MIT 6.829: Computer Networks — Fall 2017

Lecture 2: WiFi MAC and Rate Adaptation

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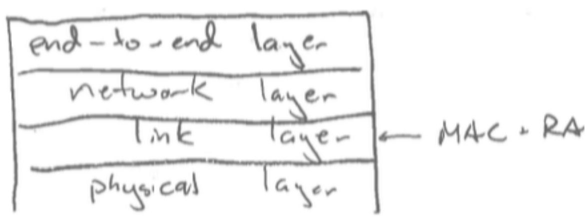
1 Overview

This lecture talks about two protocols in the link layer of networks, WiFi MAC (medium access control) and Rate Adaptation. It covers basic properties of wireless channels, the CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) and SampleRate protocols.

2 The Network Stack

Note: In this class, we will use the terms *channel* and *medium* interchangeably.



We can model the Internet as a set of layers building on top of each other. The *physical layer* manages signals and frequencies, the *link layer* is for point-to-point data transmission between two nodes, the *network layer* deals with routing and packets among multiple nodes, and the *end-to-end* or *application layer* contains transport protocols and applications.

WiFi MAC and Rate Adaptation functions lie in the link layer of the network stack. We will discuss an example of both:

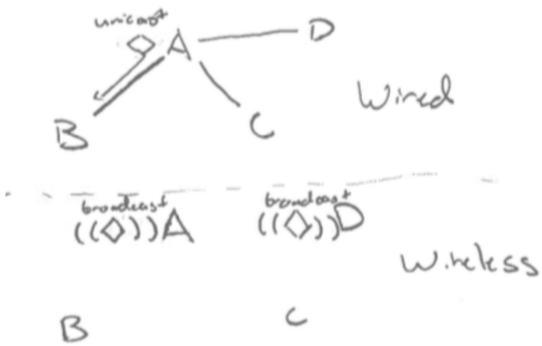
- **MAC**: CSMA/CA – used in the 802.11 wifi protocol
- **Rate Adaptation**: SampleRate

Definition: A *MAC* arbitrates the communication medium between nodes.

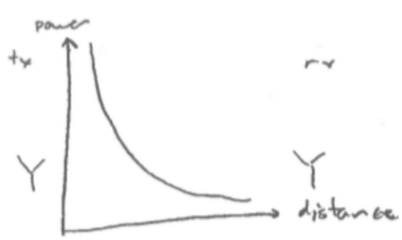
3 Properties of Wireless Channels

Wireless channels differ from wired channels in several ways.

1. **Shared**: In a wireless network, all transmissions of data are broadcast to all nodes (unlike in a wired network).



2. **Range**: There exists a range, defined by *power*, at which sends on the eventually fade out. Power falls proportional to distance squared $P = \frac{1}{d^2}$.



Definition: The *RSSI* or Received Signal Strength Indicator of a signal is defined by its power at the receiver.

Power decays due to many factors:

- Distance
- Occlusion/obstacles
- Directionality
- Differences in hardware
- The multipath effect

Wireless signals may traverse multiple paths from a transmitter to a receiver. Since signals are actually waves, they can combine in different ways (e.g., constructively or destructively) at the receiver. In general, it is not possible to predict these patterns *a priori* even though the exist.

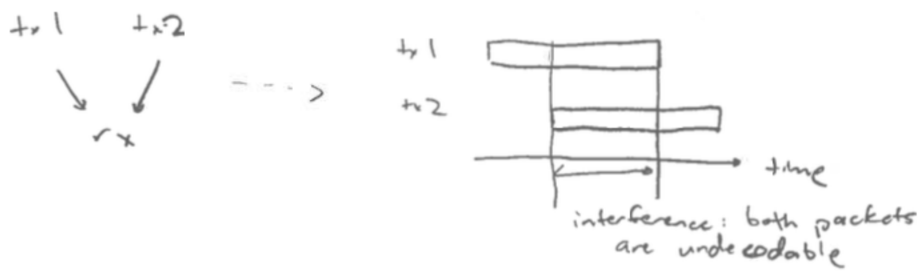
Definition: We can define the *signal-to-noise ratio (SNR)* of a transmission with the following formula: SNR = RSSI / (noise power + interference power).

In addition to a signal, the receiver will hear noise (e.g., coming from hardware) and interference from the environment (e.g., someone else is transmitting at the same time). We can define two additional thresholds and ranges:

- **Decoding range**: there exists a *decoding threshold* threshold$_{decoding}$ where the decoding range is defined as the area over which SNR > threshold$_{decoding}$.
- **Detection range**: there exists a *detection threshold* threshold$_{detection}$ where the detection range is defined as the area over which SNR > threshold$_{detection}$.

In general, threshold$_{decoding}$ >> threshold$_{detection}$. This is important in wireless communications because it suffices to listen above threshold$_{detection}$ to identify if someone else is transmitting on some medium.

3. **Half-Duplex**: Wireless radios cannot transmit and receive at the same time.



In this case, neither one of `tx1` nor `tx2` can detect the transmissions of the other while it transmits itself. However, `tx2` can listen for the transmissions of `tx1` first.

4 MAC Protocols

All MAC protocols want to achieve two objectives:

- **Fairness**: We want equal allocation of some resource. Candidate resources:
  1. Frequency spectrum
  2. Time
  3. Throughput

  These may be different notions of fairness; for instance, if two nodes transmit at different rates, time $\neq$ throughput.
- **Efficiency**: We want to maximize usage of a channel (i.e. maximize throughput, minimize delay).

MAC protocol are based on two ideas:

- **Reservation**-based: a special centralized *base station* allocates resources

- **Contention**-based: nodes attempt to transmit and back off if they fail

Some reservation-based MACs:

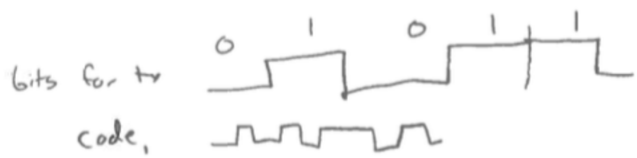
1. TDMA (by time slot)

User1	User2	User3	...
t_1	t_2	t_3	...

2. FDMA (by frequency)

User1	User2	User3	...
f_1	f_2	f_3	...

3. CDMA (using orthogonal codes)



The transmitter will transmit bits $*$ code_1.

The receiver then computes

$$S_1 = \sum_i \text{bits}_i * \text{code}_1 * \text{code}'_1$$
$$S_2 = \sum_i \text{bits}_i * \text{code}_1 * \text{code}'_2$$
$$\dots$$

where code'_1 is the complex conjugate of code_1.

Due to the orthogonality of the code_k, S_1 will show a high correlation while none of the others will. Note that this allows for simultaneous usage of the channel by multiple nodes, but does not increase the total available capacity of the channel due to the overhead of the codes—it's just another way to divide up resources.

Pros of reservation-based MAC:

- Can achieve very high efficiency

Cons of reservation-based MAC:

- Requires centralized node to arbitrate
- Performs poorly with bursty traffic

Pros of contention-based MAC:

- Distributed; no need for centralized entity
- Deals with bursty traffic

Cons of contention-based MAC:

- Can be less efficient (due to collisions)

4.1 CS/CSMA

The main idea of Carier Sense Multiple Access (CS/CSMA) is to listen before transmitting. As a sketch of the protocol, each node:

1. Chooses (at random) a number $b \in [0, CW_M]$ for some waiting period CW_M (30μs)
2. Listens until the medium is idle
3. If the medium is idle, waits for the DIFS interval (50 μs)
   (a) Decrements b
   (b) If $b = 0$ and the medium is idle, transmits
4. If there was a collision (did not hear an ACK), back off, setting $CW_M = 2CW_M$
5. If transmission succeeded, set $CW_M = 0$

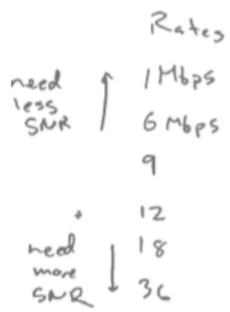
Example (letting $b_1 = 2, b_2 = 5$):

Note that if CSMA resets b while someone else is talking, carriers with higher numbers will never get the chance to talk. Instead, after it's detected that the other transmitter has stopped transmitting, a transmitter resumes with the old counter.

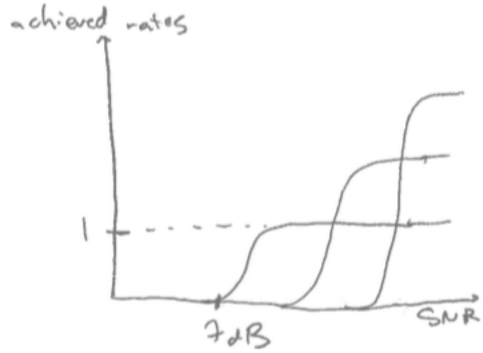
If both transmitters picked the same value of b, a collision happens, and then neither receiver receives an ACK. (Packets have a checksum to detect collisions.)

5 RA and SampleRate

With a wireless transmitter we can choose a bitrate. Lower bitrates work at a lower SNR.



Below some SNR a bitrate is undecodable; above it, it rises to its maximum throughput.



The goal of RA is to pick the transmission rate that maximizes throughput. An RA mechanism involves

- A feedback mechanism (ACKs, SNR, BER) and
- An algorithm (how to choose a transmission rate based on the feedback)

SampleRate uses the number of ACKs. Given a 10-second window:

- After every 9 packets, sample a random rate.
- To test that rate, transmit at that rate and see whether it is acknowledged.
- Measure the average rate T_{avg}.