Wireless Communication Technologies

Lin DAI
Requirement

• Prerequisite: Principles of Communications

• A certain math background
  – Probability, Linear Algebra, Matrix

• Be interactive in class!

• Think independently!
Assessment

• Exam (60%)
  – Two hours
  – Closed-book
  – Five to six questions

• Coursework (40%)
  – Presentation (50%)
  – Report (50%)
  – Bonus

✓ Important Deadlines:
  – Oct. 2: proposal
  – Dec. 4: final report
References


• Andreas F. Molisch, *Wireless Communications*, John Wiley & Sons Ltd, 2005.


Lecture 1. Overview of Wireless Communications
Electromagnetic Radiation

- Faraday: Electromagnetic Induction
- Maxwell: Equations for Electromagnetic Field
- Hertz: Discovery of Electromagnetic Waves
- Marconi: Wireless telegraph
Electromagnetic Spectrum

- Below 30 kHz: submarine
- 30-3000 kHz: AM longwave and medium-wave broadcasting
- 3-30 MHz: AM shortwave broadcasting
- 30-300 MHz: FM broadcasting, broadcast TV, aviation, paging
- 300-3000 MHz: cellular, cordless phone, wireless LANs, wireless PANs, trunking radio, microwave oven
- 3-30 GHz: wireless LANs, WiMAX, radar, satellite TV
- Above 30 GHz: microwave radio relay, fixed wireless services
Radio Waves

• Propagation in free space
  - Speed = 299,792,458 m/s
  - Isotropic
    • Received power at a particular location decays with distance: $P \sim r^{-2}$

• Propagation in terrestrial environment
  - Propagation loss: $P \sim r^{-\alpha}$, $\alpha > 2$
  - Reflection, diffraction and scattering
A Glimpse of Wireless Channels

- propagation loss
- multipath
- mobility

✓ How to model the fading channel?

✓ How to achieve reliable communications over fading channels?
A Glimpse of Wireless Channels

- broadcast

Interference

✓ How to share the channel?
Challenges of Wireless Communication

✓ Fading channel

PHY Techniques
(Equalization, OFDM, MIMO …)

✓ Interference

MAC Protocols
(TDMA, CDMA, OFDMA, Random Access, …)

✓ Small size of terminal

- Limited energy

Power-efficient Techniques
(power control, …)

- Limited image resolution

Lossy source coding algorithms
Course Organization

- Lecture 2: Fading Channel
- Lecture 3: Diversity
- Tutorial 1
- Lecture 4: Capacity of Fading Channels
- Tutorial 2
- Lecture 5: Multiple Access
  - Part I: Centralized MAC
  - Part II: Distributed MAC
- Tutorial 3
- Group Presentation
- Case Study
Appendix
Principles of Communications
Point-to-Point Communication Systems

- **Transmitter**: to convert the electrical signal into a form that is suitable for transmission
- **Receiver**: to recover the message contained in the corrupted received signal
Digital Communication Systems

- **Channel**: How to model the effect imposed by the channel on the transmitted signals?

- **Digital Modulation**: How to design the transmitted signals to best “utilize” the channel (to maximize the bandwidth efficiency)?

- **Digital Demodulation**: How to retrieve the original information with the least “errors” (to minimize the symbol/bit error rate)?
Channel Modeling

LTI (Linear Time Invariant): \( y(t) = \int_{-\infty}^{\infty} s(t-\tau)h(\tau)d\tau + z(t) \)

- Suppose that \( h(t) \) is a deterministic function of time \( t \).
  - If \( s(t) \) is a deterministic signal: \( Y(f) = H(f) \cdot S(f) \)
  - If \( s(t) \) is a WSS random signal:
    - \( y(t) \) is also a WSS signal with mean \( \mu_y = \mu_s \int_{-\infty}^{\infty} h(t)dt = \mu_s H(0) \)
    - Autocorrelation \( R_y(\tau) = R_s(\tau) \ast h(\tau) \ast h(-\tau) \)
    - Power spectrum \( G_y(f) = G_s(f) \cdot |H(f)|^2 \)
- The thermal noise \( z(t) \) is modeled as a white Gaussian WSS process.
• **Baseband Amplitude Modulation:**  \( s(t) = \sum_{n=-\infty}^{\infty} Z_n \cdot \nu(t - n\tau) \)
  - \( Z_n \) is a discrete random variable with  \( \Pr\{Z_n = a_i\} = 1/M, \ i = 1,\ldots, M \),
  - \( \nu(t) \) is a unit baseband signal.
  - Power spectrum of \( s(t) \):  \( G_s(f) = \frac{1}{\tau} |V(f)|^2 \cdot \left( \sigma^2 + \frac{\mu^2}{\tau} \sum_{m=-\infty}^{\infty} \delta\left( f - \frac{m}{\tau} \right) \right) \)

• **Bandwidth efficiency:**  \( \gamma \triangleq \frac{\text{Information Bit Rate } R_b}{\text{Required Channel Bandwidth } B_h} \)

• Ignore the noise. What is the maximum bandwidth efficiency for distortionless binary transmission over a baseband channel, and how to achieve it?
Digital Demodulation

- Probability of Bit Error (BER): \( P_b = \Pr\{\hat{b}_i=1, b_i = 0\} + \Pr\{\hat{b}_i=0, b_i = 1\} \)

- Suppose binary modulation is adopted. With AWGN noise, what is the optimal BER, and how to design the receiver to achieve the optimal BER performance?
Performance Comparison of Digital Modulation Schemes

\[ \gamma = \frac{R_b}{B_h} \]

The highest achievable bandwidth efficiency \( \gamma^* \):

\[ \frac{2^{\gamma^*} - 1}{\gamma^*} = \frac{E_b}{N_0} \]

Required \( E_b/N_0 \) when \( P_b^* = 10^{-5} \):

- BPSK: 9.6dB
- QPSK: 9.6dB
- 8PSK: 12.9dB
- 16PSK: 17.4dB
Digital Communication Systems

- Bandwidth Efficiency
  \[ \gamma \Delta \frac{\text{Information Bit Rate } R_b}{\text{Required Channel Bandwidth } B_h} \]

- BER (Fidelity Performance)
  Binary: \[ P_b = Q\left(\sqrt{\frac{E_b(1-\rho)}{N_0}}\right) \]

- What if the channel is not an LTI system?
- What is the highest bandwidth efficiency for given \( E_b/N_0 \)?
- How to achieve the highest bandwidth efficiency?