Lecture 5: Wireless Physical Layer: Wrap-up

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Recap

- Radio waves as carriers of data bits in mobile physical layers
- Modulation techniques
  - Single carrier: ASK, FSK, PSK, QAM
  - Multi-carrier: OFDM
- Channel coding
  - Block codes
  - Convolutional codes
- Wireless channel
  - Path loss (slower timescale)
  - Multipath fading (faster timescale)
  - Channel noise
  - Channel impulse response (h) and channel frequency response (H)
  - Coherence bandwidth and coherence time of the channel
- Shannon’s channel capacity formula
  - Signal to noise ratio (SNR) decides how easily you can distinguish bits
  - Channel bandwidth and limits on how fast you can send digital pulses

Putting it all together: transmission

- We will describe how a WiFi / 802.11 physical layer works. Let's take the example of 802.11g
- 20 MHz bandwidth in the 2.4Ghz band is used
- The physical layer transmits one frame (obtained from higher MAC layer) at a time
- CRC is added to the message to enable error detection
- Bits in a packet converted to coded bits using a convolutional code
- Interleaving of coded bits to withstand burst errors
- Bits split into 48 parallel streams for OFDM (OFDM uses 64 subcarriers, but only 48 carry data)
- In each subcarrier stream, bits are grouped into symbols based on the modulation scheme used (BPSK has 1 bit per symbol, QPSK has 2, QAM16 has 4, QAM64 has 8)

Putting it all together: transmission (2)

- Each group of bits is modulated using the corresponding subcarrier
  - Group of bits mapped to amplitude/phase values of the subcarrier wave (using constellation diagrams)
  - The vector of 64 such aplitude/phase values are passed through iFFT to get a 64-sample time domain signal
  - The time domain signal is converted to the appropriate higher frequency by modulating with a carrier at 2.4 Ghz
- A physical layer header describing the modulation, coding, frame length etc is added to the start of the packet
- A special preamble symbol is added to the start of the frame. The preamble is a known set of bits modulated by BPSK, so all WiFi nodes know what the signal looks like

Putting it all together: reception

- Receiver is always searching the radio waves at the given frequency for the special known preamble
- When the preamble is found, the receiver detects start of the frame and starts decoding the samples
- The wireless channel h is estimated from the preamble and compensated on all subsequent samples of the packet
- The receiver takes each OFDM symbol, splits it into subcarriers (by using FFT), uses the amplitude and phase of the subcarrier to demodulate the transmitted bits
- The demodulated bits are de-interleaved and passes through a channel decoder (e.g., Viterbi decoder) to recover the original message bits from the decoded bits
- Finally, CRC is checked to see if all bits received correctly
- Correct frames are passed up to higher layers

Bit rate of a transmission

- Each OFDM symbol has 64 samples
  - 64 subcarriers, after iFFT, result in 64 time samples
- On a 20MHz channel, we can send 20M samples per second
- At 20M samples/sec, each symbol takes 3.2 microseconds
- A 0.8 microsecond guard time added to each symbol
- Therefore, each OFDM symbol takes 4 microsec.
- Channel delay spread of the order 100ns, so very little ISI
- If single carrier modulation were used, note that symbols have had to be 64 times shorter

Bit rate of a transmission (2)

- Bit rate depends on modulation and coding scheme used
- For example, QAM16 and rate ½ code
- Each OFDM symbol has 48 data subcarriers -> 48*4 coded bits -> 48*2 data bits
- 96 bits in one symbol in 4 microsec -> bit rate is 96/4 = 24 Mbps
- Similarly, we can get all bit rates in 802.11g (6, 9, 12, 18, 24, 36, 48, 54 Mbps) by various combinations of modulation (BPSK, QPSK, QAM16, QAM64) and coding rates (1/2, 2/3, 3/4)

Bit rate of a transmission (3)

- Higher bit rates require higher SNR to work properly
- For example, if SNR is 10dB, 6Mbps and 9Mbps rates may have 0% loss, 12 Mbps rate has 10% loss, 18 Mbps has 50% loss, and 24Mbps and higher have 100% loss. What is the best bit rate to use?
- Clearly, 12 Mbps has higher throughput = bit_rate * packet_delivery_ratio
- We will study how bit rates are picked in WiFi in detail later in the course
- For now, understand where the numbers in the rates come from.

MIMO – new idea

- Recent physical layer designs (e.g., newer WiFi standards like 802.11n, and cellular systems like LTE) use a new concept called multiple-input-multiple-output (MIMO) to improve physical layer rates further
- In MIMO, you have multiple antennas at transmitter and receiver
- You can use multiple antennas in two ways
  - Send and receiver multiple copies of the same signal, to increase chances of successful reception (transmit / receive diversity mode)
  - Send multiple parallel streams of data (spatial multiplexing mode)
- Notation: 2X2 MIMO means 2 transmit antennas and 2 receive antennas

MIMO (2)

- Receive diversity – if you have multiple antennas at receiver, you can receive multiple copies of the signal and combine them in an optimal way. This way, you can get lower errors.
- Transmit diversity – send multiple copies of the signal in a clever way so that they combine constructively at receiver
- Spatial multiplexing – send multiple parallel streams of information between sender and receiver. If you have N transmit antennas and N receive antennas, you can theoretically send N parallel streams of data between sender and receiver
- For example, consider the 54 Mbps rate (in a single antenna system). If used in spatial multiplexing mode in 2X2 MIMO configuration, we can get a rate of 108 Mbps