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:

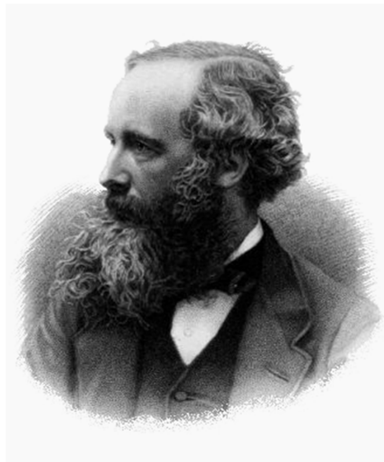
- Oct. 2: proposal
- Dec. 4: final report

References

- David Tse and Pramod Viswanath, *Fundamentals of Wireless Communication*, Cambridge University Press, 2005.
- Andrea Goldsmith, *Wireless Communications*, Cambridge University Press, 2005.
- Andreas F. Molisch, *Wireless Communications*, John Wiley & Sons Ltd, 2005.
- Dimitri Bertsekas and Robert Gallager, *Data Networks* (2nd Edition), Prentice Hall, 1992.
- Robert G. Gallager, *Principles of Digital Communication*, Cambridge University Press, 2008.
- John G. Proakis and Masoud Salehi, *Digital Communications* (5th Edition), McGraw Hill, 2005.
- B. Sklar, *Digital Communications: Fundamentals and Applications* (2nd Edition), Prentice-Hall, 2001.

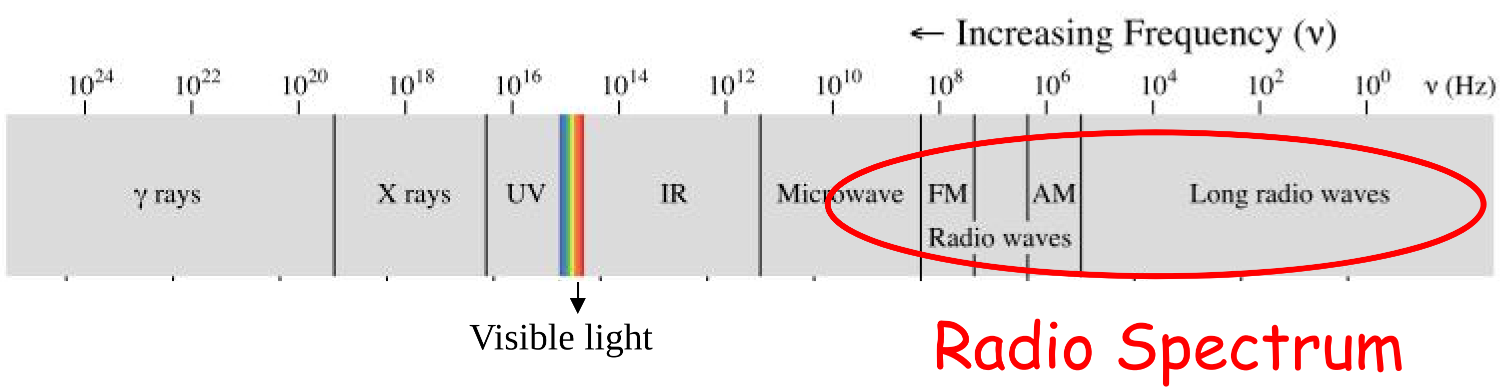
Lecture 1. Overview of Wireless Communications

Electromagnetic Radiation

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

Electromagnetic Spectrum

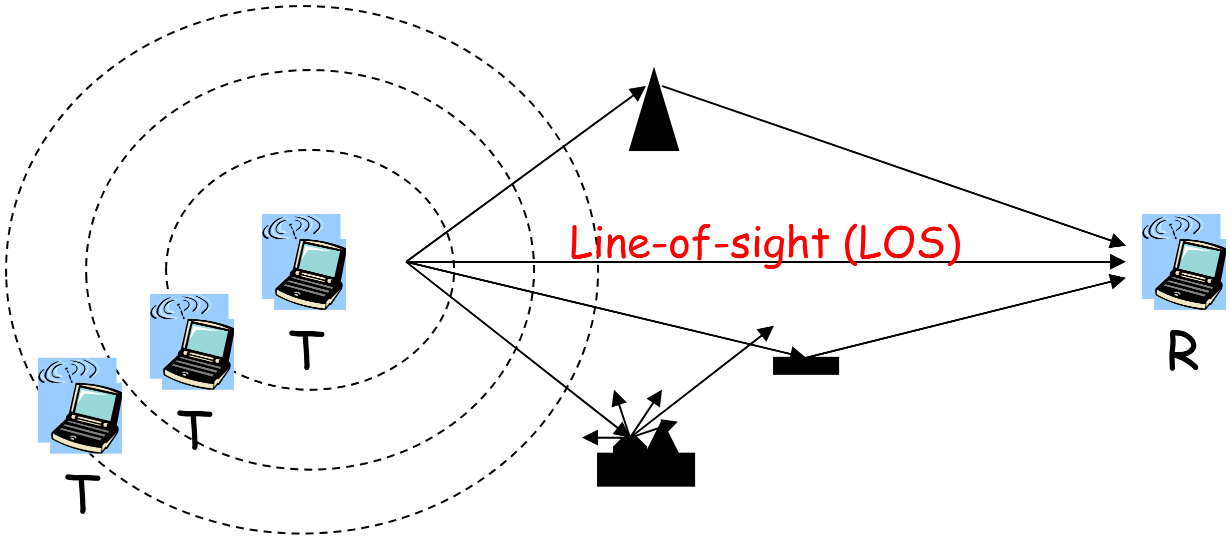


- Below 30 kHz: submarine
- 30-3000 kHz: AM longwave and medium-wave broadcasting
- 3-30 MHz: AM shortwave broadcasting
- 30-300 MHz: FM broadcasting, broadcast TV, aviation, paging
- 300-3000 MHz: cellular, cordless phone, wireless LANs, wireless PANs, trunking radio, microwave oven
- 3-30 GHz: wireless 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



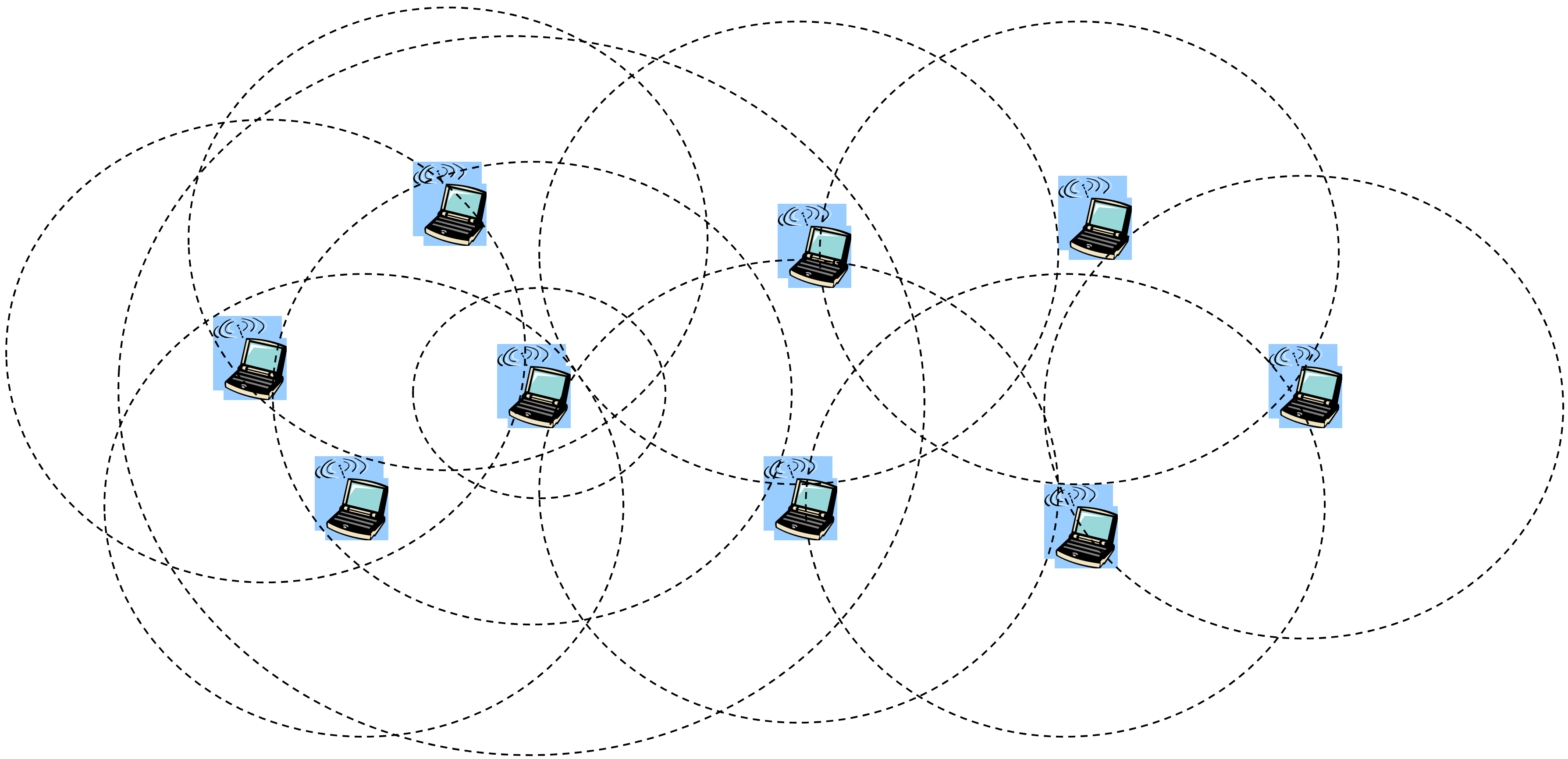
- propagation loss
- multipath
- mobility

⇨ Fading channel

✓ 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

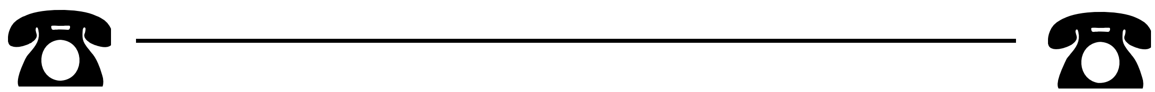
✓ Fading channel	PHY Techniques (Equalization, OFDM, MIMO …)
✓ Interference	MAC Protocols (TDMA, CDMA, OFDMA, Random Access, …)
✓ Small size of terminal	
– Limited energy	Power-efficient Techniques (power control, …)
– Limited image resolution	Lossy source coding algorithms

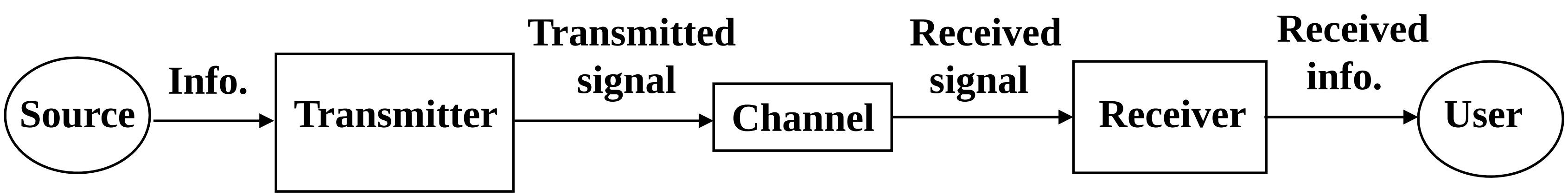
Course Organization

- 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

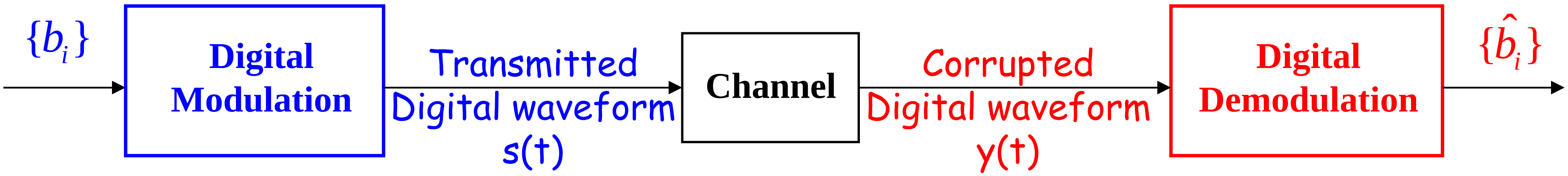




- Transmitter: to convert the electrical signal into a form that is suitable for transmission

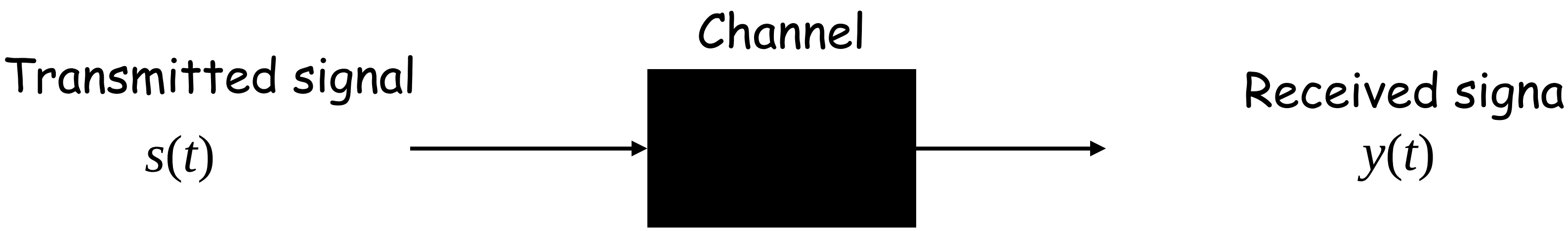
- Receiver: to recover the message contained in the corrupted received signal

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): $y(t)=\int_{-\infty}^{\infty} s(t-\tau)h(\tau)d\tau + z(t)$

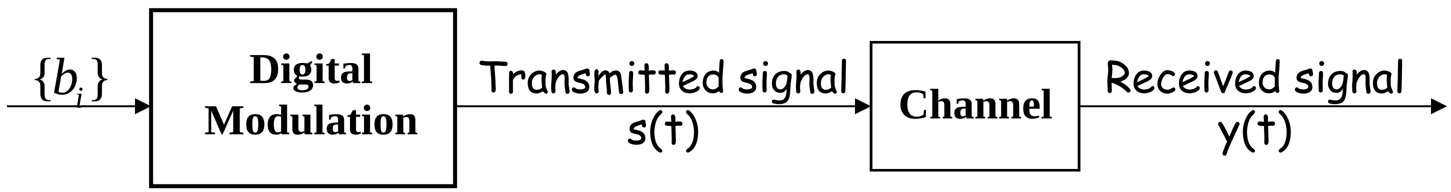
- Suppose that h(t) is a deterministic function of time t.
  - ✓ If s(t) is a deterministic signal: $Y(f)=H(f)\cdot S(f)$
  - ✓ If s(t) is a WSS random signal:

    y(t) is also a WSS signal with mean $\mu_Y=\mu_S\int_{-\infty}^{\infty} h(t)dt=\mu_S H(0)$

    autocorrelation $R_Y(\tau)=R_S(\tau)*h(\tau)*h(-\tau)$

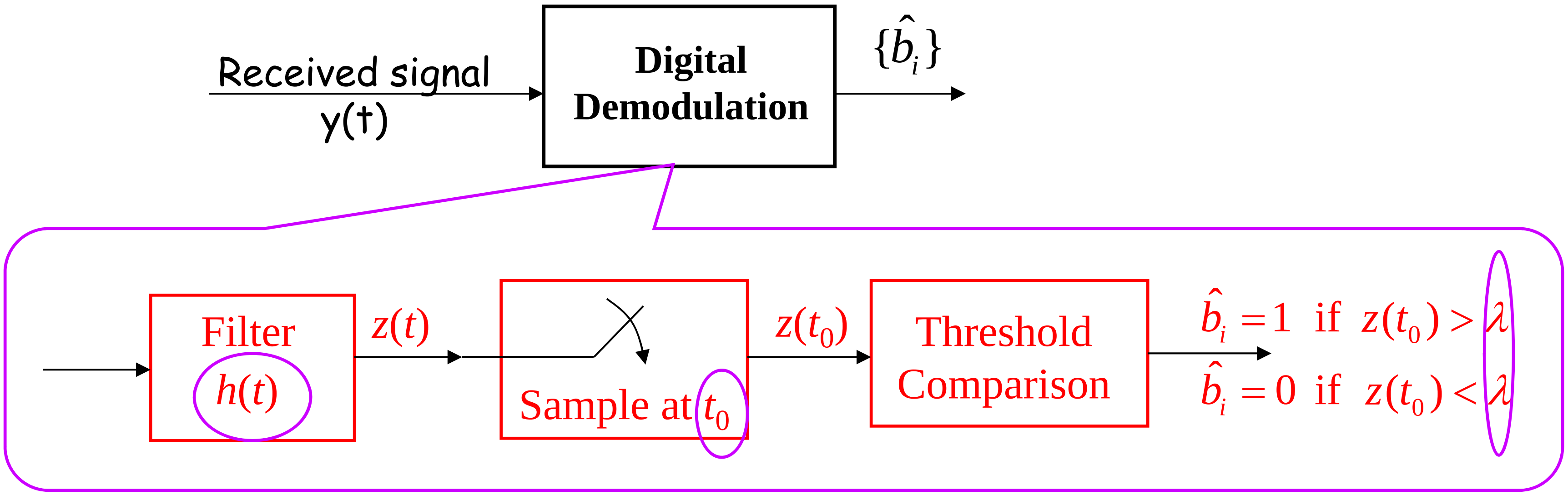
    power spectrum $G_Y(f)=G_S(f)\,|H(f)|^2$
- The thermal noise z(t) is modeled as a white Gaussian WSS process.

Digital Modulation



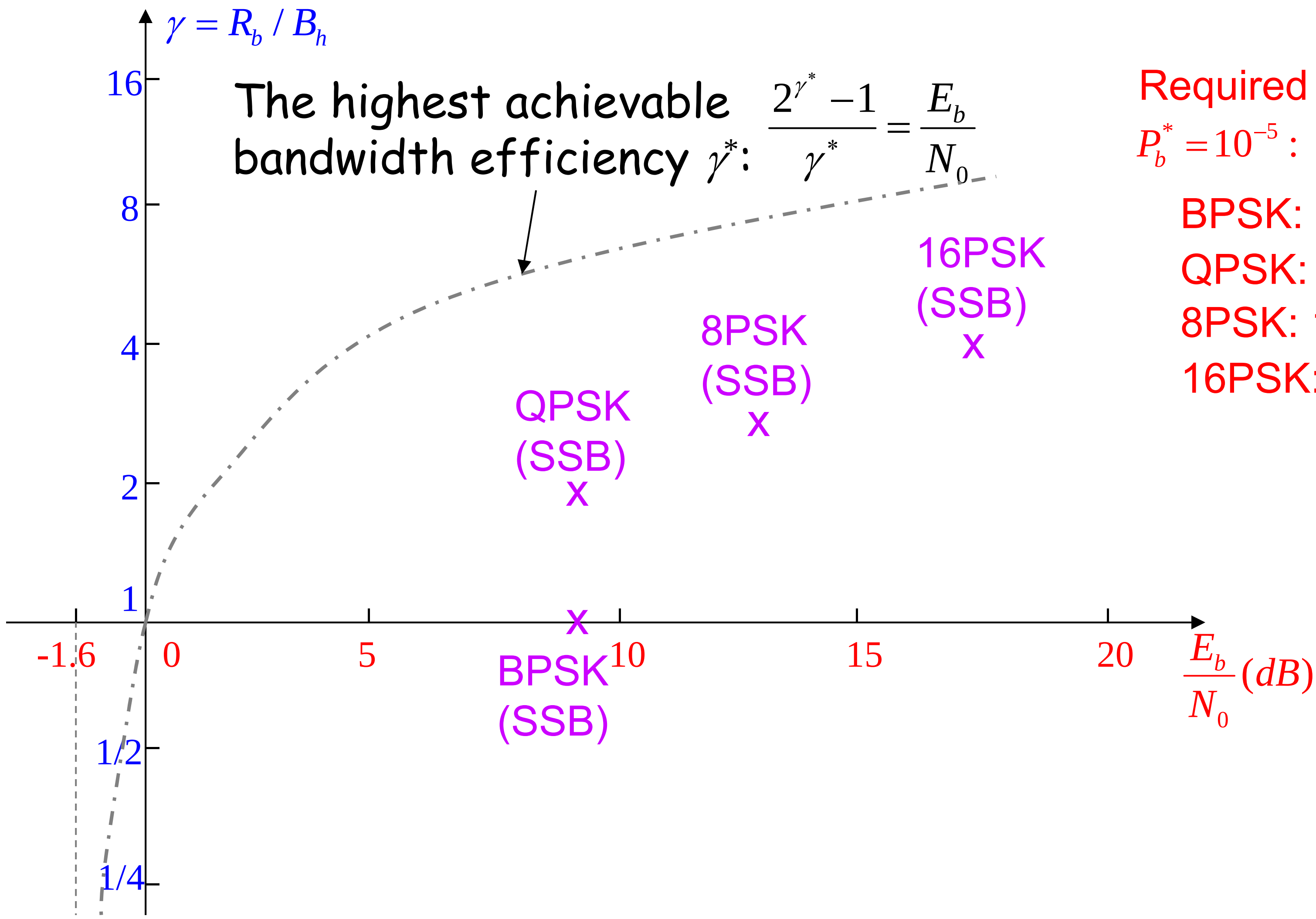
- Baseband Amplitude Modulation: $s(t) = \sum_{n=-\infty}^{\infty} Z_n \cdot v(t - n\tau)$
  - ✓ Z_n is a discrete random variable with $\Pr\{Z_n = a_i\} = 1/M,\ i = 1, \ldots, M,$
  - ✓ $v(t)$ is a unit baseband signal.
  - ✓ Power spectrum of s(t): $G_s(f) = \frac{1}{\tau}|V(f)|^2 \cdot \left(\sigma_Z^2 + \frac{\mu_Z^2}{\tau}\sum_{m=-\infty}^{\infty}\delta\left(f - \frac{m}{\tau}\right)\right)$
- 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?

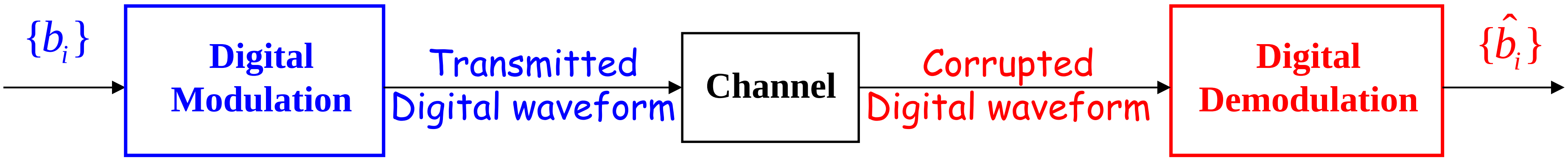
Performance Comparison of Digital Modulation Schemes



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**

$$\gamma \triangleq \frac{\text{Information Bit Rate } R_b}{\text{Required Channel Bandwidth } B_h}$$

- **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?