Wireless Ad Hoc and Sensor Networks

MAC Layer Introduction & the IEEE802.11 standard

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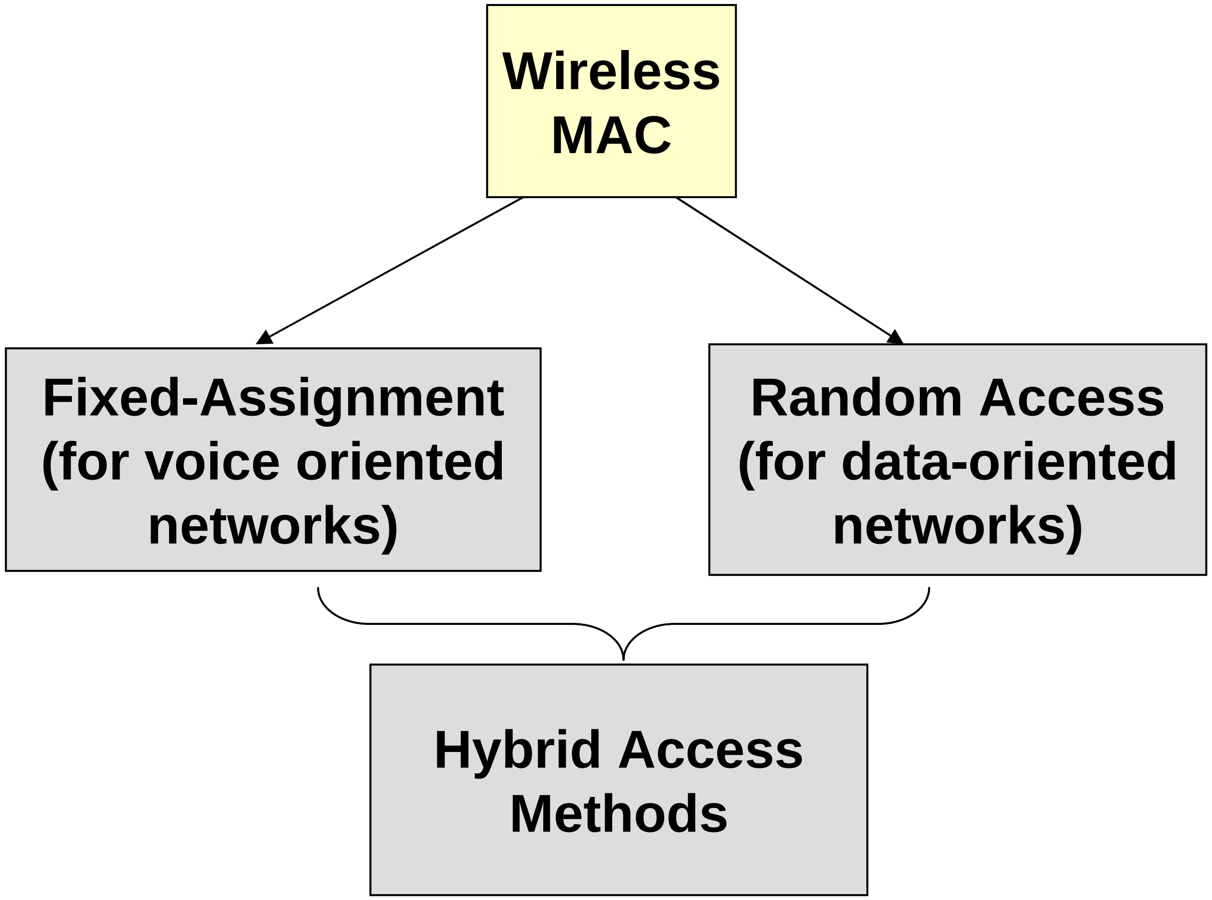
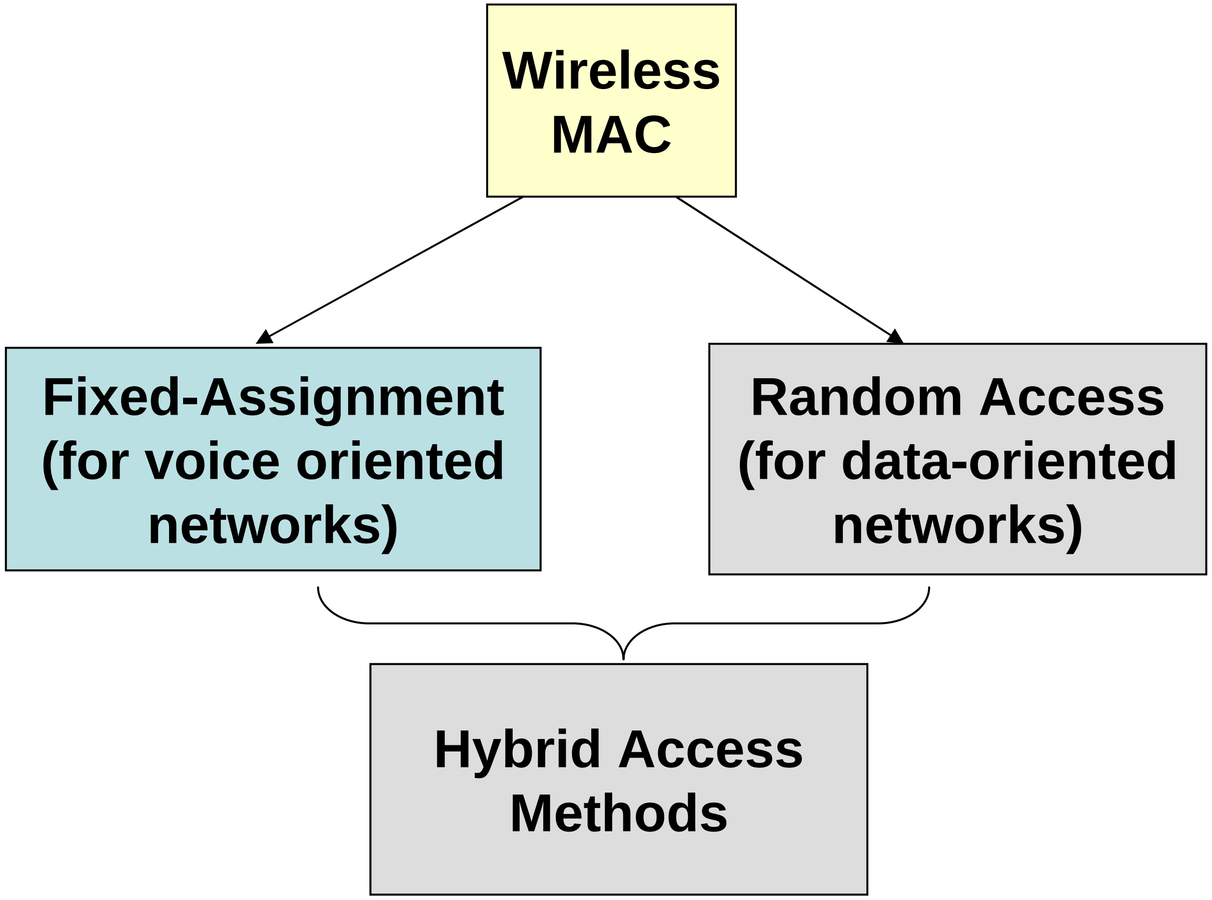
Wireless MAC Classification



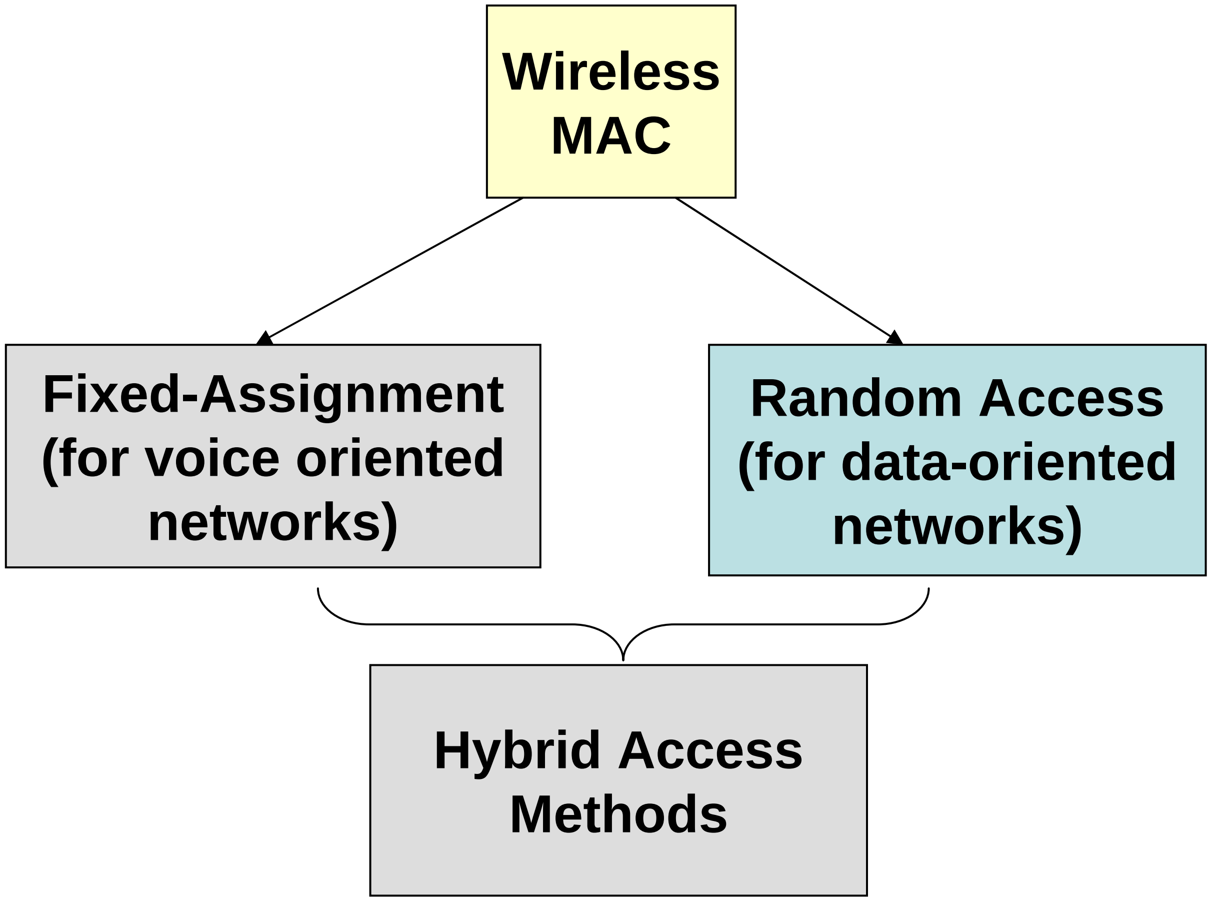
Wireless MAC Classification



Fixed-Assignment MAC

- All existing voice-oriented wireless networks, such as cellular telephony or PCS services, use fixed-assignment channel partitioning techniques
- A fixed allocation of channels are made on a predetermined basis to a single user for the duration of the communication session.
- Channels are formed by allocating different frequencies (FDMA), time slots (TDMA), or spread spectrum codes (CDMA).
- Choice has a great impact on the network performance, to the extent that various voice-oriented wireless systems are commonly referred to by their channel access method (although it is only a part of the layer two specification!).

Wireless MAC: A Simple Classification



Random Access MAC Classification

- Two broad classes of random access methods:
  - ALOHA-based random access methods [Abramson70]
    - Used mainly for wide-area data networks
  - Carrier-sense based random access methods
    - Used mainly for wireless LANs
    - Hidden terminal and exposed terminal problems
    - From CSMA/CD to CSMA/CA
    - CSMA/CA with RTS/CTS (MACA, MACAW, etc.)
    - Priority and Fairness
    - Power conservation
    - MAC for directional antennas

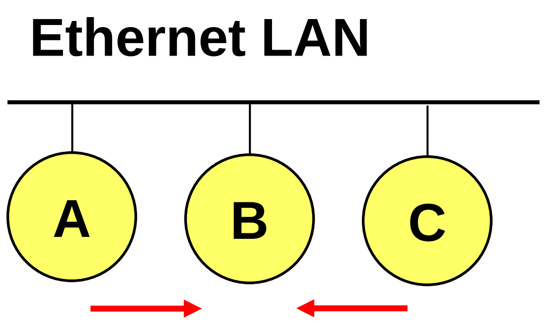
Random Access MAC

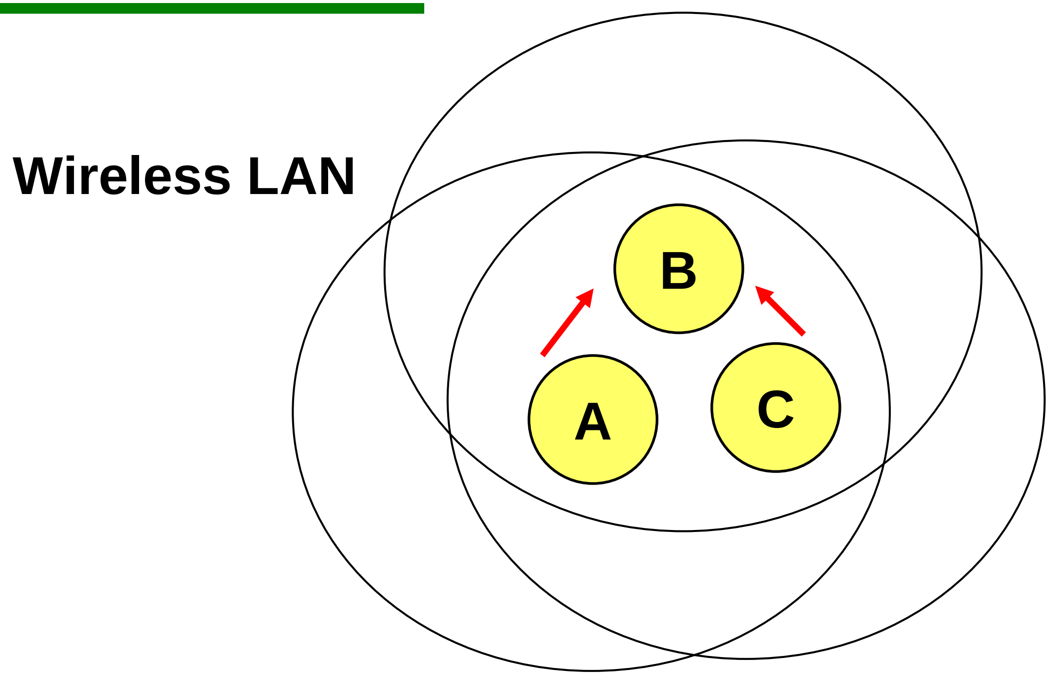
- Evolved around bursty data applications in computer networks.
- Fixed-assignment methods
  - make relatively efficient use of communications resources when each user has a steady flow of information to be transmitted during each session
  - Could be a waste of resources for intermittent traffic
  - Require an “arbitrator”
- Random access methods provide more flexible and efficient ways of managing medium access for short bursty messages
  - Could think of them as distributed statistical multiplexing techniques
- A natural consequence is that there is contention among the users for access to the medium channels – manifested in “collisions” of contending transmissions
- These methods are sometimes called contention schemes
- Mainly used in wired and wireless LANs and data-oriented WANs

From CSMA/CD to CSMA/CA

- Carrier Sense Multiple Access with Collision Detection (CSMA/CD) is used in IEEE 802.3 but not IEEE 802.11. Why?

Difference Between Wired and Wireless Random Access MAC





- If both A and C sense the channel to be idle at the same time, they send at the same time.
- Collision can be detected at sender in Wired LANs (Ethernet).
- In wireless, it might not be possible to detect collision at sender.

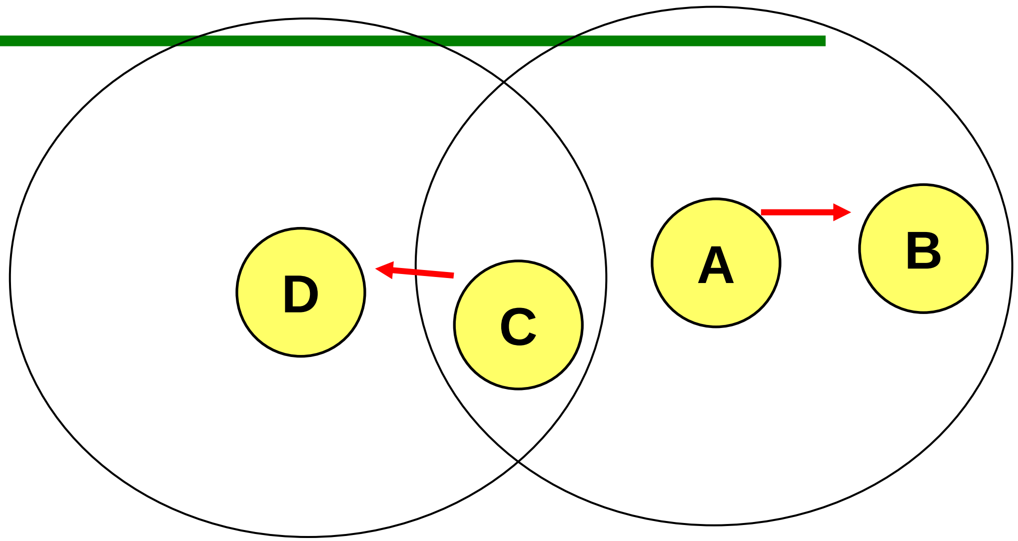
MAC: from wired to wireless

- Can we apply the same MAC methods of wired networks to wireless networks?

- CSMA/CD
  - Carrier Sense Multiple Access with Collision Detection
  - Basic method in IEEE 802.3 standards
  - “Sense” the medium, send as soon as the medium is free, and listen to the medium to “detect collisions”
- CSMA/CD does not work in wireless networks

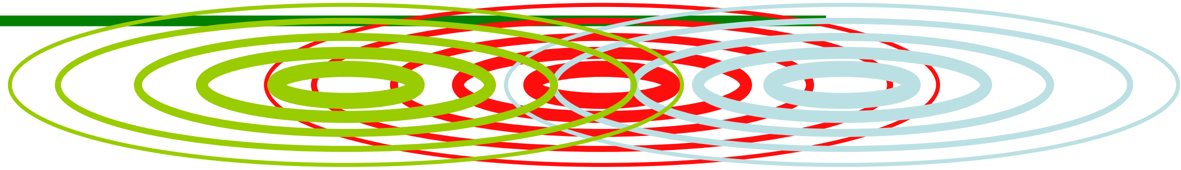
  - Signal strength decreases proportional to the square of the distance (assuming free space propagation) → Hidden Terminal and Exposed Terminal problems
    - Sender would apply CS and CD, but collisions happen at the receiver
    - Might be the case that a sender cannot “hear” the collision or cannot “sense” another carrier at the receiver

Exposed Terminal Problem



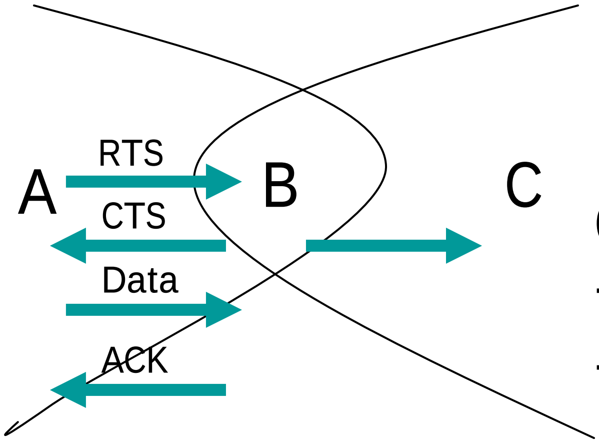
- Exposed terminals (A valid comm can not take place because the sender is exposed)
  - A starts sending to B.
  - C senses carrier, finds medium in use and has to wait for A->B to end.
  - D is outside the range of A, therefore waiting is not necessary.
  - A and C are “exposed” terminals i.e. A and C could communicate to their receivers at the same time (since their receivers are far apart), but because A and C can exposed to each other (I.e. can hear each other), one of them needlessly refrains from transmitting.
- A->B and C->D transmissions could have taken place in parallel without collisions

Hidden Terminal Problem [Tobagi75]



- Hidden terminals: *A node within the range of two nodes that are out of range*
  - A and C cannot hear each other.
  - A sends to B, C cannot receive A.
  - C wants to send to B, C senses a “free” medium (CS fails)
  - Collision occurs at B.
  - A cannot hear the collision (CD fails).
  - A is “hidden” for C.
- Solution?
  - Hidden terminal is peculiar to wireless (not found in wired)
  - Need to sense carrier at receiver, not sender!
  - “virtual carrier sensing”: Sender (node C) “asks” receiver (node B) whether it senses the channel is busy. If so, behave as if channel busy.

RTS/CTS solution of Hidden Terminal Problem



C knows B is listening to A. Will not attempt to transmit to B.

Hidden Terminal Problem Solved through RTS-CTS exchange!

CSMA/CA + RTS/CTS (Contd.)

- 802.11 DCF MAC:
  - CSMA/CA
  - Control packet transmissions precede data packet transmissions to facilitate collision avoidance
  - 4-way (RTS, CTS, Data, ACK) exchange for every data packet transmission

- Can there be collisions?
  - Control packet collisions (C transmitting RTS at the same time as A)
  - C does not register B's CTS
  - C moves into B's range after B's CTS

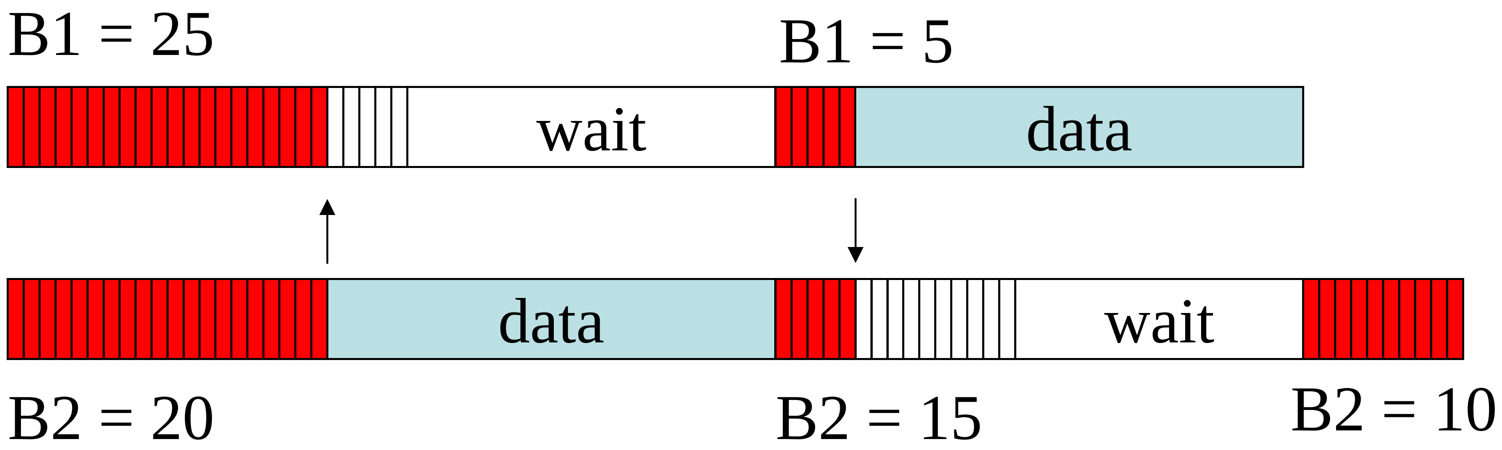
CSMA/CA Algorithm

- Sense channel (CS)
- If busy
  - Back-off to try again later
- Else
  - Send RTS
  - If CTS not received
    - Back-off to try again later
  - Else
    - Send Data
    - If ACK not received
      - Back-off to try again later
    - Next packet processing

CSMA/CA Algorithm (Contd.)

- Maintain a value CW (ContentionWindow)
- If Busy,
  - Wait till channel is idle. Then choose a random number between 0 and CW and start a back-off timer for proportional amount of time (Why?).
  - If transmissions within back-off amount of time, freeze back-off timer and start it once channel becomes idle again (Why?)
- If Collisions (Control or Data)
  - Binary exponential increase (doubling) of CW (Why?)

DCF Example



cw = 31

B1 and B2 are backoff intervals at nodes 1 and 2

Backoff Interval

- The time spent counting down backoff intervals is a part of MAC overhead
- Choosing a *large cw* leads to large backoff intervals and can result in larger overhead
- Choosing a *small cw* leads to a larger number of collisions (when two nodes count down to 0 simultaneously)

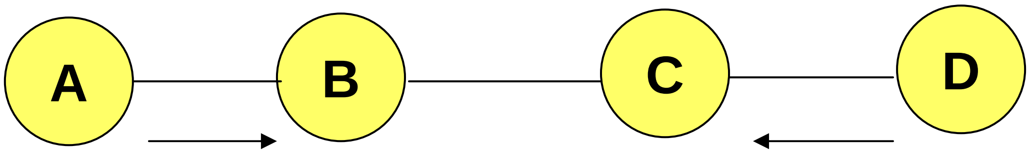
- Since the number of nodes attempting to transmit simultaneously may change with time, some mechanism to manage contention is needed
- IEEE 802.11 DCF: contention window *cw* is chosen dynamically depending on collision occurrence

Binary Exponential Backoff in DCF

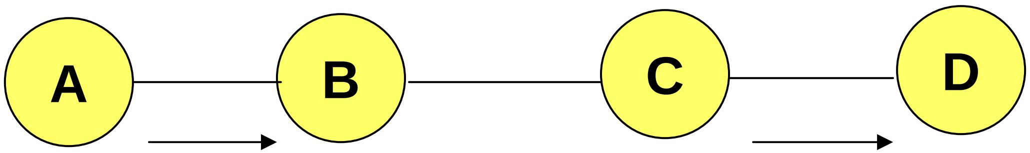
- When a node fails to receive CTS in response to its RTS, it increases the contention window
  - *cw* is doubled (up to an upper bound)
- When a node successfully completes a data transfer, it restores *cw* to Cw_{min}
- *cw* follows a sawtooth curve

Several MAC improvements proposed…

- For the scenario below, when node A sends an RTS to B, while node C is receiving from D, node B cannot reply with a CTS, since B knows that D is sending to C
- When the transfer from C to D is complete, node B can send a Request-to-send-RTS to node A [Bharghavan94Sigcomm]
  - Node A may then immediately send RTS to node B



- This approach, however, does not work in the scenario below
  - Node B may not receive the RTS from A at all, due to interference with transmission from C



IEEE 802.11

- The 802.11 standard
  - provides MAC and PHY functionality for wireless connectivity of fixed, portable and moving stations moving at pedestrian and vehicular speeds within a local area.
- Specific features of the 802.11 standard include the following:
  - Accommodation of transmission rates of 1, 2, 11, and 54 Mbps
  - Operates at either 2.4 GHz or 5 GHz unlicensed ISM bands
  - Support Multicast/broadcast services
  - Network management services
  - Registration and authentication services
  - In certain modes, could support of asynchronous and time-bounded delivery service

IEEE 802.11 modes of operation

- Infrastructure Mode
  - Each Mobile Station (MS) associates itself with an Access Point (AP)
  - An AP+MS's associated with it are called a Basic Service Set (BSS)
  - BSS's may (should? For handoff) overlap
    - An isolated BSS is called an Independent BSS
    - A set of Ap's connected with a LAN are called an Extended BSS
  - Modes of communication permitted are AP←→MS
- Ad-Hoc Mode
  - MS ←→MS i.e. no access point

IEEE 802.11 Logical Architecture

- The logical architecture of the 802.11 standard that applies to each station consists of a single MAC and one of multiple PHYs
- PHYs
  - Frequency hopping PHY
  - Direct sequence PHY
  - Infrared light PHY
- MAC
  - Point Coordination Function (**PCF**)
    - in infrastructure mode – centralized MAC
  - Distributed Coordination Function (DCF)
    - in ad-hoc mode – distributed MAC)

PHYs

- The original (~1997) 802.11 supported three options
  - FHSS, 2.4 GHz, 1 or 2 Mbps (depending on modulation scheme)
  - DSSS, 2.4 GHz, 1 or 2 Mbps
  - Infrared, 850-950-nm range, 1 or 2 Mbps

Newer standards:

- 802.11b (1999)
  - Improvement to DSSS (2.4 GHz) to support rates of 5.5 and 11 Mbps (new modulation techniques)
- 802.11a (1999)
  - Uses OFDM in the 5 GHz band, rates up to 54 Mbps
- 802.11g
  - Aims at providing .11a speeds at 2.4 GHz band.

IEEE 802.11 MAC

- DCF
  - CSMA/CA+RTS/CTS – A distributed contention based protocol
- PCF
  - Contention-free access protocol usable on infrastructure network configurations containing a controller (AP) called a point coordinator within the BSS
- Both the DCF and PCF can operate concurrently within the same BSS to provide alternative contention and contention-free periods

PCF in 802.11 MAC

- Its objective is to provide QoS guarantees (e.g. bound the max access delay, bound the minimum guaranteed txmt rate)
- Is a centralized MAC – applicable only in the infrastructure mode
- The AP polls the nodes in its BSS
- A PC (point coordinator) at the AP splits the access time into super frame periods
- A super frame period consists of alternating contention free periods (CFPs) and contention periods (CPs)
- The PC then determines which station transmits at any point in time

DCF in 802.11

- The AP doesn’t control the medium access
- CSMA/CA+RTS/CTS – distributed random access

Events during 802.11 DCF exchange

- Time measured in terms of a basic time-slot (depends on PHYs e.g. 9 ms in .11a)
- IFS
  - Inter-frame spacing
  - Transmission of a pkt is allowed only after the appropriate IFS has passed while the channel remains idle
  - SIFS: the shortest of all, used for high priority frames such as control messages
  - SIFS<PIFS<DIFS
  - EIFS: longest, used for least priority data e.g. resynch
  - Figure !

Other Issues (to be discussed in future meetings)

- Energy Conservation
  - Power save
- Power control
- Directional Antennas
- Fairness

Impact of Power Save on Upper Layers

- IEEE 802.11 has a Beacon-based power-save mode
- If each node uses the 802.11 power-save mechanism, each hop will require one beacon interval for wake-up
  - This delay could be intolerable
- Allow upper layers to dictate whether a node should enter the power save mode or not [Chen01mobicom]

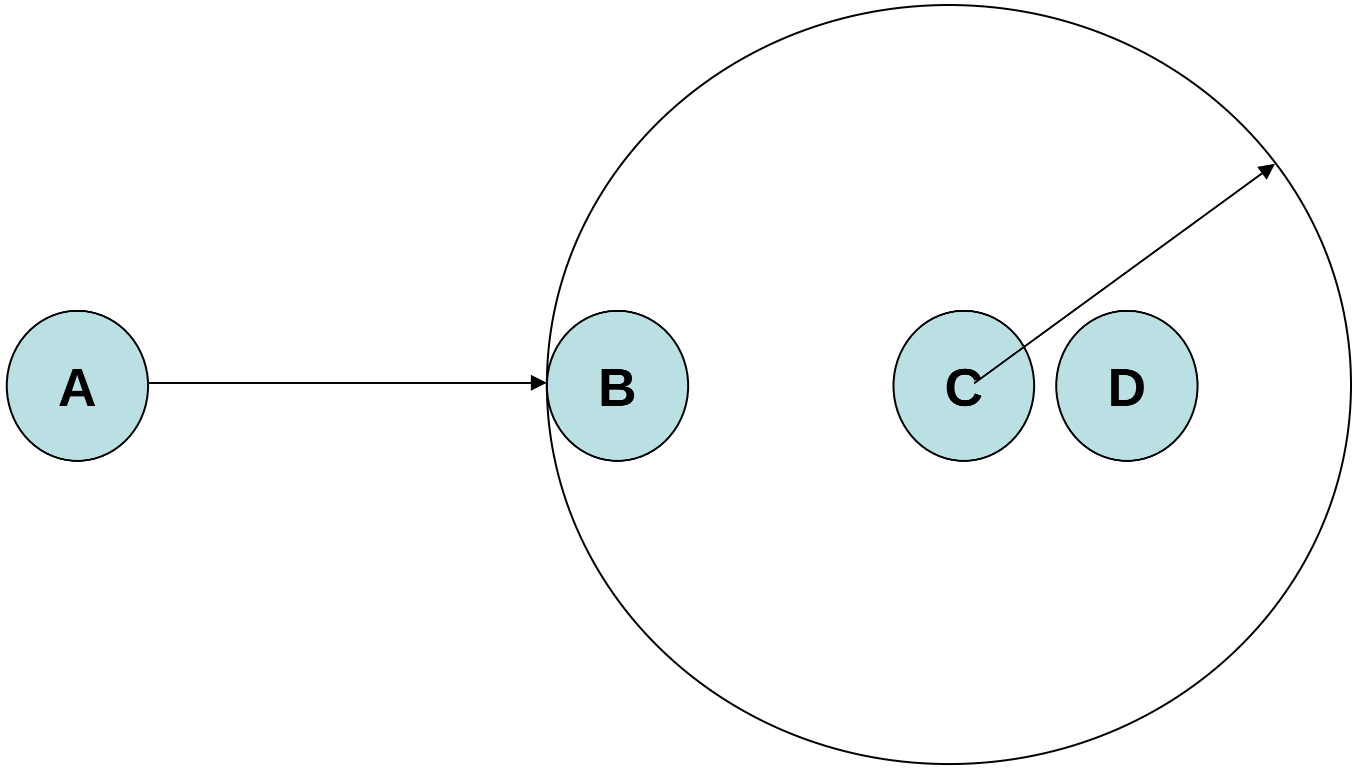
Power Control

Power control has (at least) two potential benefits

- Reduced interference & increased spatial reuse
- Energy saving

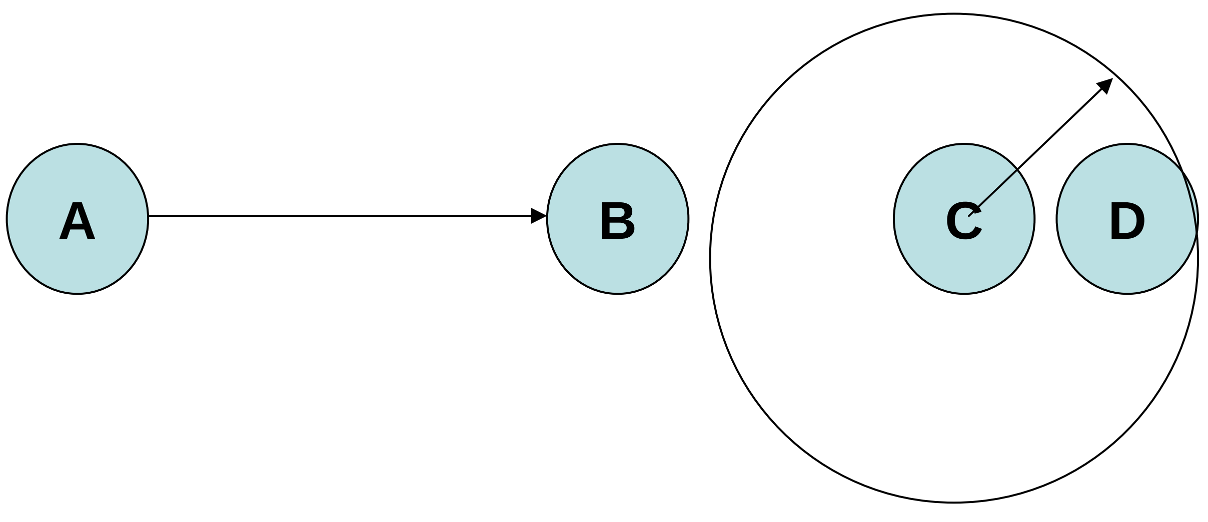
Power Control

- When C transmits to D at a high power level, B cannot receive A's transmission due to interference from C



Power Control

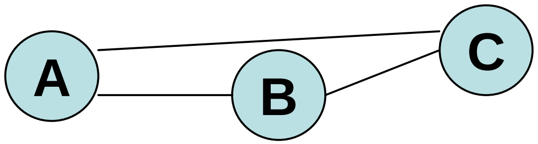
- If C reduces transmit power, it can still communicate with D
  - Reduces energy consumption at node C
  - Allows B to receive A’s transmission (spatial reuse)



Power Control

- Received power level is proportional to inverse square of distance

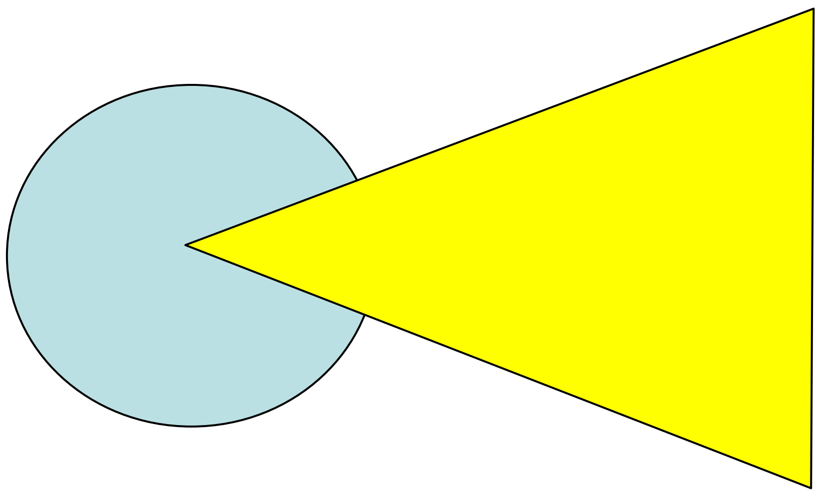
- If power control is utilized, potential energy savings



- Shorter hops typically preferred for energy consumption
  - Transmit to C from A via B, instead of directly from A to C

Directional Antennas

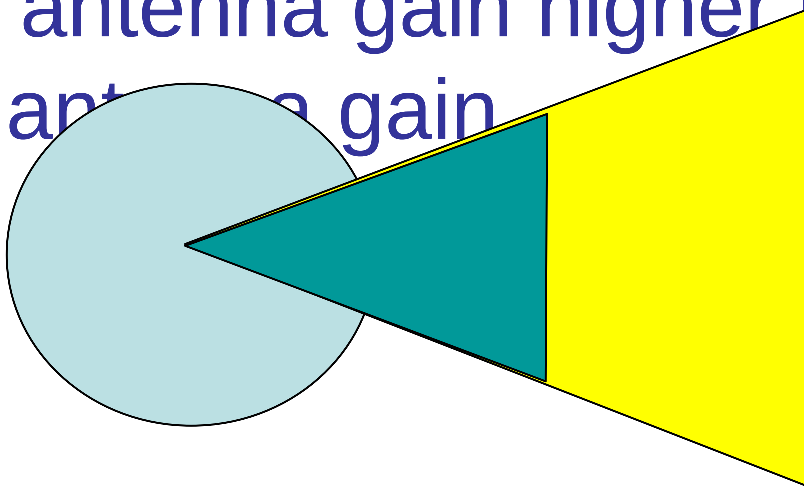
- Increased range by limiting energy waste in unnecessary directions



- Directional antenna gain higher than omni-directional antenna gain
- Number of neighbors may be greater
- Number of hops to a destination may be smaller

Directional Antennas

- Directional antenna gain higher than omni-directional antenna gain



- Reach a given neighbor with less power than omni-directional transmission

Directional Antennas

Potential benefits

- Higher spatial reuse
- Greater range (for given transmit power)
- Reduction in energy consumption

But need new MAC protocols to best utilize directional antennas

Wireless Fair Queuing

- Wireless channel capacities are scarce
- Fair sharing of bandwidth becomes critical
- Both short-term and long-term fairness important
- Location dependent and bursty errors
  - For the same wireless channel, a mobile station might experience a clean channel while another might experience high error rates.

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