

Carrier sensing zone
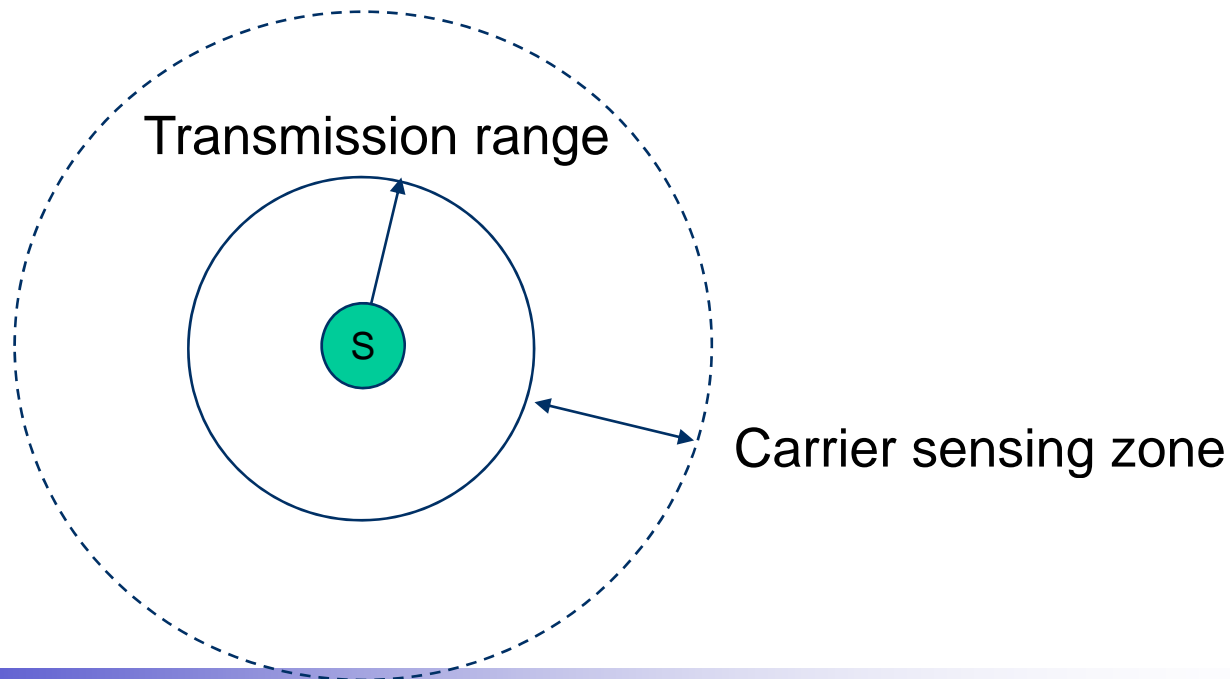
Related Work: ARF

■ *A. Kamerman, L. Monteban.* "**WaveLAN-II: A high-performance wireless LAN for the unlicensed band**", Bell Labs Tech. Journal, 97 Summer.
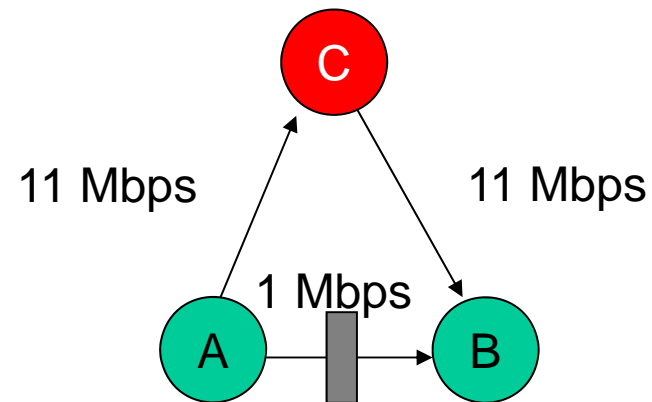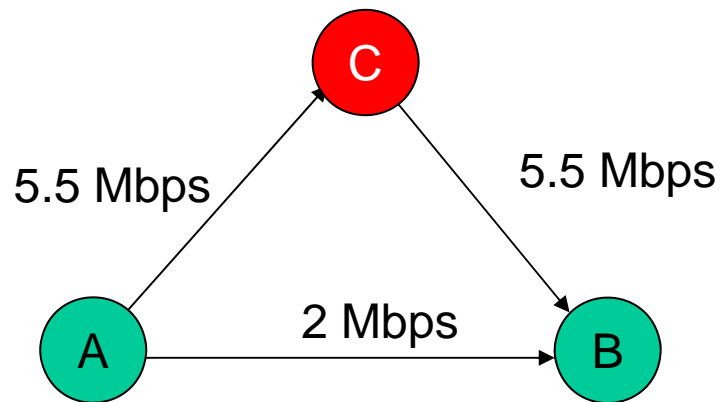
Related Work: **RBAR**

- *G. Holland, N. Vaidya, P. Bahl*, "**A Rate-Adaptive MAC Protocol for Multi-Hop Wireless Networks**", ACM Mobicom 01.

CTS Frame
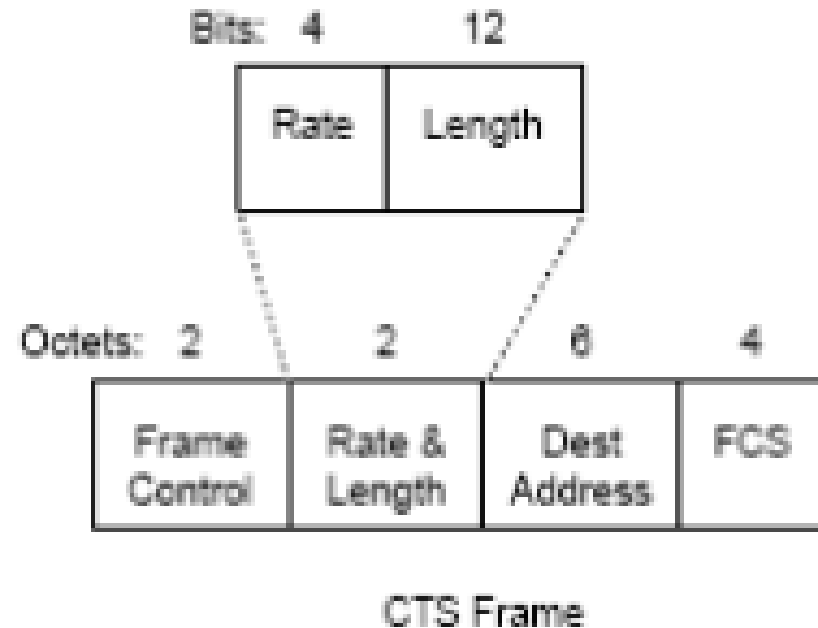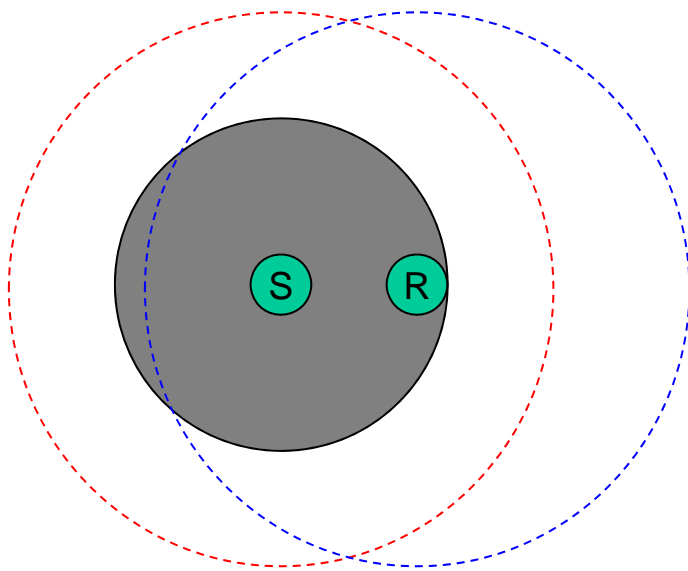
Motivation

- A lower rate link can be replaced by two higher rate links.
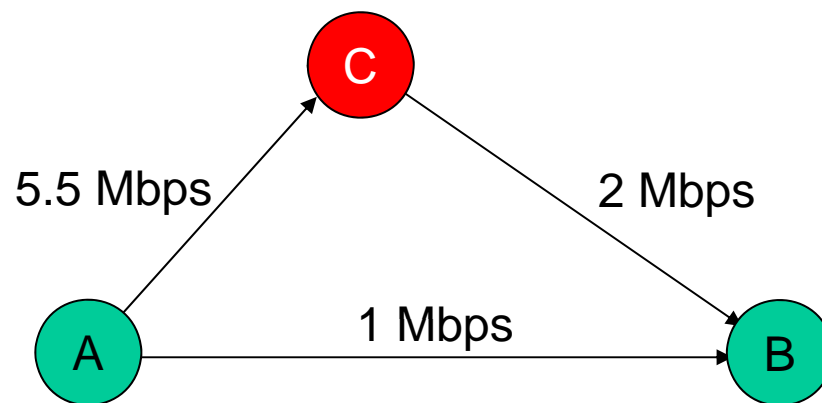   - $T_{AC} + T_{CB} < T_{AB}$

Relay-based Multi-rate MAC Protocol Process

- **Relay node discovery**
  - ❑ Let A know that a relay node C which exists between A and B can help A transmitting to B via C.
- **Relay-based transmission**
  - ❑ A sends data to B via C if $T_{AC} + T_{CB} < T_{AB}$
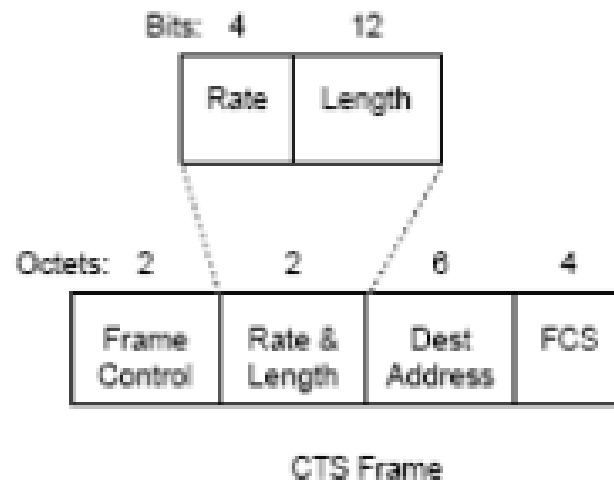

5.5 Mbps

2 Mbps

1 Mbps

rDCF, IEEE Trans. on Mobile Computing, Sept. 06

- **Assumption**
  - Each node transmits its packets using a constant transmission power.
 - The wireless channel between the sender and the receiver is to be almost symmetric.

- **Based on RBAR**
  - Receiver notifies the sender of the transmission rate via CTS


CTS Frame

rDCF (Relay node discovery)

- **C** measures channel quality for a given flow between a pair of sender and receiver.
  - ❑ C obtains R_{AB} by extracting the piggybacked transmission rate in the CTS.
  - ❑ C estimates RTS and CTS to acquire R_{AC} and R_{CB}.

  if satisfying relay condition
  - ❑ Adding the identity of A and B into its willing list.
  - ❑ Periodically advertising its willing list to its neighbors
- **A adds C into its relay table**
  - ❑ If finding that A -> B is in the willing list of C.

5.5 Mbps   C   2 Mbps

A   1 Mbps   B
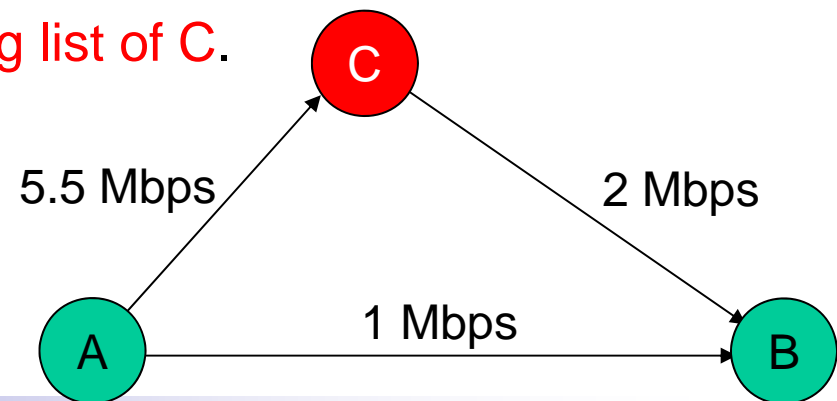
rDCF (Relay Transmission) (Decision of B)

- **A** don't find a relay node
  - RBAR

- **A** finds a relay node
  1. **A** broadcasts **RRTS1** (**C** estimates R_{AC})
  2. **C** broadcasts **RRTS2** (carry R_{AC}, **B** estimates R_{CB})
  3. if the packet can't be transmitted faster with relay

      B broadcasts **CTS** (carry R_{AB})

   else

      B broadcasts **RCTS** (carry R_{CB})
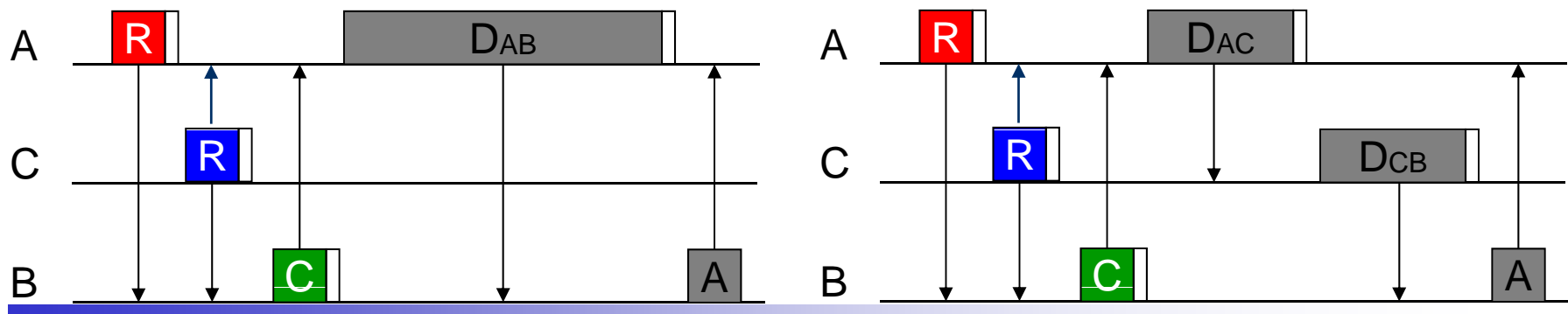
rDCF (How to Choose One of Relay Nodes)

- The channel condition may change frequently in wireless networks.
  - Relay node may suffer hidden terminal.
- Each relay node in the relay table of A
  - Be associated with a credit ranging [0.0, 1.0]
- A chooses the one with the largest credit
  - Generating a random number in [0.0, 1.0]
    - If random number >= credit

            A does rDCF

            if rDCF is success

                    the credit of C is increased

            else if rDCF is failed

                    the credit of C is decreased

        else if random number < credit

            A does RBAR

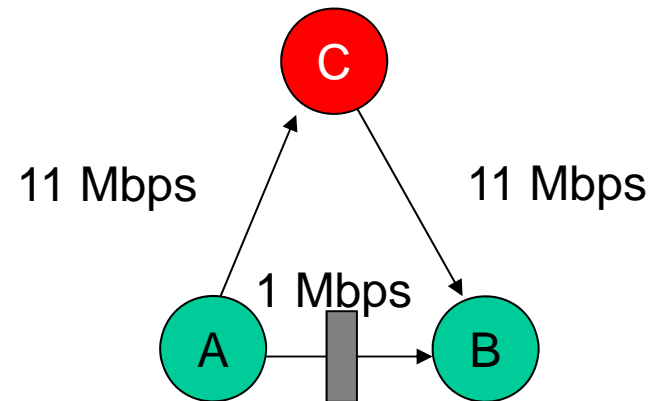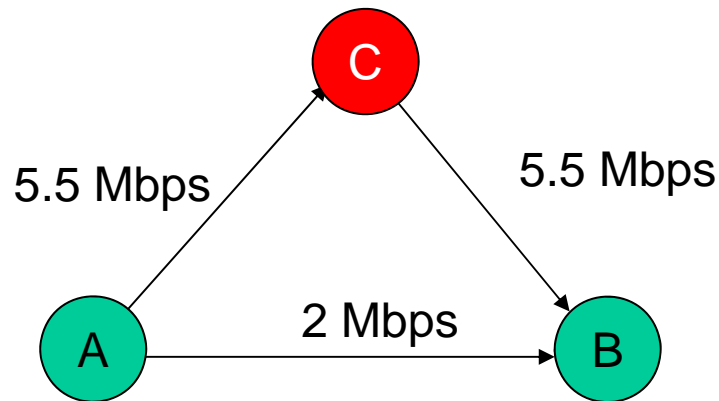# Carrier Sensing Zone Analysis

■ Increased sensing zone is small

| d (meters)	210	220	230	240	250
Upper bound of increased sensing area (%)	11.5	10.5	9.2	8.2	7.2
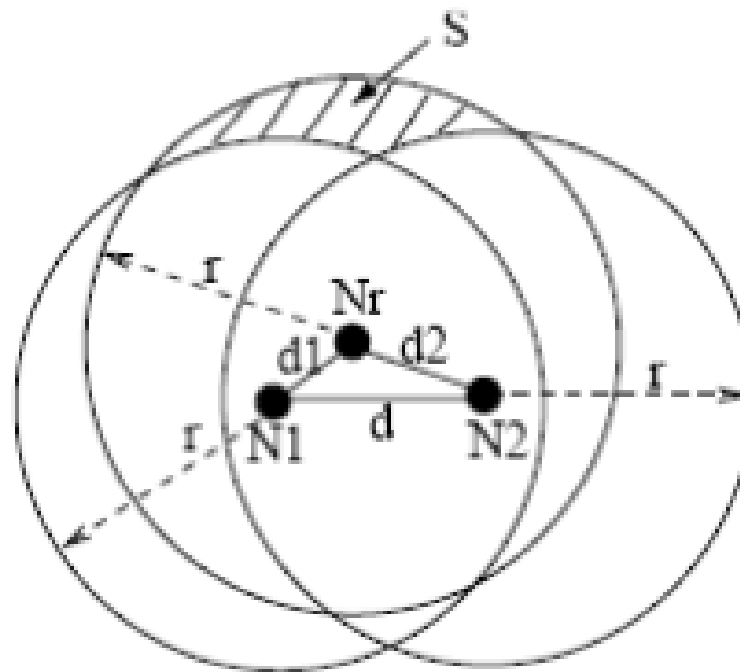
■ **Assumption**

❑ In DCF, each node must transmit with the same power.

❑ Channel gain between the two nodes is the same in both directions. Based on RBAR

RAMA (Relay node discovery)

- C obtains R_{AB} from PHY header of $DATA_{AB}$.
- C estimates $DATA_{AB}$ and ACK to acquire R_{AC} and R_{CB}.

  if satisfying relay condition

  C will broadcast an invitation frame to A

  – Source, Relay, Destination, R_{AC} and R_{CB}
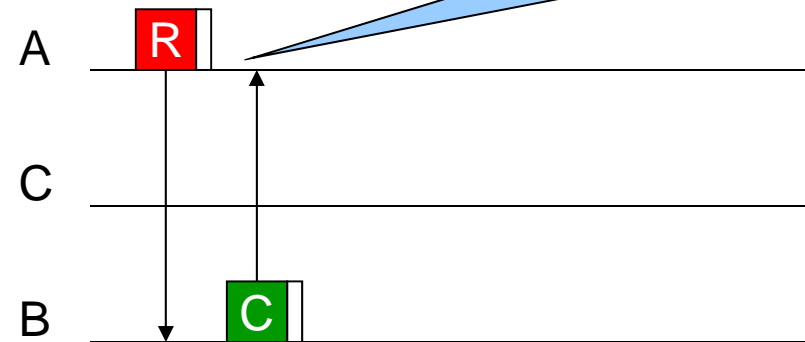
- A will record it in Relay List.

5.5 Mbps   2 Mbps

1 Mbps
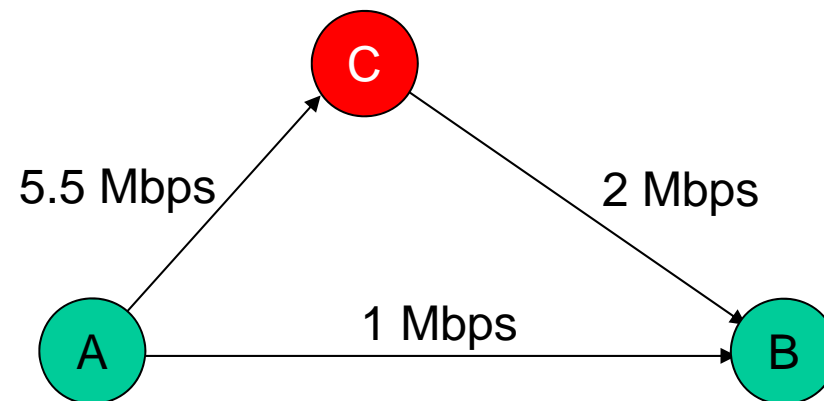
RAMA (Relay Transmission) (Decision of A)
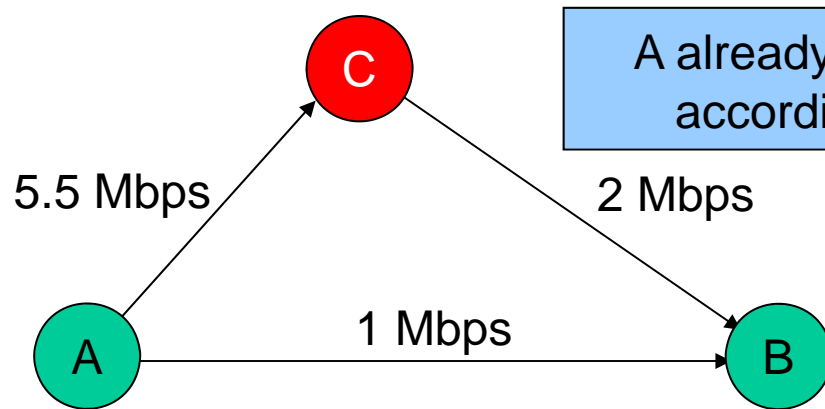
A already has R_{AC} and R_{CB} according to Relay List

A knows R_{AB}

5.5 Mbps

2 Mbps

1 Mbps

Relay List:
Source, Relay, Destination, R_{AC} and R_{CB}

Case 1

A   R D_{AB}

C

B   C   A

Case 2

A   R D_{AC}

C D_{CB}

B   C   A
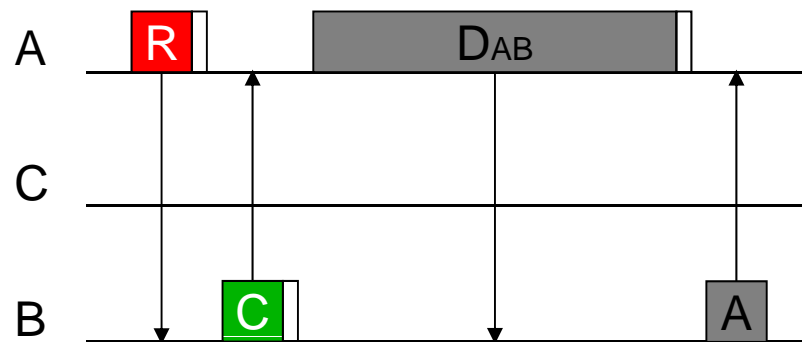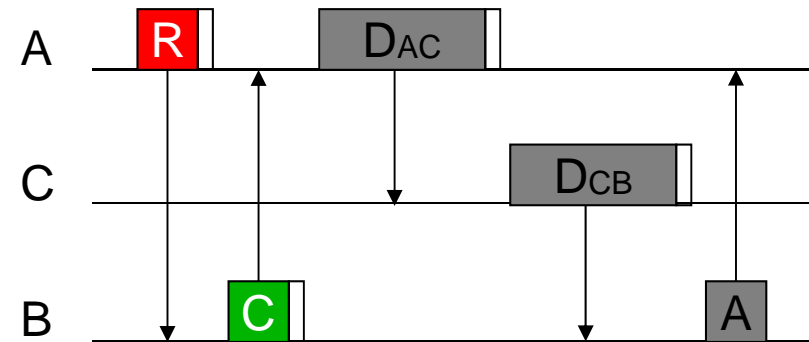
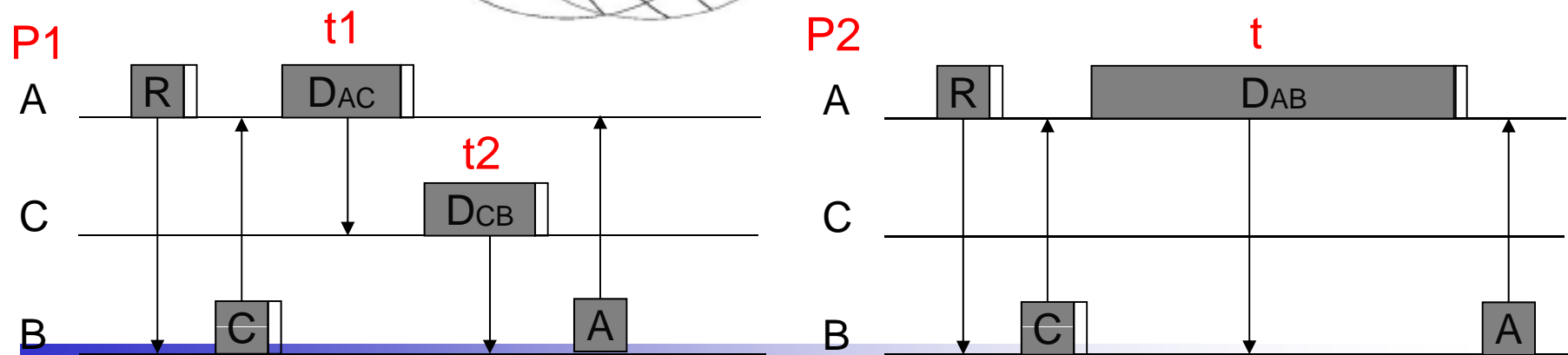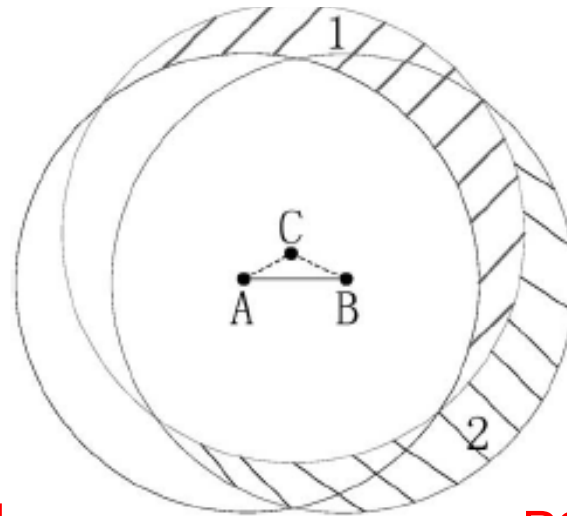# Carrier Sensing Zone Analysis

$a_1 < a$ and $a_2 < a$ because $d_{AC} < d_{AB}$ and $d_{CB} < d_{AB}$

$t_1 + t_2 < t$ $\qquad p_1 = e^{-a_1 \lambda t_1} \times e^{-a_2 \lambda t_2} > p_2 = e^{-a \lambda t}$

Summary

- According to the channel condition, data can transmitted with different data rate modulation.

- Multi-rate transmission vs. single-rate transmission
  - Increasing overall throughput
  - Decreasing transmission time

- Data also may be delivered faster through a relay node than through the direct link if the direct link has low quality and low data rate.
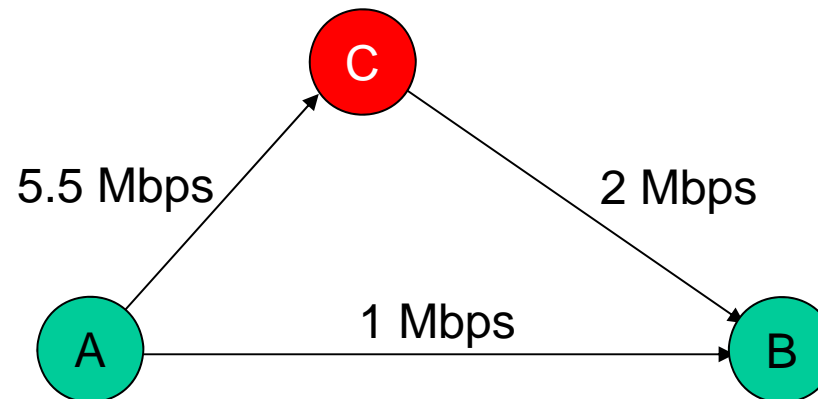
Homework #3:

1. What's relay-based multi-rate MAC protocol ?
2. What's the difference between rDCF and RAMA protocols ?