Wireless communication

- Electromagnetic waves propagating through space
- Data is carried over the waves
Physical properties of electromagnetic waves

• Defined by a frequency (or wavelength)

\[ \text{Wavelength} = \frac{\text{speed}}{\text{frequency}} \]

• All electromagnetic waves travel at the speed of light (in vacuum)
  – What is the wavelength of a 100MHz wave?

• Fact: Bigger the wavelength, bigger the antenna
Electromagnetic spectrum

- Different frequencies have different properties
  - Higher frequencies more directional, e.g., light
  - Lower frequency waves pass through buildings
Radio spectrum

- Travel long distances, penetrate through buildings
- Omnidirectional
- Used by radio, TV stations (when TV stations where analog), Microphones, Cellular, Public safety, Government,.....

- But......
  - Interference is a huge problem

- Solution
  - Government licenses spectrum
Spectrum is expensive!!!
Unlicensed band

- ISM bands – Industrial, Scientific, and Medical
- Free for use at low power; devices manage interference
  - Widely used for networking;, Bluetooth, Zigbee, Microwave
  - Most importantly WiFi
- What percentage of the entire spectrum is used by 802.11?
  - 0.06%
Recap

• What kinds of communications can occur in the radio spectrum?
• Why is the radio spectrum suitable for many kinds of communication?
• Will you use the radio spectrum to operate your remote? Why? Why not?
• Why is 802.11 (relatively speaking) free while you pay for cellular connectivity?
WiFi

- The frequency of the data signal is much less than the frequency of the radio wave
- Usually data is sent at the baseband frequency, but it now needs to be converted to the frequency of the radio wave (passband)
WiFi modulation

- Modulate the carrier signal with the modulating signal
  - The modulating signal has data; the carrier signal is the radio wave

- To modulate, you can change the amplitude, the phase, or the frequency

![Frequency shift keying](image)

```
<table>
<thead>
<tr>
<th>Bit Sequence</th>
<th>NRZ Signal of Bits</th>
<th>Amplitude Shift Keying</th>
<th>Frequency Shift Keying</th>
<th>Phase Shift Keying</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 1 0 1 1 0 0</td>
<td>0 1 0 1 1 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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Adding more bits per symbol

- Combine the amplitude, frequency, and phase modulation to add more symbols per bit

- BPSK: 2 symbols, 1 bit/symbol
- QPSK: 4 symbols, 2 bits/symbol
- QAM-16: 16 symbols, 4 bits/symbol
- QAM-64: 64 symbols, 6 bits/symbol

BPSK/QPSK varies only phase
QAM varies amplitude and phase
Difference between wired and wireless links

- Guided versus un-guided medium
  - Path loss: radio signal attenuates as it propagates through matter
  
  - multipath propagation: radio signal reflects off objects ground, arriving at destination at slightly different times
  
  - interference from other sources: standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices

But the most important of all, wireless loss is a lot more difficult to predict, than wired.
Path loss

- Path loss for unobstructed Line of sight path
- Power falls off:
  - Proportional to $1/d^2$
- Without line of sight, power falls of proportion to $1/d^n$, for $n$ between 2 and 4
Problems with the simple path loss model

Usually perfect line of sight is not available
– Reflection: From objects very large (wrt to wavelength of the wave).

– Diffraction: From objects that have sharp irregularities.

– Scattering
  • From objects that are small (when compared to the wavelength)
  • E.g.: Rough surfaces
Multipath propagation

11110010 ...

Host A

Reflection

Diffraction

Host B
Wireless interference
Recap

• What is a modulated signal? Why do signals need to be modulated?
  – What properties can I vary to modulate a signal?
  – What if I have to increase the number of symbols per bit?
  – Can I infinitely increase the number of symbols per bit?

• Why are wireless signals much more unpredictable than wired signals?
Other wireless technologies

- **Indoor**
  - 10-30m

- **Outdoor**
  - 50-200m
  - 200m – 4 Km
  - 5Km – 20 Km

- **Data rate (Mbps)**
  - 0.056
  - 0.384
  - 5-11
  - 4
  - 1
  - 54
  - 200

- **WiFi**
  - 802.15
  - 802.11b
  - 802.11a,g
  - 802.11n

- **Bluetooth**
  - 802.15

- **Cellular**
  - IS-95, CDMA, GSM
  - UMTS/WCDMA, CDMA2000
  - UMTS/WCDMA-HSPDA, CDMA2000-1xEVDO

- **WiMax**
  - 802.16 (WiMAX)
  - 802.16 (WiMAX) enhanced

- **Data rates**
  - 2G
  - 3G
  - 3G cellular enhanced

- **Enhancements**
  - 802.11n
  - 802.11a,g
  - 802.11b
  - 802.15
  - UMTS/WCDMA, CDMA2000
  - UMTS/WCDMA-HSPDA, CDMA2000-1xEVDO
  - 802.16 (WiMAX)
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Generations of mobile telephone systems

1G, analog voice
  • AMPS (Advanced Mobile Phone System) is example, deployed from 1980s.

2G, analog voice and digital data
  • GSM (Global System for Mobile communications) is example, deployed from 1990s. Modulation based on QPSK.

3G, digital voice and data
  • UMTS (Universal Mobile Telecommunications System) is example, deployed from 2000s. Modulation based on CDMA

4G, digital data including voice
  • LTE (Long Term Evolution) is example, deployed from 2010s. Modulation based on OFDM
Cellular mobile phone systems

Fundamental difference between cellular and WiFi: Long range communication

• Needs more bandwidth
• More interference: Frequencies need to be re-used

For the same spectrum, why does WiFi not have to do frequency re-use?
So, where are we?

- Abstract model is typically all we will need
  
  Message $M$ bits  \hspace{4cm} \text{Rate } R \text{ Mbps} \hspace{4cm} \text{Delay } D \text{ seconds}

- In wireless, you also need the Bit Error Rate (BER)
Message Latency

• How long does it take to send a message?

  ![Diagram of message latency with two blue squares connected by an arrow labeled Delay D, Rate R and a red line connecting a square labeled Message M to another square.]

• Two terms:
  – Propagation delay = distance / speed of signal in media
    • How quickly a message travels over the wire
    • 2/3c for copper wire
  – Transmission delay = message (bits) / rate (bps)
    • How quickly you can inject the message onto the wire
  – Propagation delay tells you when the FIRST bit arrives,
    Transmission delay tells you when the LAST bit arrives.

• Later we will see queuing delay ...
One-way Latency

Dialup with a modem:
- \( D = 10\text{ms}, \ R = 56\text{Kbps}, \ M = 1024\text{ bytes} \)
- \[ \text{Latency} = 10\text{ms} + \frac{(1024 \times 8)}{(56 \times 1024)} \text{ sec} = 153\text{ms}! \]

Cross-country with T3 (45Mbps) line:
- \( D = 50\text{ms}, \ R = 45\text{Mbps}, \ M = 1024\text{ bytes} \)
- \[ \text{Latency} = 50\text{ms} + \frac{(1024 \times 8)}{(45 \times 1024 \times 1024)} \text{ sec} = 50\text{ms}! \]

- Either a slow link or long wire makes for large latency
Latency and RTT

- Latency is typically the one way delay over a link
  - Arrival Time - Departure Time

- The round trip time (RTT) is twice the one way delay
  - Measure of how long to signal and get a response
Throughput

• Measure of system’s ability to “pump out” data
  – NOT the same as bandwidth
• Throughput = Transfer Size / Transfer Time
  – E.g., “I transferred 1000 bytes in 1 second on a 100Mb/s link”
    • BW?
    • Throughput?

• Transfer Time = SUM OF
  – Time to get started shipping the bits
  – Time to ship the bits
  – Time to get a response if necessary
Messages Occupy Space On the Wire

• Bandwidth delay product $= \text{bandwidth} \times \text{latency}$

• How many bits can the network store?
  – Consider a 1b/s network.
  – Suppose latency is 16 seconds.
  – Number of bits that the network “store” $= 1b/s \times 16s = 16b$
  – This is the BANDWIDTH-DELAY product
  – Measure of “data in flight.”

• Tells us how much data can be sent before a receiver sees any of it.
  – Twice B.D. tells us how much data we could send before hearing back from the receiver something related to the first bit sent.
  – What are the implications of high B.D.?
Bit error rate

• BER = number of error in bits/ number of transferred bits

• 101101 → 000101, BER = ?

• Packet error rate = number of incorrect data packets/total number of packets