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ADVANCED DIGITAL SIGNAL PROCESSING

Chapter 2: Wireless Channel

20/02/2017

Content

- Review
- Wireless Channel Overview
- Large-scale fading
  - Path loss
  - Shadowing
- Small-scale fading
  - Multi-path fading
  - Time variance

Frequency and Wavelength

- $c=\lambda f$
  - c: speed of light
  - λ: wavelength
  - f: frequency
- Example:
- AM radio with frequency 1710 kHz
- What's the wavelength? Ans: 175m
- What's the period? Ans: 584 ns

dB

- Decibels
  - $10 \log_{10}(x)$
  - Power in decibels
    - dB
    - Y dB=$10 \log_{10}$ (x Watt)
  - Power ratio in decibels
    - dB
    - Power P1, P2 in Watt
    - $10 \log_{10}(P1/P2)$
  - Example:
    - Input power 100W and output power 1W
    - What's the power ratio in decibel? Ans: 20dB

dBm

- dBm
  - Reference power is 1 mW
  - 10 $\log_{10}$ (Watts/10^{-3})
- Example:
  - 0 dB= 30dBm=1 Watt
- Summary
  - P (dBW) = 10 log (P/1 Watt)
  - P (dBm) = 10 log (P/1 mWatt)

Gain and Attenuation in dB or dBm

- Gain/attenuation in dB
  - $10\log_{10}$ (output power/input power)
    - Gain(dB)=Pout(dB)-Pin(dB)
  - Gain: Pout > Pin
  - Attenuation Pout<Pin
- Gain/attenuation in dBm
  - X(dBm)+Y(dB) =??(dB)=??(dBm)
  - X(dBm)-Y(dB) =??(dB)=??(dBm)
  - Example:
    - Input power is 2dBm, system gain is 5dB
    - What s output power? Ans: 7dBm
  - Notice: is it dB or dBm?

Wireless communication system

- Antenna gain
  - Transmitter antenna
  - Receiver antenna
- Wireless channel attenuation

- Questions: how do you represent the relationships between P_{tx} and P_{rx} ?
  - In dB
  - In Watt

Signal-to-Noise ratio

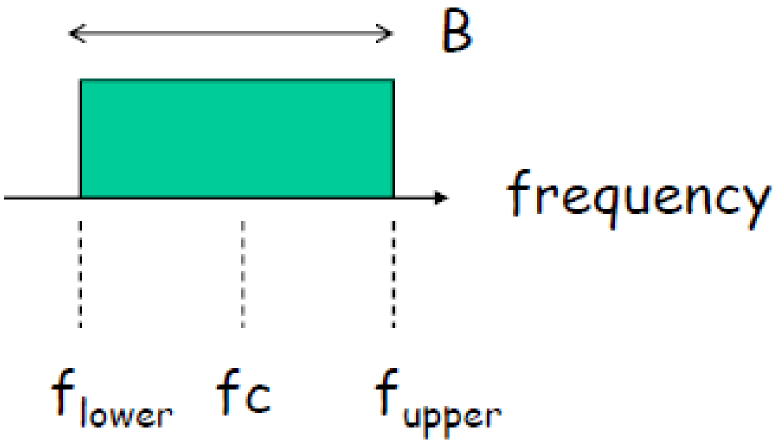
- S/N
  - SNR= signal power(Watt)/noise power(Watt)
  - Signal-to-Noise power ratio
  - Relate to the performance of communications systems
    - Bit-error probability
    - Shannon capacity
- SNR in dB
  - S/N(dB)= 10 $\log_{10}$ (S/N power ratio)
  - 10 $\log_{10}$ (signal power(Watt)/noise power(Watt))

Noise, Interference, SNR

- SNR
  - (signal power)/(noise power)
  - Noise: thermal noise
- SIR
  - Signal-to-Interference
    - Sometimes known as C/I (carrier-to-interference ratio)
  - (signal power)/(interference power)
  - Interference: signals from other simultaneous communications
- SINR
  - Signal-to-Interference-Plus-Noise ratio
  - (signal power)/(interference power + noise power)

Bandwidth

- $B=f_{upper}-f_{lower}$
- Carrier frequency: fc
- Example:
  - 802.11 2.4GHz ISM band (channel 1)
    - f_{upper}=2434 MHz
    - f_{lower}=2412 MHz
    - fc=2423 MHz
    - B=22 MHz



Thermal Noise

- Thermal noise power
  - $N = kT_N B$
  - N: power in Watt
  - k: Boltzman's constant= $1.38*10^{-23}$
  - T_N: temperature (degree Kelvin)
  - B: bandwidth of channel (Hz)

Bit Energy to Noise Ratio

- E_b/N_0
  - Energy per bit over the noise power spectral density
  - Related to SNR power ratio
  - Independent of bandwidth

Relate E_b/N_0 to SNR

- SNR=S/N (Watt/Watt)
- $E_b=St_b$
  - E_b: energy per bit (J)
  - S: signal power (carrier power) (W)
  - t_b: duration of a bit (s)
- $E_b/N_0=(S/N_0)*t_b = (S/N_0)*(1/f_b)$
- $N_0=N/B$
- N: total noise power (W)
- B: bandwidth (Hz)
- $E_b/N_0=(S/N)(B/f_b)$

S/N (or E_b/N_0)

- To compare systems, generally they should have the same transmitted S/N (or E_b/N_0)
- The S/N (or E_b/N_0) at the input to the receiver will determine the system performance

Example

- Find the Eb/N0 for a system operating at 2Mbps in a bandwidth of 1MHz. The carrier power is 0.1pW. The system noise temperature is 120K.
- Ans:

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Capture model

- $SNR_{received} \geq SNR_{threshold}$
  - Minimum SNR requirement, given a target bit error-rate (or frame-error-rate)

Shannon Capacity

- Theoretical (upper) bound of communication systems
- $C = B * \log_2 (1+S/N)$
  - C: capacity (bits/s)
  - B: bandwidth (Hz)
  - S/N: linear Signal-to-Noise ratio
- How to evaluate the performance of a communication scheme?
  - How close to Shannon bound?
  - Spectral efficiency
  - bit/s/Hz

Concepts Related to Channel Capacity

- Data rate
  - rate at which data can be communicated (bps)
- Bandwidth
  - the bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium (Hertz)
- Noise
  - average level of noise over the communications path
- Error rate - rate at which errors occur
  - Error
    - transmit 1 and receive 0
    - transmit 0 and receive 1

Shannon Capacity Formula

- Equation:

$$C = B \log_2(1 + SNR)$$

- Represents theoretical maximum that can be achieved in AWGN channel)
- In practice, only much lower rates achieved
  - Formula assumes white noise (thermal noise)
  - Impulse noise is not accounted for
  - Attenuation distortion or delay distortion not accounted for

Nyquist Bandwidth

- For binary signals (two voltage levels)
  - $C = 2B$
- With multilevel signaling
  - $C = 2B \log_2 M$
    - M = number of discrete signal or voltage levels

Example of Nyquist and Shannon Formulations

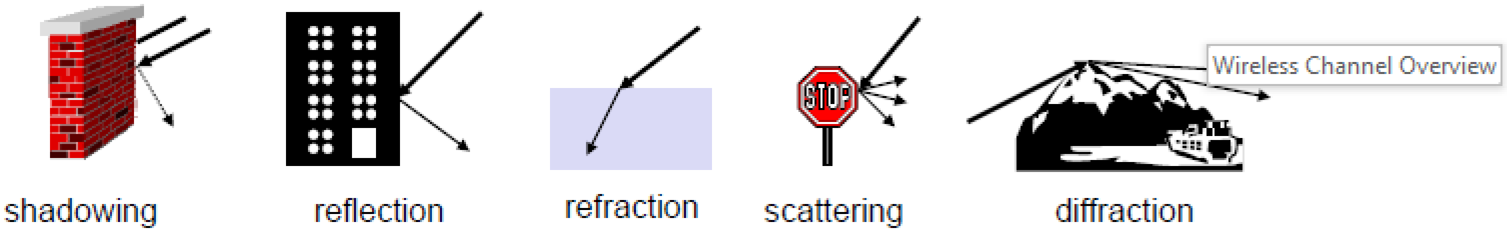
- Spectrum of a channel between 3 MHz and 4 MHz ; SNR_{dB} = 24 dB
  - B = 4MHz − 3MHz =1MHz
  - $SNR_{dB} = 24\ dB = 10\log_{10}(SNR)$
  - SNR = 251
- Using Shannon's formula
  - $C = 10^6 \times \log_2(1 + 251) \sim 10^6 \times 8 = 8Mbps$

Example of Nyquist and Shannon Formulations

- How many signaling levels are required?
  - $C = 2B\log_2 M$
  - $8x10^6 = 2x10^6 x\log_2 M$
  - $4 = \log_2 M$
  - $M = 16$

Signal propagation

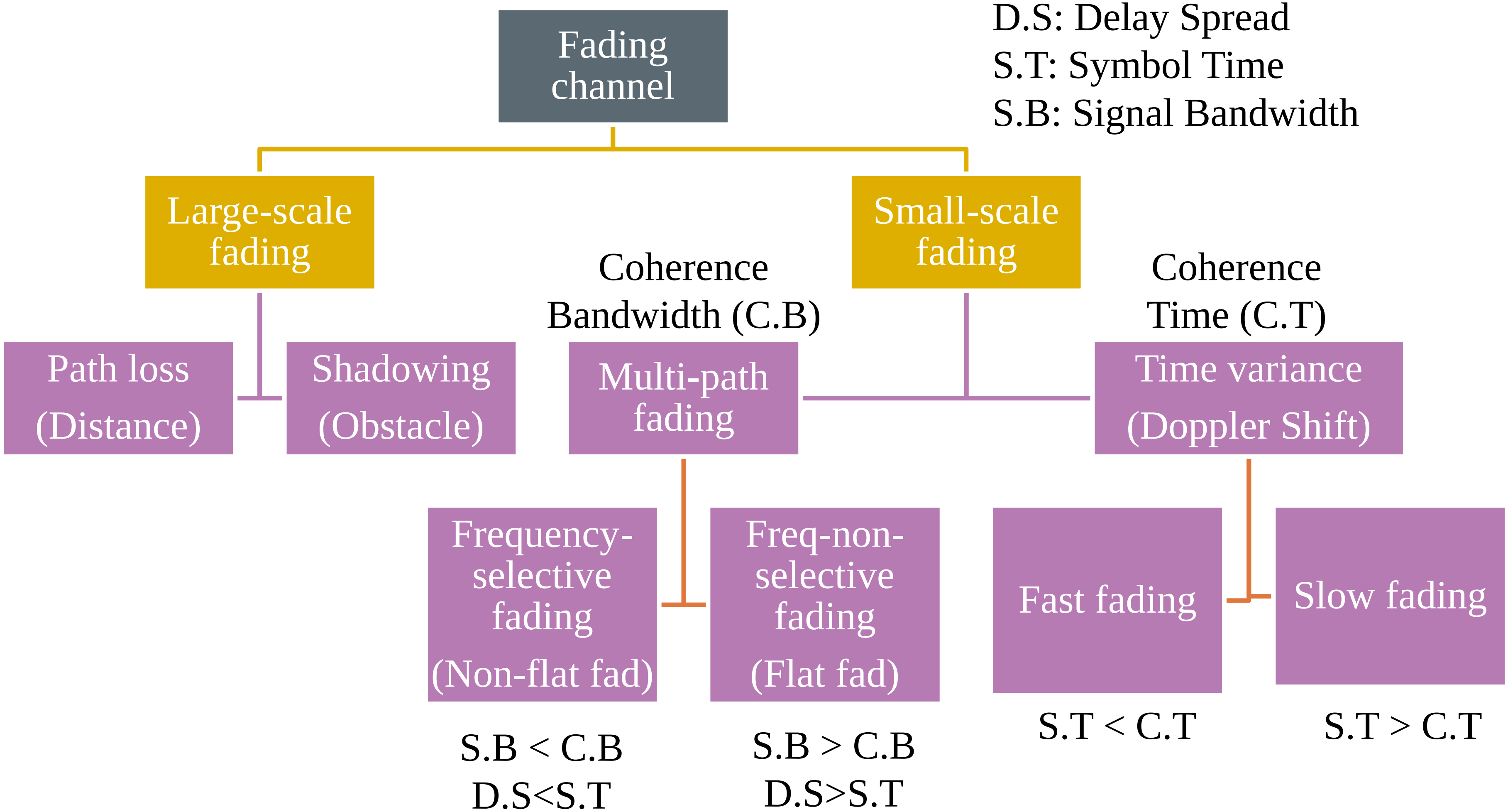
- Propagation in free space always like light (straight line)
- Receiving power proportional to $1/d^2$ in free-space
- Receiving power additionally influenced by
  - fading (frequency dependent)
  - shadowing
  - reflection at large obstacles
  - refraction depending on the density of a medium
  - scattering at small obstacles
  - diffraction at edges



Wireless Channel Overview

Wireless Channel Overview

C.B: Coherence Bandwidth
C.T: Coherence Time
D.S: Delay Spread
S.T: Symbol Time
S.B: Signal Bandwidth

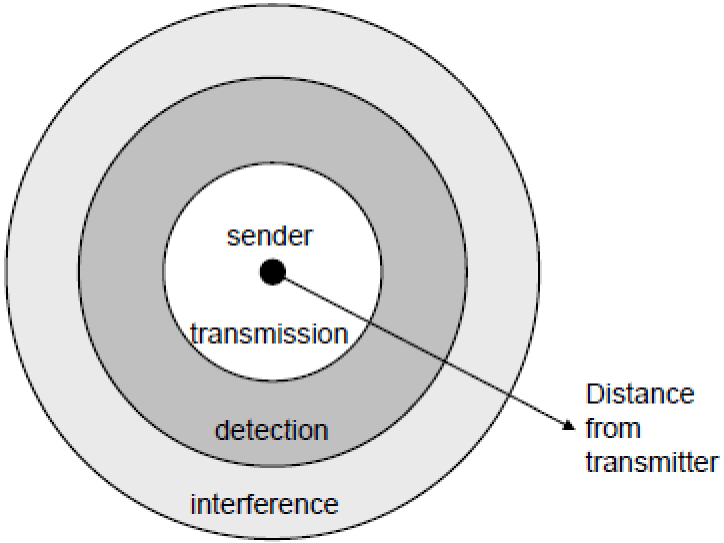


The Effects of Multipath Propagation

- Multiple copies of a signal may arrive at different phases
  - If phases add destructively, the signal level relative to noise declines, making detection more difficult
- Inter-symbol interference (ISI)
  - One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit

Signal Propagation Ranges

- Transmission range
  - communication possible
  - low error rate
- Detection range
  - detection of the signal possible but communication may not be possible due to high error rate
- Interference range
  - signal may not be detected
  - signal adds to the background noise



Radio Propagation Models

- Three components
  - Path-loss
    - Radio signal attenuation due to transmission over a certain distance
    - Free-space path loss model
- Shadowing
  - Signal attenuation due to penetration of buildings and walls.
  - Log-normal distribution model
- Fading
  - Due to multi-path transmission (reflection creates multiple radio paths) and Doppler Shift
  - Rayleigh distribution model, Ricean distribution model

Radio Propagation Models

- Signal power at receiver: $G_{channel}$ includes 3 components
  - Path-loss (g1)
  - Log-normal shadowing (g2)
  - Rayleigh fading (g3)

$$P_{tx} \rightarrow \boxed{G_{ant,tx}} \rightarrow \boxed{G_{channel}} \rightarrow \boxed{G_{ant,rx}} \rightarrow P_{rx}$$

$$P_{rx} = G_{channel} \text{ x } G_{ant,tx} \text{ x } G_{ant,rx} \text{ x } P_{tx}$$

$$G_{channel} = g1 \text{ x } g2 \text{ x } g3$$

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Path-loss model

- Free-space path-loss model

Log-normal shadowing model

Rayleigh distribution model

Summary of radio propagation and mitigations

- Shadowing
  - Problem: received signal strength
  - Mitigation:
    - increase transmit power
    - reduce cell size
- Fast fading
  - Problem: error rate (BER, FER, PER)
  - Mitigation:
    - Interleaving
    - Error correction coding
    - Frequency hopping
    - Diversity techniques
- Delay spread
  - Problem: ISI and error rates
  - Mitigation:
    - Equalization
    - Spread spectrum
    - OFDM
    - Directional antenna

END