

# Lecture 6: Wireless Link Layer, MAC protocols, CSMA

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# Wireless Link Layer

- Link layer (layer 2) is above physical layer
  - Gives frames to PHY to transmit
  - Gets correct (and incorrect) frames from PHY
- Link layer has a notion of a “link” between sender and receiver, adds a link layer header to identify src / dst
- Link layer functions
  - Medium access control (MAC): share access to the broadcast wireless medium
  - Link rate adaptation: configure suitable PHY parameters (modulation / coding rate) to match the bit rate and signal quality of each link
  - Error control: retransmissions to recover from errors

# MAC protocols

- MAC protocols arbitrate access to the medium
- Two broad classes
  - Scheduling-based / centralized. A central entity decides who sends when. E.g., cellular base stations schedule transmissions of users on uplink and downlink.
  - Contention-based / decentralized. Nodes decide who transmits when in a distributed fashion. E.g., WiFi clients and access point contend for medium using CSMA MAC protocol. ← Topic of this lecture

# The idea of multiplexing

- MAC protocols multiplex users over time, frequency, etc.
  - Time division multiplexing (TDM) – different users transmit at different times. The time of transmission can be decided by a central entity (scheduling-based) or in a distributed fashion (contention-based)
  - Frequency division multiplexing (FDM) – different users use different frequencies. Frequency allocation typically happens in a centralized fashion.
  - Some combination of the above. For example, different sets of users are allocated different frequencies (FDM) followed by multiple users in the same frequency band sharing channel using TDM.
  - Other dimensions –space division multiplexing (use different geographic regions), code division multiplexing. These concepts will be clearer in the next lecture.
- If multiplexing is not done properly (e.g., two users send at same time on same frequency), the users interfere with each other.
- Efficient multiplexing without causing interference to any user is the goal of medium access control (MAC) protocols.

# MAC protocols - Roadmap

- This lecture: contention-based MAC protocols
  - ALOHA: simplest such protocol
  - CSMA: widely used in WiFi etc
- Next lecture: scheduling-based MAC protocols
  - TDMA, and its variants
  - Different scheduling algorithms used in cellular networks
  - CDMA
  - OFDMA etc.

# Contention-based MAC: ALOHA

- ALOHA is the simplest contention-based MAC protocol.
- $N$  nodes in a network, all want to send packets on a shared medium.
- Only one node can successfully send at a time, more than one transmission leads to collision.
- In ALOHA, each node with a packet sends with probability  $p$ .
- Probability of successful transmission = probability that only one of the  $N$  nodes sends =  $Np(1-p)^{N-1}$
- This probability is maximum when  $p = 1/N$
- That is, ALOHA works efficiently when nodes choose the attempt probability  $p$  intelligently
- Even with this optimal choice of  $p$ , the fraction of time when useful data is sent (without collisions) for large  $N$  is roughly 18% (i.e., works out to  $1/e$  mathematically). Not very efficient!
- Key idea – randomness is essential for distributed MAC

# Can we do better?

- Yes we can. We can “listen” to the medium for some time to see if someone is sending. Transmit only if the medium is idle. This is the idea behind carrier sense.
- Ethernet (most common wired MAC) and the MAC layer of WiFi are both based on this idea.
- What is the difference between wired and wireless? In wired, the voltage levels across a wire do not change much between sender and receiver. So we know exactly when a collision happens. In wireless, the conditions at sender and receiver may be different, so cannot always detect collisions.
- Wireless – use link layer ACK to check if collision or not
- Ethernet implements CSMA/CD (carrier sense multiple access with collision detection)
- WiFi implements CSMA/CA (carrier sense multiple access with collision avoidance) since we cannot be fully sure of collisions.

# CSMA (Carrier Sense Multiple Access)

- Time is divided into slots (a few microsec each). Nodes measure energy of channel over a slot to decide if channel is busy or idle
- Every node maintains a variable called its contention window (CW)
- When a node has a packet to send:
  - If channel is free, then send
  - If channel is busy, pick a “backoff counter” between 0 and CW
  - Wait for “r” idle slots. That is, in every slot where channel is idle, decrement backoff counter.
  - When backoff counter is zero, and channel is idle, start transmission in that slot
  - If no ACK, retransmit packet again (pick backoff counter, wait etc)

# CSMA – contention window CW

- CW decides how aggressively nodes contend for the channel. Roughly equivalent to the attempt probability in ALOHA.
- Small CW – nodes will contend more as average backoff will be lower. Large CW – contention is less
- Initially, nodes use  $CW = CW_{min}$
- When collision, double CW (up to  $CW_{max}$ ). So successive retransmissions of a packet will see longer and longer backoffs
- When packet successfully sent after retries, reset CW to  $CW_{min}$
- If many nodes in the network, CW will be high on average.

# CSMA – inter-frame spacing

- After every data frame, the receiver sends an ACK if frame is successfully received
- ACK is sent immediately after data packet (after a “short inter frame spacing” SIFS)
- All other nodes wait for a longer inter frame spacing (DIFS) after a transmission. Allows sender and receiver to reset their PHY and get ready for a new transmission.
- That is, a transmission blocks the medium for the duration of the transmission + SIFS + duration of ACK + DIFS. Only then can other nodes contend.

# Problems with CSMA

- **Hidden node problem:**  $A \rightarrow B \leftarrow C$

A and C are out of carrier sense range of each other, so transmit simultaneously to B. Causes collisions at B.

- Fix: RTS/CTS mechanism. Before transmitting, A sends RTS (Request to Send). B sends CTS (Clear to Send). A sends data only after getting CTS. C hears CTS and avoids transmissions.
- RTS/CTS imposes high delay, especially in high throughput networks. Turned off by default.
- **Exposed node problem:**  $A \leftarrow B \quad C \rightarrow D$   
B and C are sending to far away receivers. They can both send concurrently, but do not do so due to carrier sense.
- These problems because carrier sense does not tell you conditions at receiver, only at sender.

## Problems with CSMA (2)

- Unfairness to high rate users. CSMA gives equal transmission opportunities. A node sending at 10Mbps gets 10 times *less* time than a node sending at 1 Mbps. The network is limited by the slowest node.
- When high user density, nodes often pick same backoff value and collide