Lecture 12 Channel Impairments

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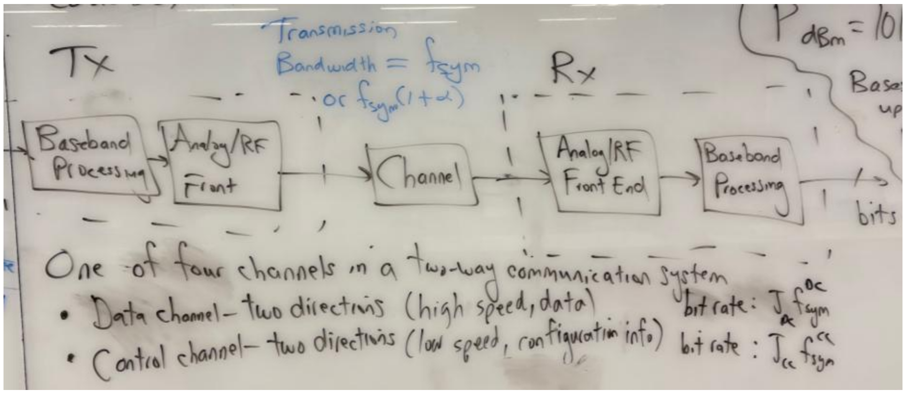
Review of Previous Lecture



- General block diagram to send bits from transmitter to receiver in a digital comm system
- A two-way digital communication system has four channels
  - bidirectional data channel (high speed, data)
  - bidirectional control channel (low speed, configuration info)
- Bandpass Tx bandwidth is f_{sym} or (1 + *a*) f_{sym} for raised cosine pulse shaping (*a* in [0, 1])
- Control channel: small J and f_{sym} and very low symbol error rate (e.g. 10^{-7})
- Data channel: high J and f_{sym} and symbol error rate 10^{-2} to 10^{-4} (10^{-2} means 1 error in 100 symbols)

Light Painting Wi-Fi Demo (Link)

- 4-meter light pole lights up more lights vertically for higher Wi-Fi received signal strength
- Long exposure pictures to show the RSSI in different parts of a city outside at night
- In some places, Wi-Fi reception is strong, medium, weak, or even non-existent.
- The primary impact on Wi-Fi reception strength is the reflection of RF waves off of metal objects in the environment.
- The Wi-Fi access points are indoors, and hence, Wi-Fi transmissions would experience attenuation through walls, doors, and windows to reach the outside (about 10 dB).

Communications System Resources and Duplexing

- Time
  - Signals sent at different times in the same frequency band should not interfere with each other
  - *Example*: in time division duplexing (TDD), transmissions occur at different times in the same frequency band. In one-on-one conversations, TDD would be the case when one person speaks, the other listens and vice-versa.
- Frequency
  - Ideally, different signals sent in different frequency bands will not interfere with each other

- *Example*: in frequency division duplexing (FDD), two transmissions occur at the same time, but in different frequency bands

- Power
  - Increasing transmission power increases the received SNR, which lowers error
  - Cost: higher interference in adjacent frequency bands
- Space
  - Wasteful to send signal across all 360 degrees
  - *Example*: A cellular basestation divides its transmissions among three 120-degree sectors. Each sector has a separate set of antenna elements, and each antenna element has a 30-degree transmission range (12x more efficient than 360-degree transmission for the same transmit power).
- Codes
  - A 2G cellular basestation assigns each user equipment (phone) a different starting point in a very long PN sequence, and the code is used by the basestation to separate users who are transmitting at the same time in the same frequency band.
  - Satellite GPS transmitters use PN sequences to transmit data to GPS receivers

dBm

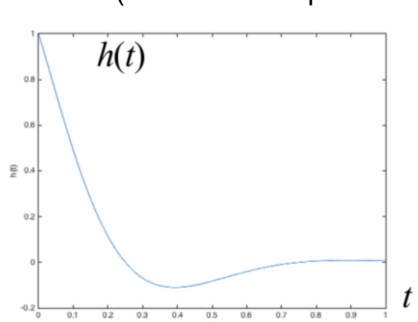
- dB calculation for power = 10 $\log_{10}$(power)
- dBm scales the power by 1mW = 10 $\log_{10}$(power/1mW)
- 1W = 30 dBm
- Cellular base stations can transmit up to 43dBm and phones up to 23 dBm

Thermal noise

- Randomness in analog/RF front end due to movement of electrons due to temperature
- NOT from channel
- Modeled as an additive Gaussian noise with zero mean and power sigma^2 due to the Central Limit Theorem applied to modeling the random fluctuations in voltage due to random motion of electrons as a sum of statistically independent random variables

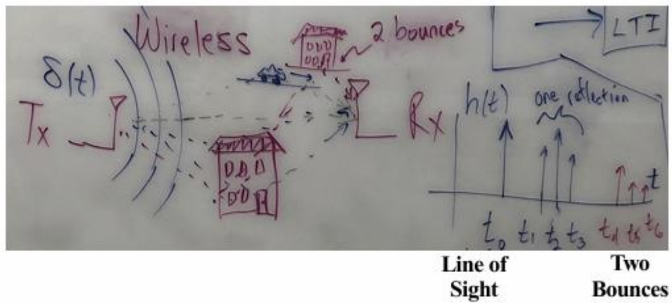
LTI effects

- RLC model of wired channel (non-trivial channel!)
- Example channel infinite impulse response dies out and can be truncated to be finite in duration (i.e. an filter impulse response filter response)

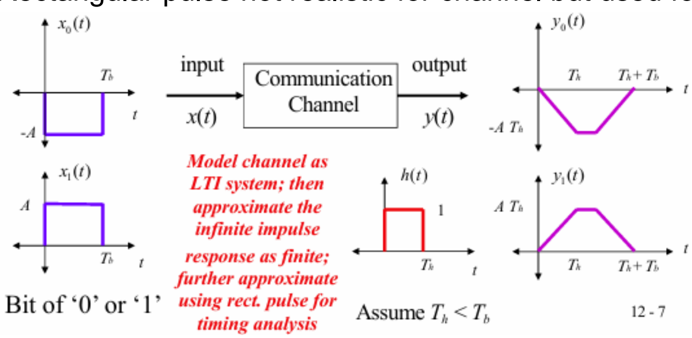


- Wireless LTI effects due to wave propagation: reflection, absorption, scattering

- ○ Different paths that have "bounced" off of physical objects will arrive later than our line-of-sight (no bounce) path
- ○ Non-LOS paths might have higher received amplitude than LOS due to constructive interference
- ○ Eventually, paths with a large number of bounces have negligible strength and the infinite impulse response can be truncated to be finite in length
- ○ Can send chirp or PN sequence to estimate channel impulse response



- Distortion in frequency: due to channel in frequency response
- Spreading in time: due to channel impulse response
  - ○ Rectangular pulse not realistic for channel but used for demonstration



- Periodically update LTI model because channel is not actually LTI
  - ○ Want to change when channel changes
- Phase jitter: fixed frequency experiences small phase shifts when passing through channel
  - ○ Visualize by superimposing each period on first in eye diagram
- Additive interference from other systems in the same band

Keysight Demo (Link, start at 0:51 mark)

- Microwave and wifi both use 2.4 GHz band
- When microwave is on, wifi speed is 5 times slower (bits per second is ⅕ of when microwave is off)
- Bluetooth transmissions are either 1 MHz or 2 MHz wide depending on which version
- Wi-Fi transmissions are 20 MHz wide
- Frequencies in the 2.90-2.99 GHz are not used by either Wi-Fi or Bluetooth – the thermal noise strength is visible there