Wireless Networks
Lecture 8: Physical Layer
Spread Spectrum and CDMA

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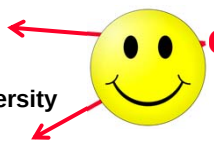
Outline

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



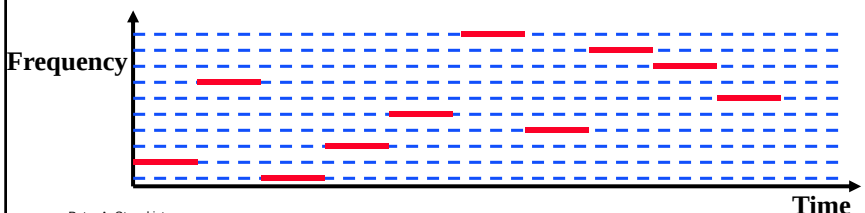
Typical Bad News Good News Story

Spread Spectrum

- Spread transmission over a wider bandwidth
  - » Don't put all your eggs in one basket!
- Good for military: jamming and interception becomes harder
- Also useful to minimize impact of a "bad" frequency in regular environments
- But what is the cost?
- What can be gained from this apparent waste of spectrum?
  - » Immunity from various kinds of noise and multipath distortion
  - » Can be used for hiding and encrypting signals
  - » Several users can independently use the same higher bandwidth with very little interference

Frequency Hopping Spread Spectrum (FHSS)

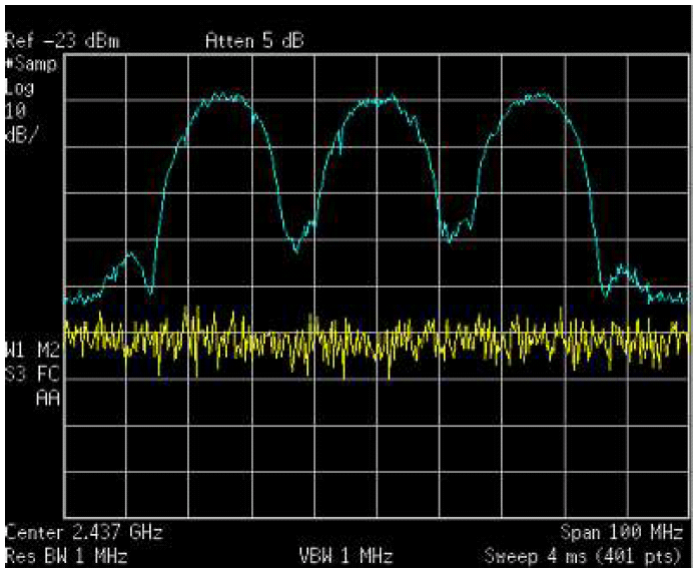
- Have the transmitter hop between a seemingly random sequence of frequencies
  - » Each frequency has the bandwidth of the original signal
- Dwell time is the time spent using one frequency
- Spreading code determines the hopping sequence
  - » Must be shared by sender and receiver (e.g. standardized)



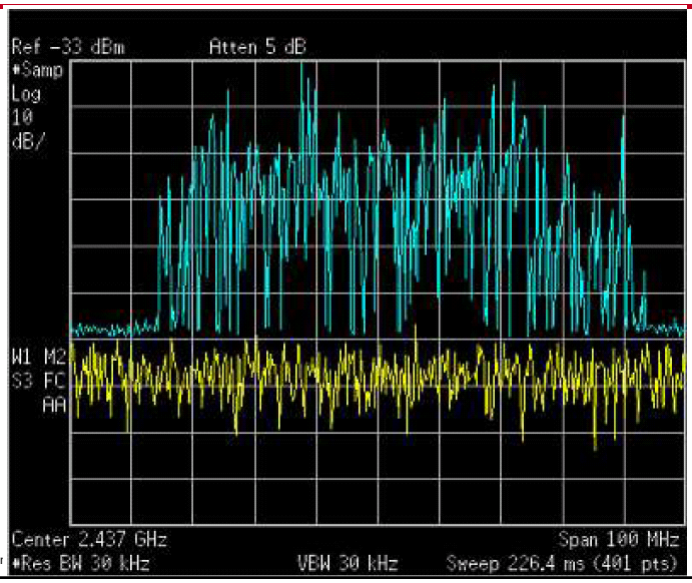
Example: Original 802.11 Standard (FH)

- Used frequency hopping: 96 channels of 1 MHz
  - » Only 78 used in US; other countries used different numbers
  - » Each channel carries only ~1% of the bandwidth
  - » Uses 2 GFSK or 4 GFSK for modulation (1 or 2 Mbps)
- The dwell time was configurable
  - » FCC set an upper bound of 400 msec
  - » Transmitter/receiver must be synchronized
- Standard defined 26 orthogonal hop sequences
- Transmitter used a beacon on fixed frequency to inform the receiver of its hop sequence
- Can support multiple simultaneous transmissions – use different hop sequences
  - » E.g. up to 10 co-located APs with their clients

802.11 Spectrogram



Frequency Hopping Spectrogram

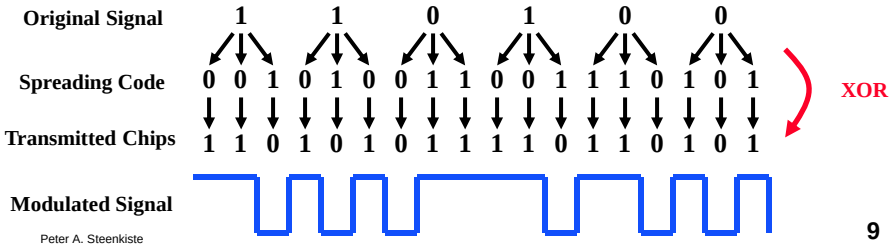


Example: Bluetooth

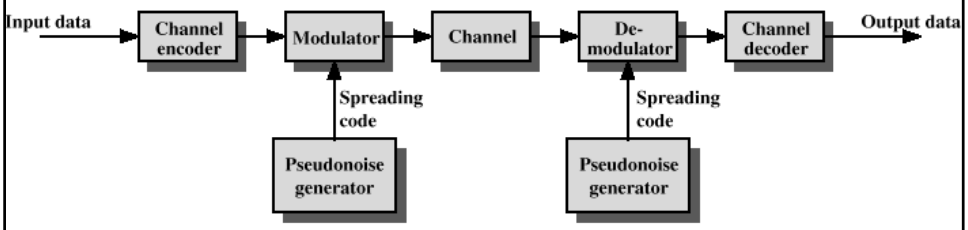
- Uses frequency hopping spread spectrum in the 2.4 GHz ISM band
- Uses 79 frequencies with a spacing of 1 MHz
  - » Other countries use different numbers of frequencies
- Frequency hopping rate is 1600 hops/s
- Signal uses GFSK
  - » Mimimum deviation is 115 KHz
- Maximum data rate is 1 MHz

Direct Sequence Spread Spectrum (DSSS)

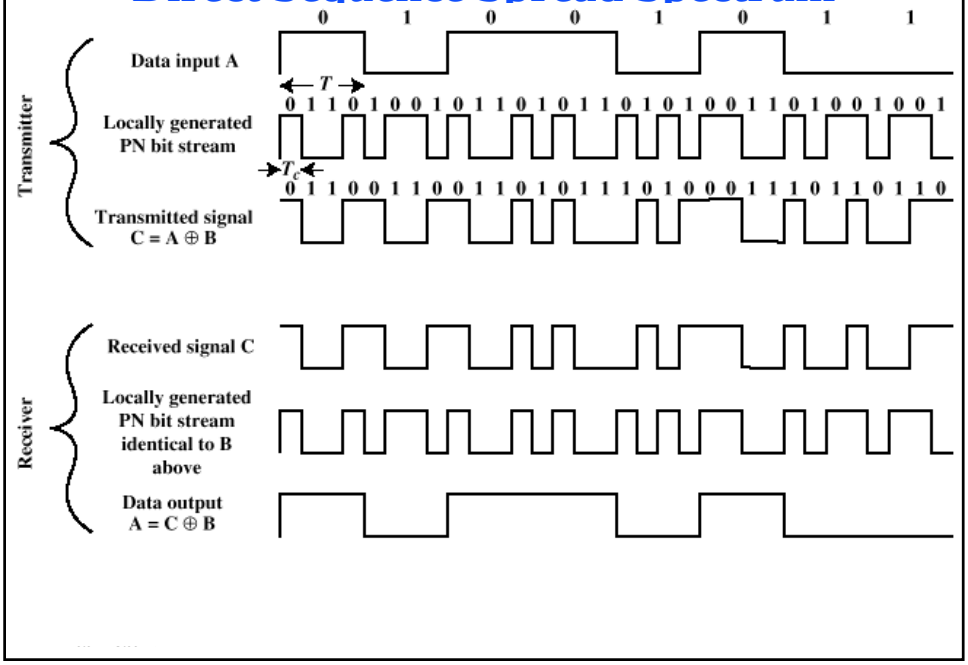
- Each bit in original signal is represented by multiple bits (chips) in the transmitted signal
- Spreading code spreads signal across a wider frequency band
  - » Spread is in direct proportion to number of bits used
  - » E.g. exclusive-OR of the bits with the spreading code
- The resulting bit stream is used to modulate the signal



Spread Spectrum



Direct Sequence Spread Spectrum



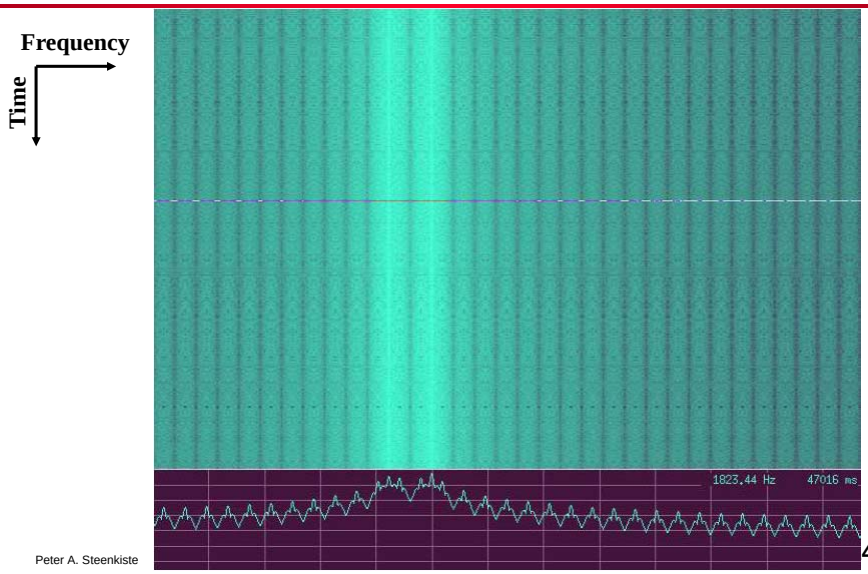
Properties

- **Since each bit is sent as multiple chips, you need more bps bandwidth to send the signal.**
  - » Number of chips per bit is called the spreading ratio
- **Given the Nyquist and Shannon results, you need more spectral bandwidth to do this.**
  - » Spreading the signal over the spectrum
- **Advantage is that is transmission is more resilient.**
  - » Effective against noise and multi-path
  - » DSSS signal will look like noise in a narrow band
  - » Can lose some chips in a word and recover easily
- **Multiple users can share bandwidth (easily).**
  - » Follows directly from Shannon (capacity is there)
  - » Next topic

Example: Original 802.11 Standard (DSSS)

- The DS PHY uses a 1 Msymbol/s rate with an 11-to-1 spreading ratio and a Barker chipping sequence
  - » Barker sequence has low autocorrelation properties – why?
  - » Uses about 22 MHz
- Receiver decodes by counting the number of "1" bits in each word
  - » 6 "1" bits correspond to a 0 data bit
- Chips were transmitted using DBPSK modulation
  - » Resulting data rate is1 Mbps (i.e. 11 Mchips/sec)
  - » Extended to 2 Mbps by using a DQPSK modulation
    - – Requires the detection of a ¼ phase shift

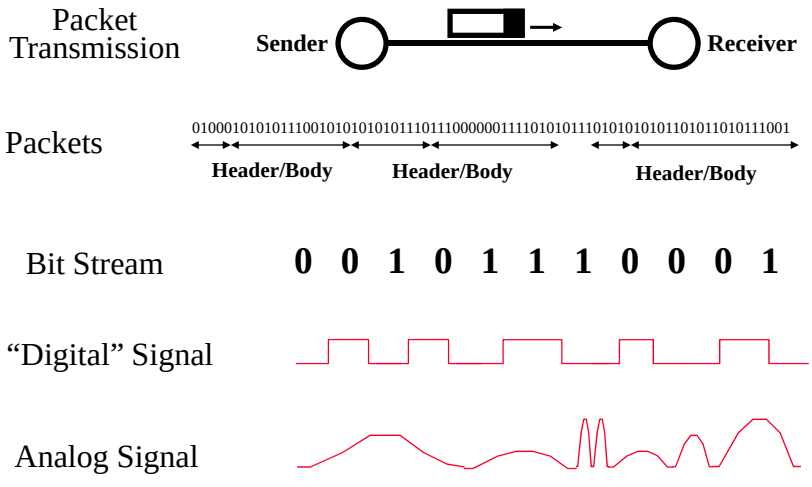
Spectrogram: DSSS-encoded Signal



Outline

- RF introduction
- Modulation and multiplexing
- Channel capacity
- Antennas and signal propagation
- Equalization and diversity
- Modulation and coding
  - » Coding and modulation
  - » Amplitude, frequency, phase
  - » Code division multiple access
  - » OFDM
- Some newer technologies
- Spectrum access

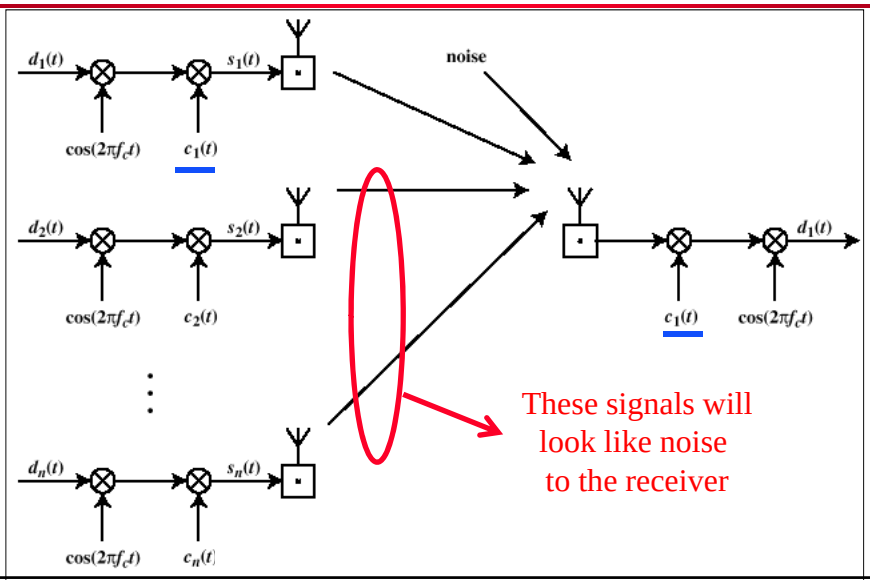
From Signals to Packets



Code Division Multiple Access

- Users share spectrum, i.e., use it at the same time, but they use different codes to spread their data over the frequency
  - » DSSS where users use different spreading sequences
  - » Use spreading sequences that are orthogonal, i.e. they have minimal overlap
  - » Frequency hopping with different hop sequences
- The idea is that users will only rarely overlap and the inherent robustness of DSSS will allow users to recover if there is a conflict
  - » Overlap = use the same the frequency at the same time
  - » The signal of other users will appear as noise

CDMA for Direct Sequence Spread Spectrum



CDMA Discussion

- CDMA does not assign a fixed bandwidth but a user's bandwidth depends on the traffic load
  - » More users results in more "noise" and less throughput for each user, e.g. more information lost due to errors
  - » How graceful the degradation is depends on how orthogonal the codes are
  - » TDMA and FDMA have a fixed channel capacity
- Weaker signals may be lost in the clutter
  - » This will systematically put the same node pairs at a disadvantage – not acceptable
  - » The solution is to add power control, i.e. nearby nodes use a lower transmission power than remote nodes

CDMA Example

- CDMA cellular standard.
  - » Used in the US, e.g. Sprint
- Allocates 1.228 MHz for base station to mobile communication.
  - » Shared by 64 "code channels"
  - » Used for voice (55), paging service (8), and control (1)
- Provides a lot error coding to recover from errors.
  - » Voice data is 8550 bps
  - » Coding and FEC increase this to 19.2 kbps
  - » Then spread out over 1.228 MHz using DSSS; uses QPSK

Summary

- Spread spectrum achieves robustness by spreading out the signal over a wide channel
  - » Sending different data blocks on different frequencies, or
  - » Spreading all data across the entire channel
- CDMA builds on the same concept by allowing multiple senders to simultaneously use the same channel
  - » Sender and receive must coordinate so receiver can decode the data