Wireless Networks

Lecture 7: Physical Layer
Diversity and Coding

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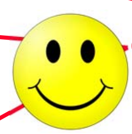
Outline

- RF introduction
- Modulation and multiplexing
- Channel capacity
- Antennas and signal propagation
- Modulation
- Diversity and coding
  - » Space, time and frequency diversity
- OFDM

Typical
Bad News
Good News
Story



Diversity Techniques

- The quality of the channel depends on time, space, and frequency
- Space diversity: use multiple nearby antennas and combine signals
  - » Both at the sender and the receiver
- Time diversity: spread data out over time
  - » Useful for burst errors, i.e., errors are clustered in time
- Frequency diversity: spread signal over multiple frequencies
  - » For example, spread spectrum
- Distribute data over multiple "channels"
  - » "Channels" experience different frequency selective fading, so only part of the data is affected

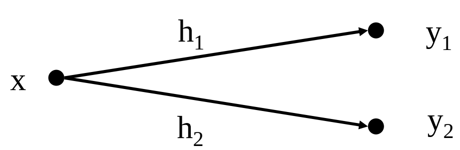
Space Diversity

- Use multiple antennas that pick up the signal in slightly different locations
- If antennas are sufficiently separated, the channels are independent
- If one antenna experiences deep fading, chances are that the other antenna has a strong signal
  - » Antennas should be separated by ½ wavelength or more
- Represents a wide class of techniques
  - » Use on transmit and receive side - channels are symmetric
  - » Level of sophistication of the algorithms used
  - » Can use more than two antennas!

Receiver Diversity

- Selection diversity: pick antenna with best SNR
  - » Simplest solution!
- But why not use both signals? What are the benefits and concerns?
  - » Contain more information
  - » Signals may be out of phase, e.g. kind of like multi-path
  - » We want to make sure we do not amplify the noise
- Maximal ratio combining: combine signals with a weight that is based on their SNR
  - » Weight will favor the strongest signal (highest SNR)
  - » Also: equal gain combining as a quick and dirty alternative

Receiver Diversity Optimization



$$\vec{\mathbf{y}} = \vec{\mathbf{h}} * \mathbf{x} + \vec{\mathbf{n}}$$

$$\vec{x} = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

- Multiply $\vec{y}$ with the complex conjugate $\vec{h}^*$ of the channel vector $\vec{h}$
  - » Aligns the phases of the two signals so they amplify each other
  - » Scales the signals with their magnitude so the effect of noise is not amplified
- Can learn $\vec{h}$ based on training data

The Details

- Complex conjugates: same real part but imaginary parts of opposite signs

$$\vec{h}^* * \vec{y} = \vec{h}^* * (\vec{h} * x + \vec{n})$$

$$\text{Where } h^* = [h_1^* \;\; h_2^*] = [\, a_1+b_1 i \;\; a_2-b_2 i]$$

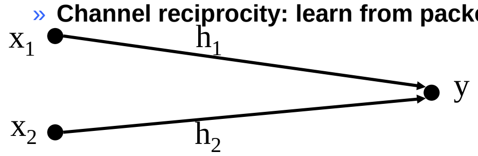
- Result:

  signal x is scaled by $a_1^2 + b_1^2 + a_2^2 + b_2^2$

  noise becomes: $h_1^* * n_1 + h_2^* * n_2$

Transmit Diversity

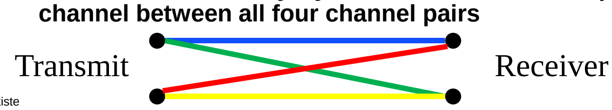
- Same as receive diversity but the transmitter has multiple antennas
- Selection diversity: transmitter picks the best antenna, i.e. with the best channel to receiver
- Maximum ratio combining: sender “precodes” the signal
  - » Pre-align the phases at receiver and distribute power over the transmit antennas (total power fixed)
- How does transmitter learn channel?
  - » Gets explicit feedback from the receiver
  - » Channel reciprocity: learn from packets received Y



$$y = \vec{h} * \vec{x} + n$$

Simple Algorithm in (older) 802.11

- Use transmit + receive selection diversity
  - » Assume packets are acknowledged – why?
- How to explore all channels to find the best one … or at least the best transmit antenna
- Receiver:
  - » Uses the antenna with the strongest signal
  - » Always use the same antenna to send the acknowledgement – gives feedback to the sender
- Sender:
  - » Picks an antenna to transmit and learns about the channel quality based on the ACK
  - » Needs to occasionally try the other antenna to explore the channel between all four channel pairs

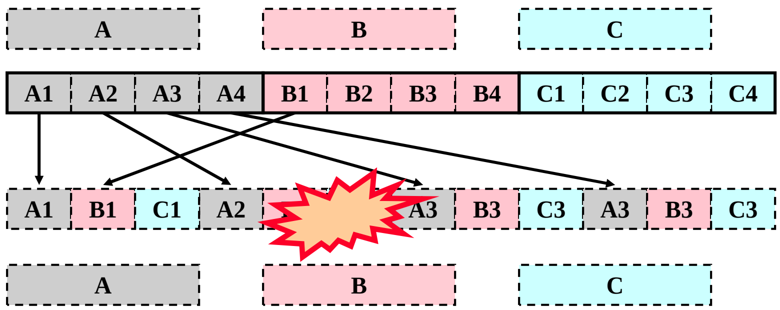


Adding Redundancy

- Protects digital data by introducing redundancy in the transmitted data.
  - » Error detection codes: can identify certain types of errors
  - » Error correction codes: can fix certain types of errors
- Block codes provide Forward Error Correction (FEC) for blocks of data.
  - » (n, k) code: n bits are transmitted for k information bits
  - » Simplest example: parity codes
  - » Many different codes exist: Hamming, cyclic, Reed-Solomon, …
- Convolutional codes provide protection for a continuous stream of bits.
  - » Coding gain is n/k
  - » Turbo codes: convolutional code with channel estimation

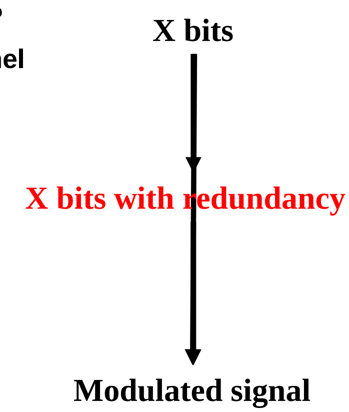
Combine Redundancy with Time Diversity

- Fading can cause burst errors: relatively long sequence of bits is corrupted
- Spread blocks of bytes out over time so redundancy can help recover from the burst
  - » Example: only need 3 out of 4 to recover the data



Bits, Symbols, and Chips

- Redundancy and time diversity can be added easily at the application layer
- Can we do it lower in the stack?
  - » Need to adapt quickly to the channel
- So far: use bits to directly modulate the signal
- Idea: add a coding layer – provides a level of indirection
- Can add redundancy and adjust level of redundancy quickly based on channel conditions



Discussion

- Error coding increases robustness at the expense of having to send more bits
  - » Technically this means that you need more spectrum
- But: since you can tolerate some errors, you may be able to increase the bit rate through more aggressive modulation
- Coding and modulation combined offer a lot of flexibility to optimize transmission
- Next steps:
  - » Apply a similar idea to frequency diversity
  - » Combine coding with frequency and time diversity in OFDM

Summary

- Space diversity really helps in overcoming fading
  - » Very widely deployed
  - » Will build on this when we discuss MIMO
- Coding is also an effective way to improve throughput
  - » Widely used in all modern standards
  - » Coding, combined with modulation, can be adapt quickly to channel conditions