Chapter 3: Relay-Based Multi-Rate MAC Protocol

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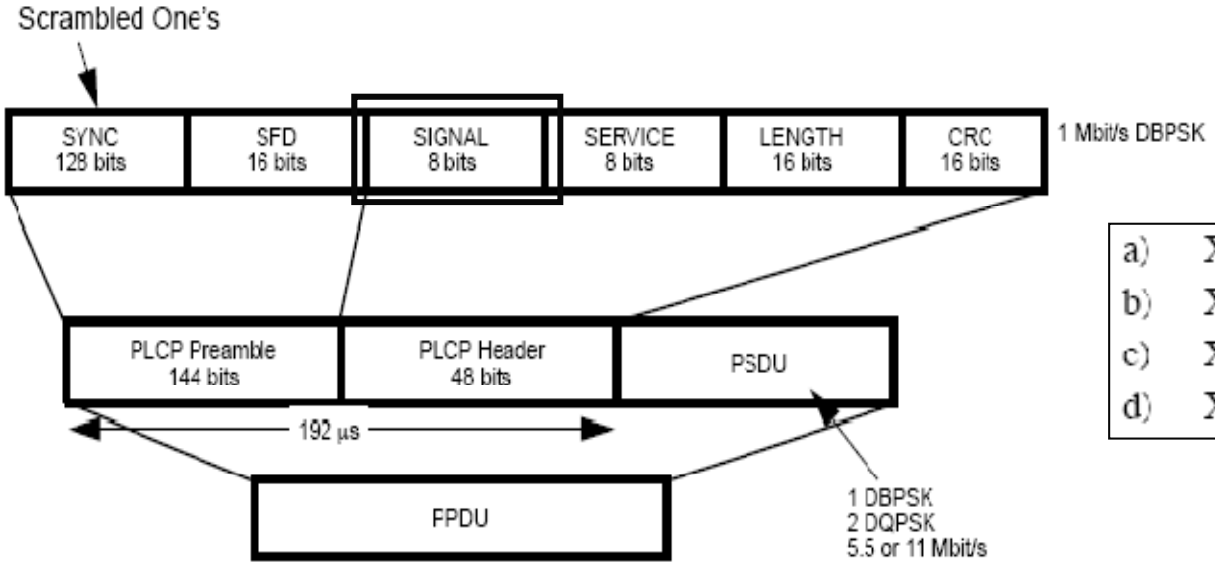
Outline

- 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

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



a) X'0A' (msb to lsb) for 1 Mbit/s;
b) X'14' (msb to lsb) for 2 Mbit/s;
c) X'37' (msb to lsb) for 5.5 Mbit/s;
d) X'6E' (msb to lsb) for 11 Mbit/s.

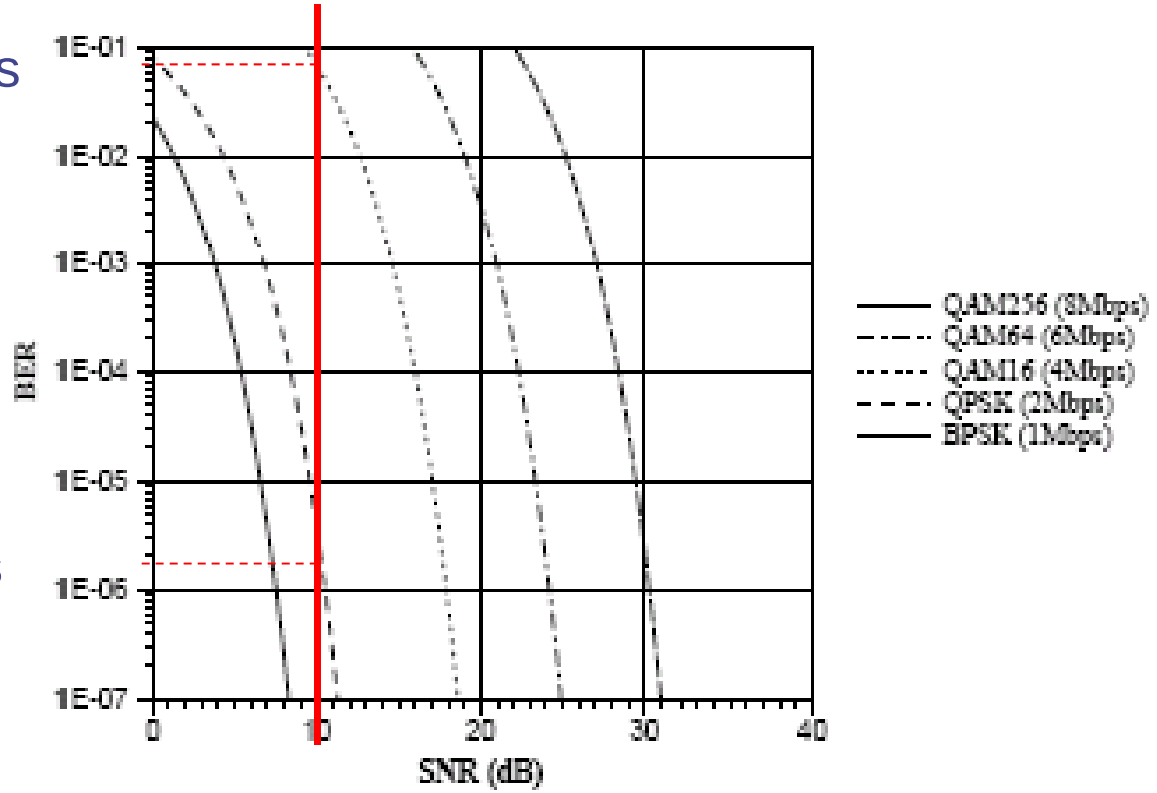
Figure 127—Long PLCP PPDU format

Modulation Scheme V.S. SNR and BER

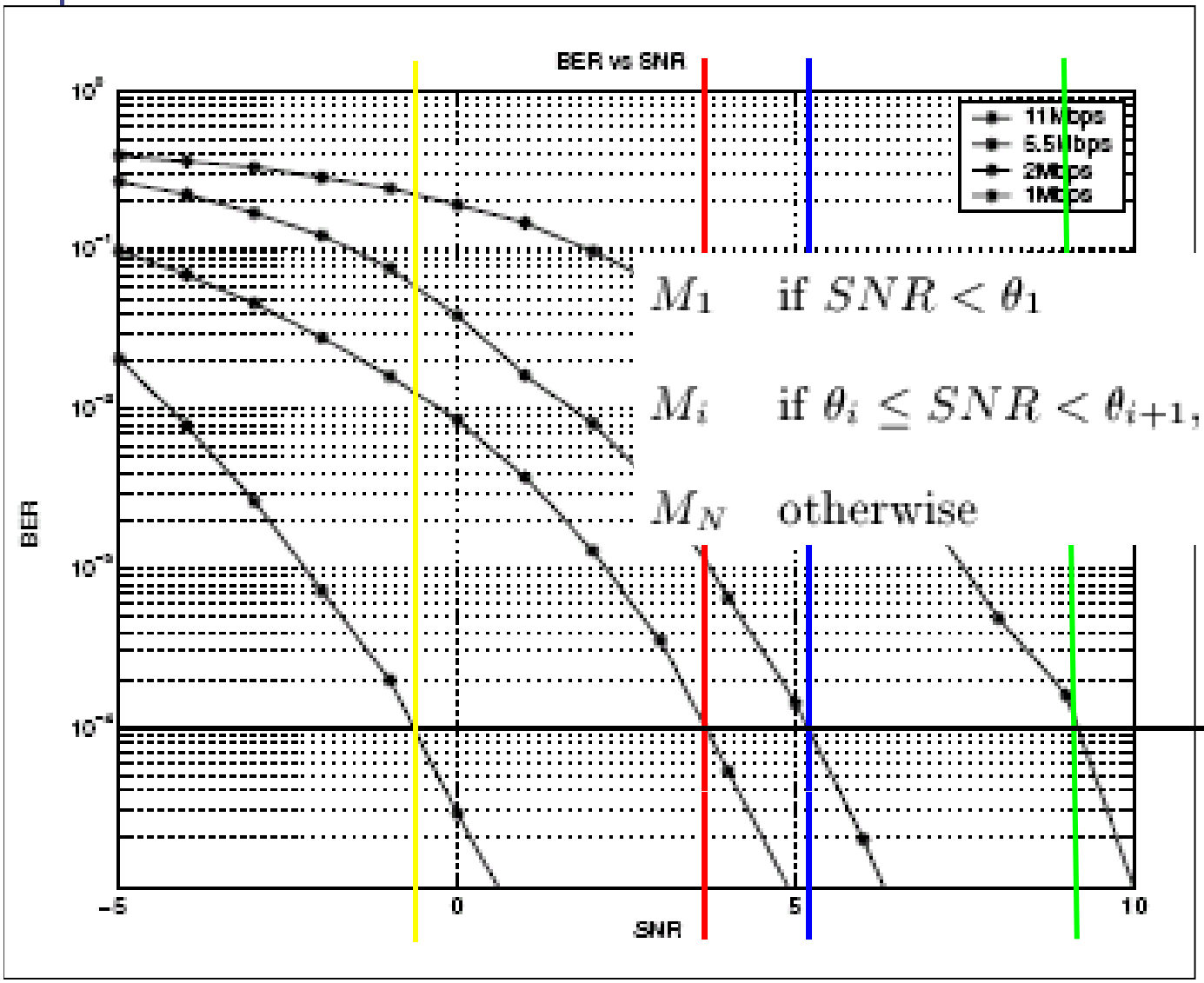
- Path loss, fading, and interference cause variations in the received signal-to-noise (SNR) radio
- Fixed SNR
  - The higher bit rate modulation, the higher BER (bit error ratio)

QAM16 4Mbps

QPSK 2Mbps



How to Choose the Bit Rate



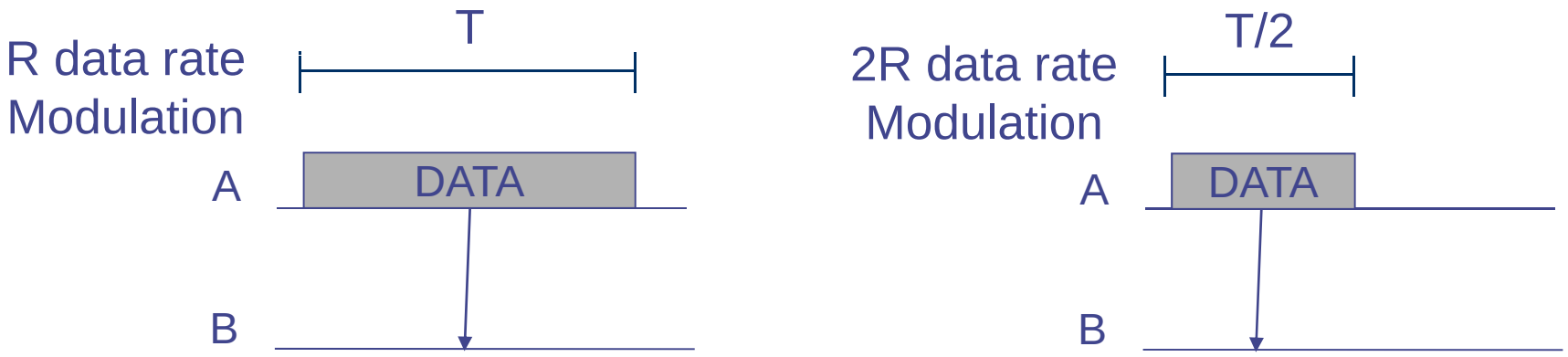
$$M_1 \quad \text{if } SNR < \theta_1$$

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

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

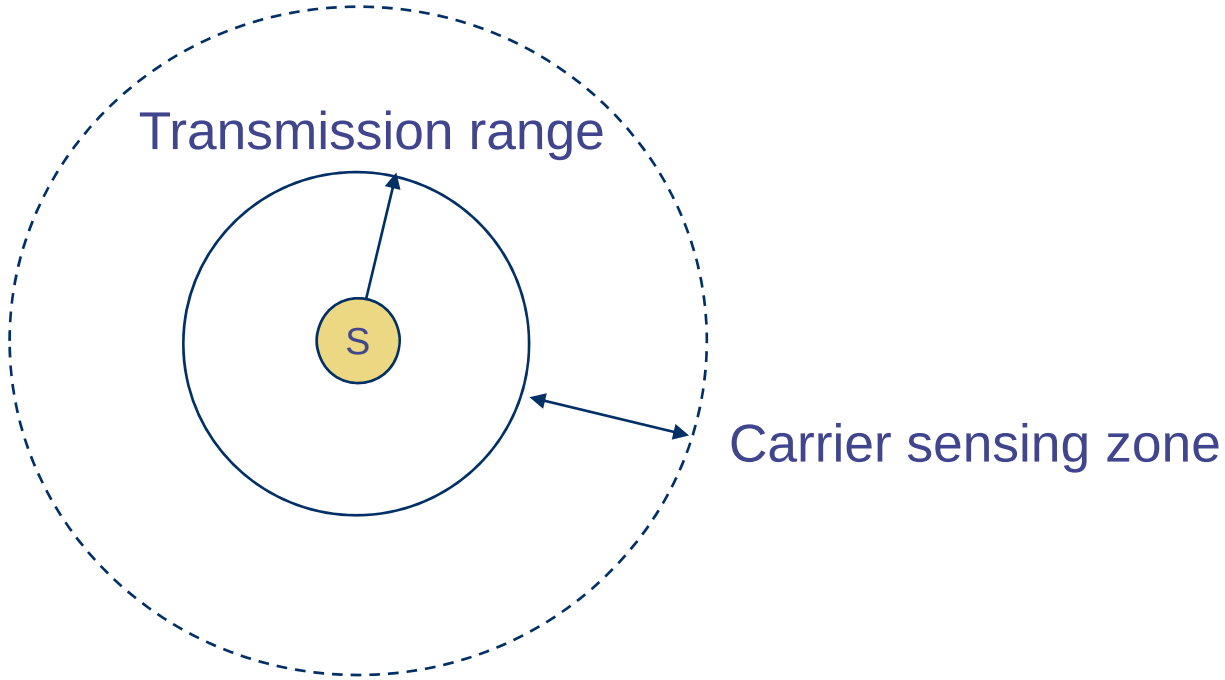
Background

- 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



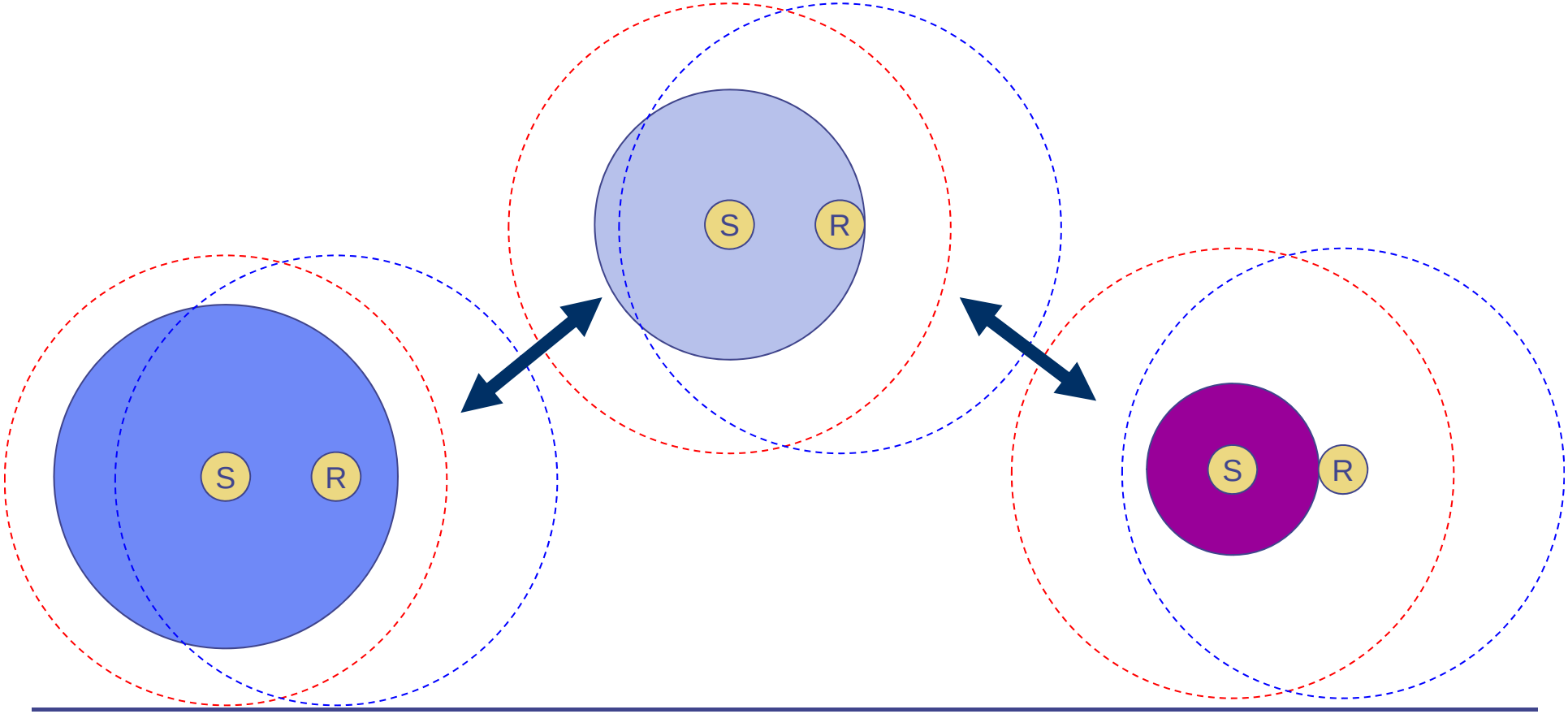
Background

- 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.



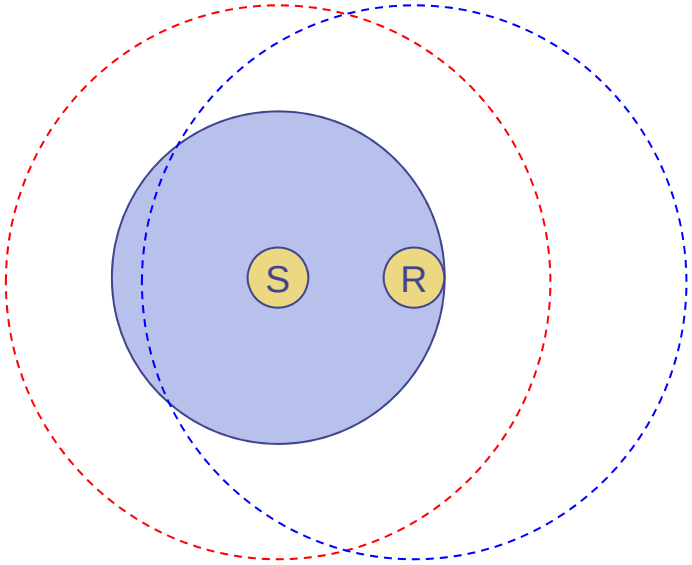
Related Work: ARF

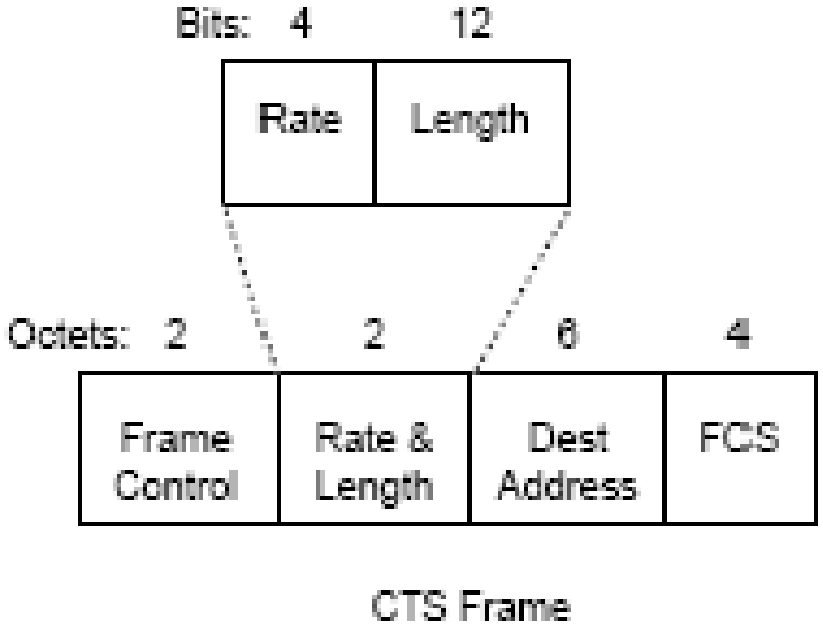
- *A. Kamerman, L. Monteban.* "**WaveLAN-II: A high-performance wireless LAN for the unlicensed band**", Bell Labs Tech. Journal, 97 Summer.



Related Work: **RBAR**

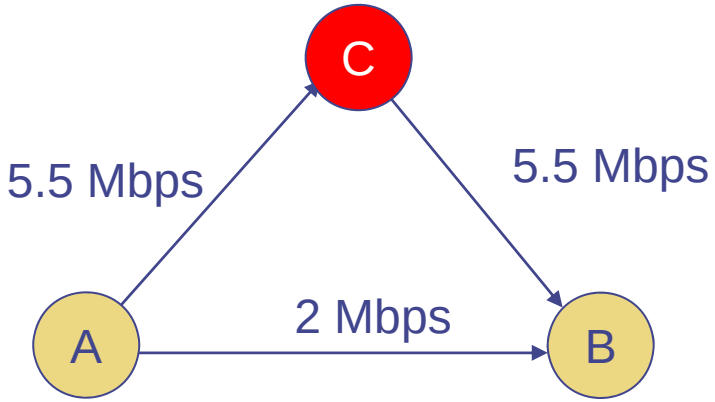
- *G. Holland, N. Vaidya, P. Bahl*, "**A Rate-Adaptive MAC Protocol for Multi-Hop Wireless Networks**", ACM Mobicom 01.

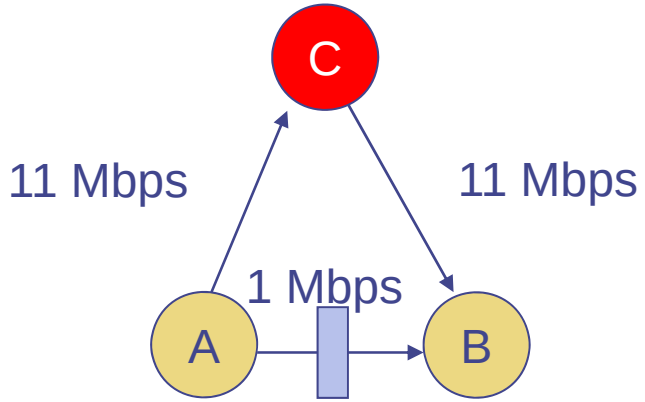




Motivation

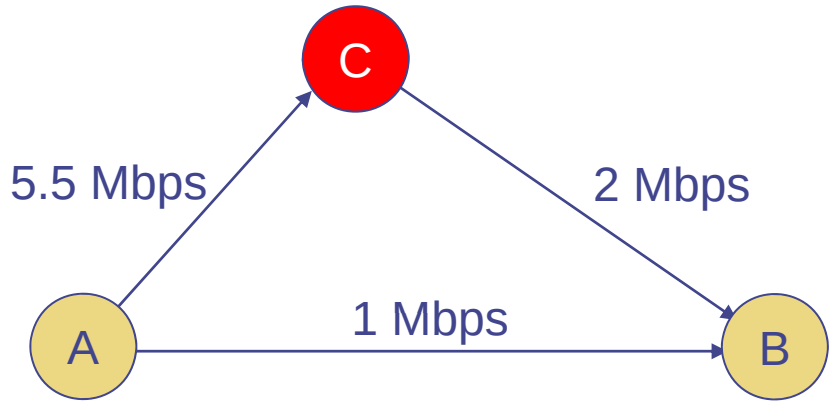
- A lower rate link can be replaced by two higher rate links.
  - $T_{AC} + T_{CB} < T_{AB}$





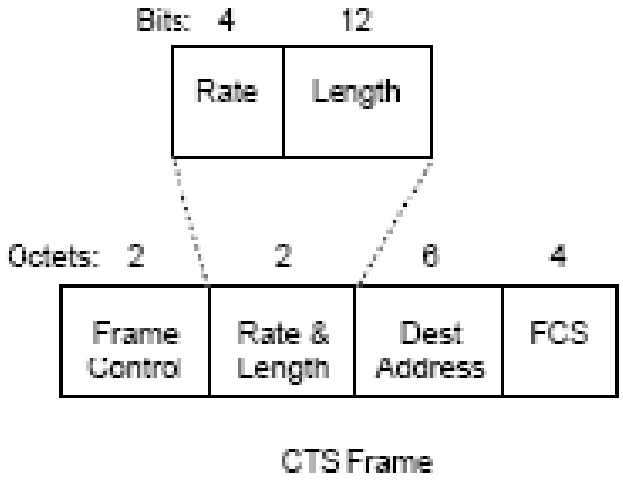
Relay-based Multi-rate MAC Protocol Process

- 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 $T_{AC} + T_{CB} < T_{AB}$



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

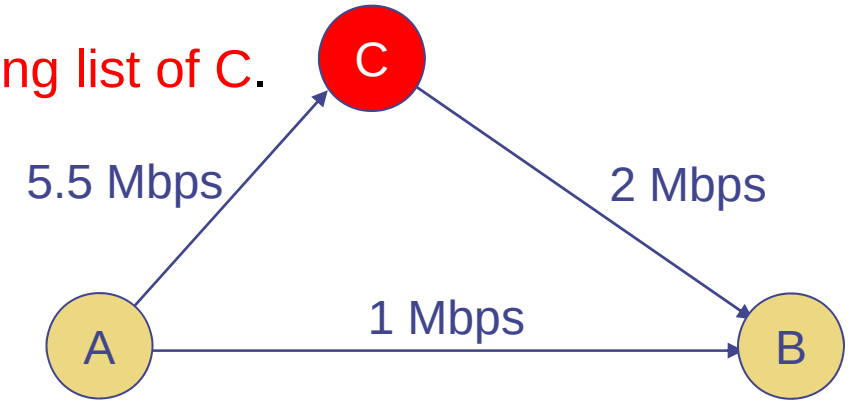


CTS Frame

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.



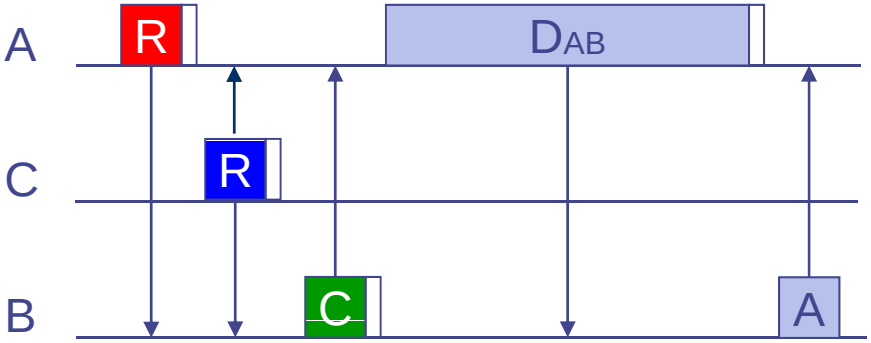
rDCF (Relay Transmission) (Decision of B)

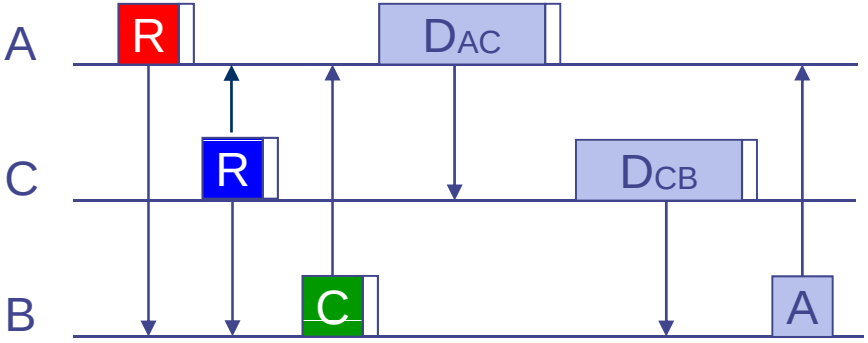
- A don't find a relay node
  - RBAR
- A finds a relay node
  1. A broadcasts RRTS1 (C estimates R_{AC})
  2. C broadcasts RRTS2 (carry R_{AC}, B estimates R_{CB})
  3. if the packet can't be transmitted faster with relay

     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

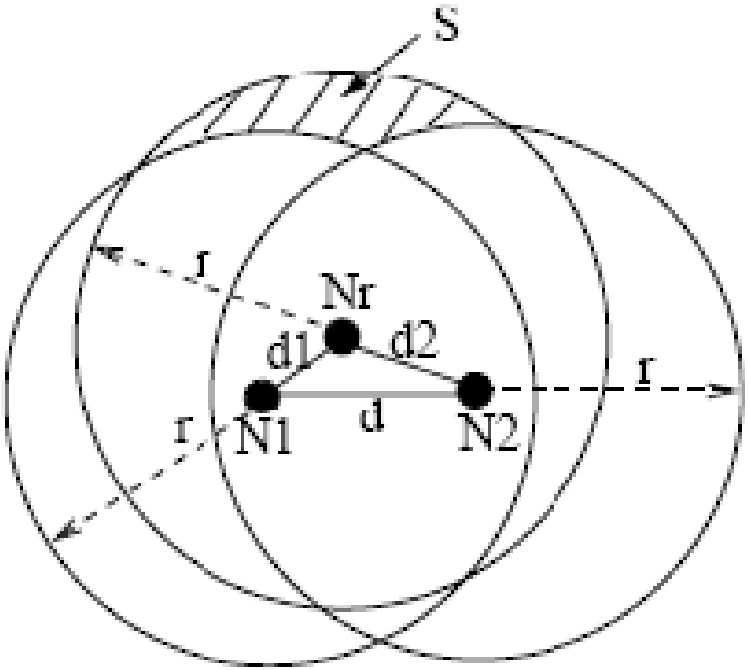
    else if random number < credit

      A does RBAR

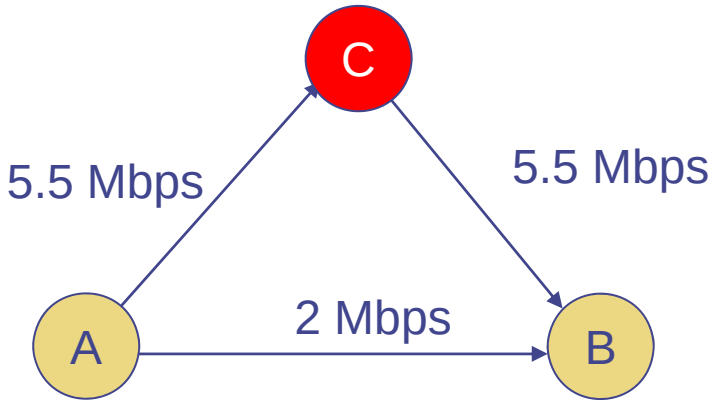
Carrier Sensing Zone Analysis

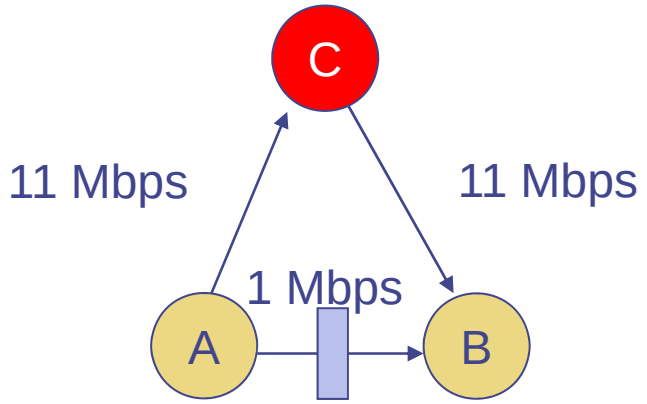
- Increased sensing zone is small

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



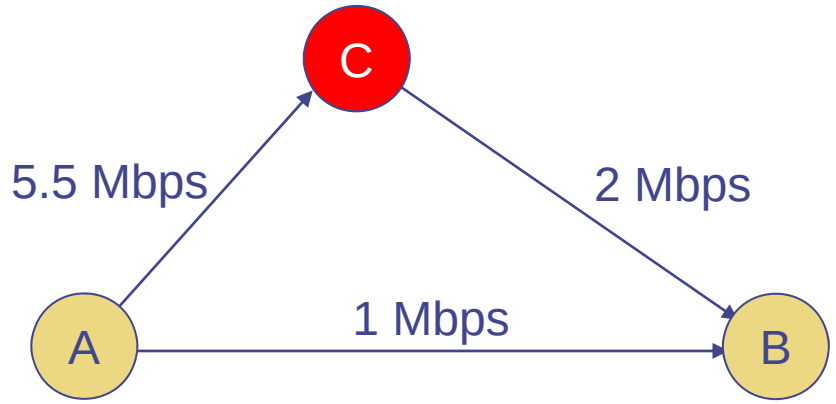
- Assumption
  - In DCF, each node must transmit with the same power.
  - Channel gain between the two nodes is the same in both directions. Based on RBAR



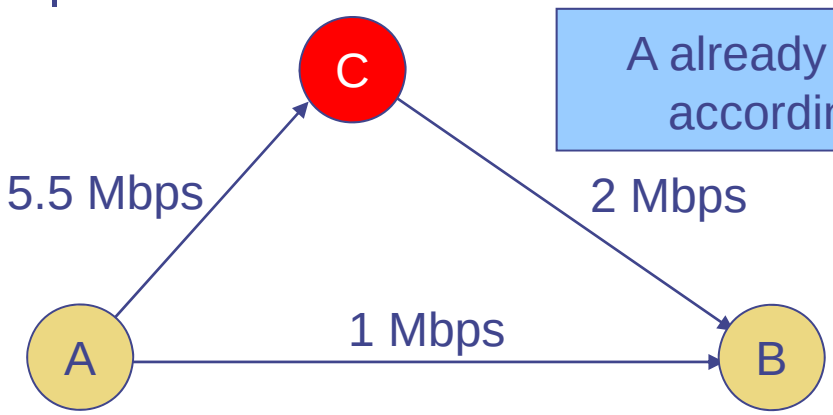


RAMA (Relay node discovery)

- 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.

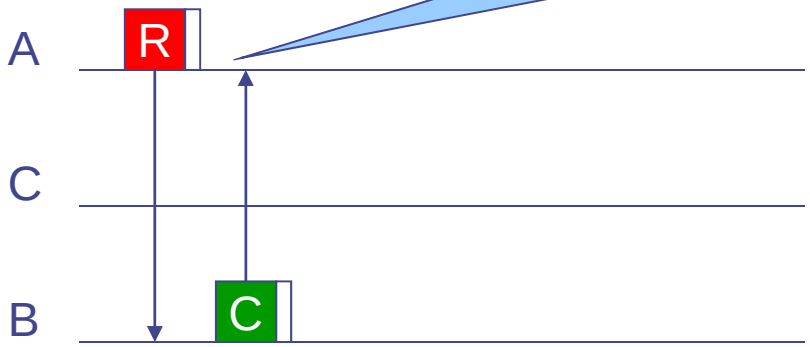


RAMA (Relay Transmission) (Decision of A)



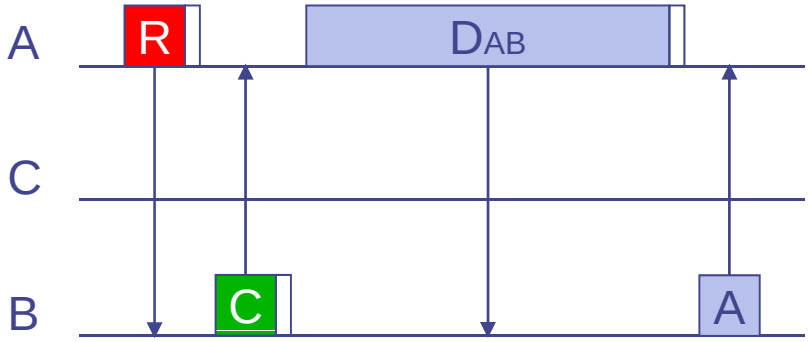
A already has R_{AC} and R_{CB} according to Relay List

A knows R_{AB}

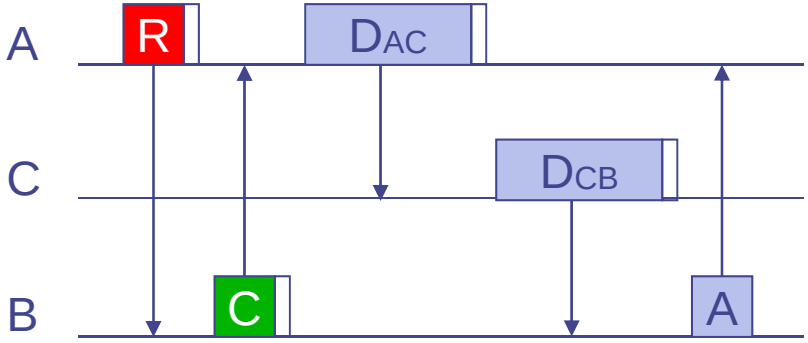


Relay List:
Source, Relay, Destination, R_{AC} and R_{CB}

Case 1



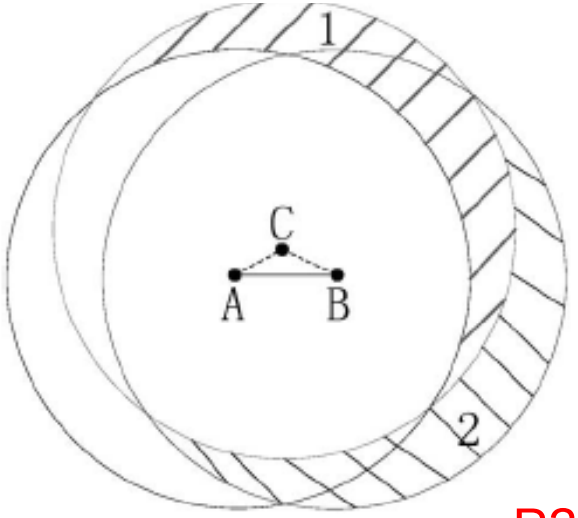
Case 2

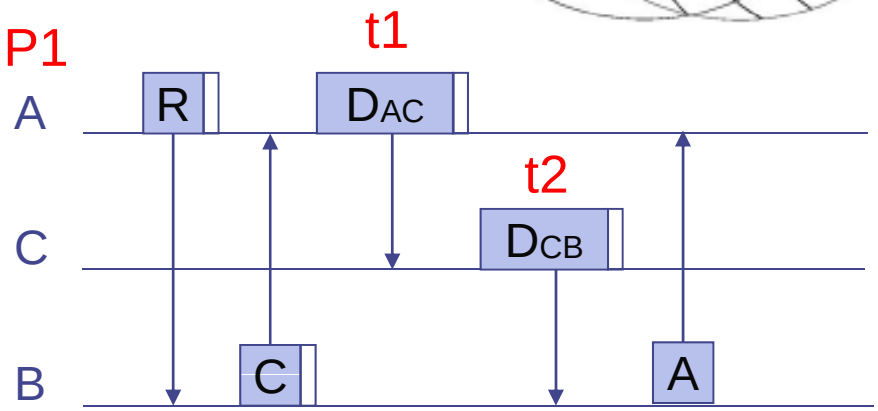


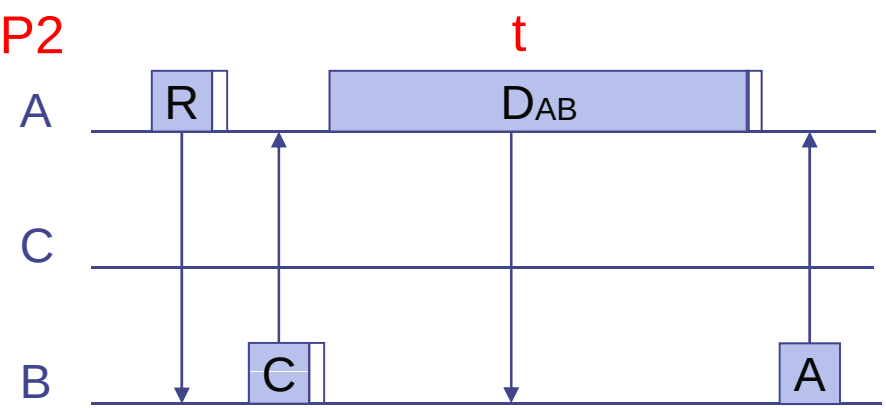
Carrier Sensing Zone Analysis

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

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

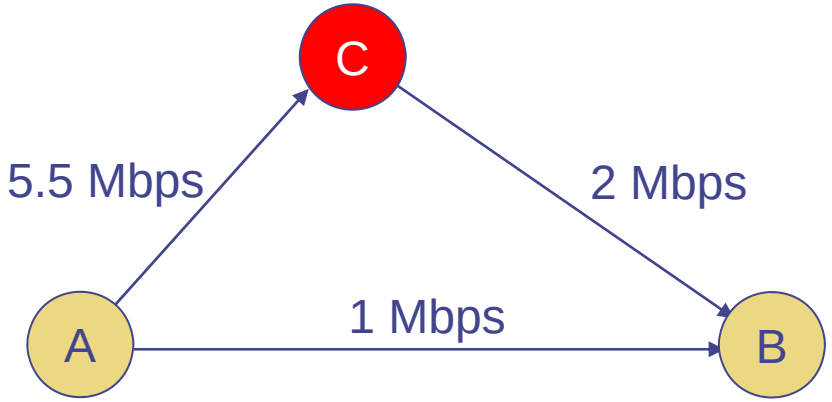






Summary

- 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. Try to analyze the throughput in multi-rate IEEE 802.11 networks.
   - "Performance analysis under finite load and improvements for multirate 802.11" , **Computer Communications, 2005.**