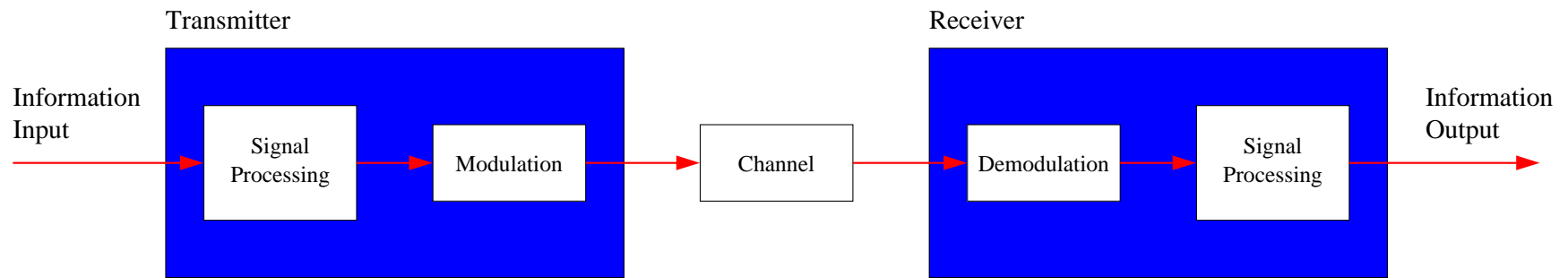# Quick Introduction to Communication Systems

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Communication System

Transmitter

Receiver

Information Input

Signal Processing → Modulation → Channel → Demodulation → Signal Processing

Information Output

Why Modulate?

- Reduce noise and interference.

- Channel assignment.

- Multiplexing or transmission of several messages over a single channel.

- Overcome equipment limitation.

Modimation

$$x_c(t) = A(t)\cos[\omega_c t + \phi(t)] \qquad (1)$$

where ω_c is known as the carrier frequency, $A(t)$ is the instantaneous amplitude, and $\phi(t)$ is the instantaneous phase deviation.

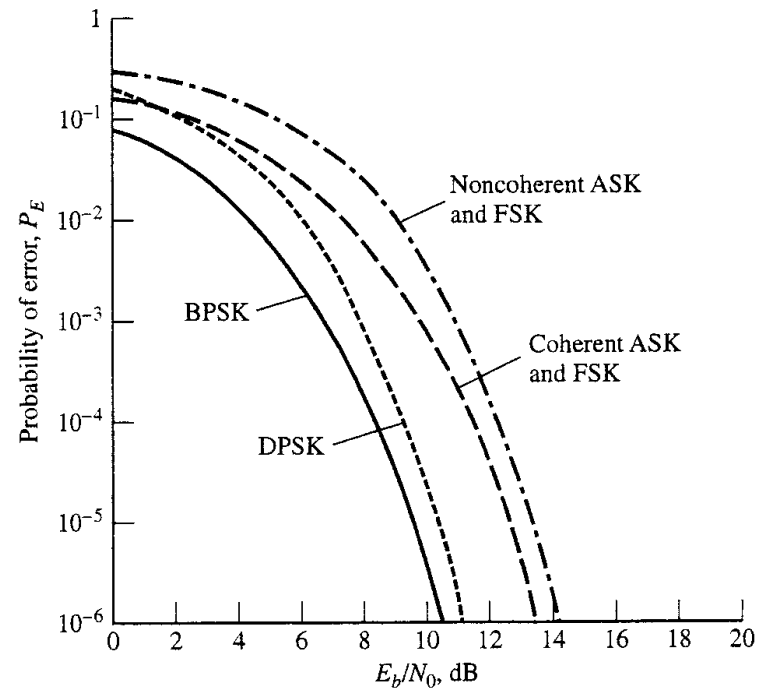If $A(t)$ is linearly related to the modulated signal, we have linear modulation.

AM, PM and FM
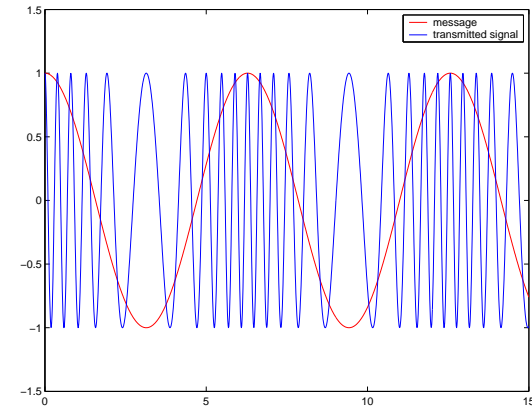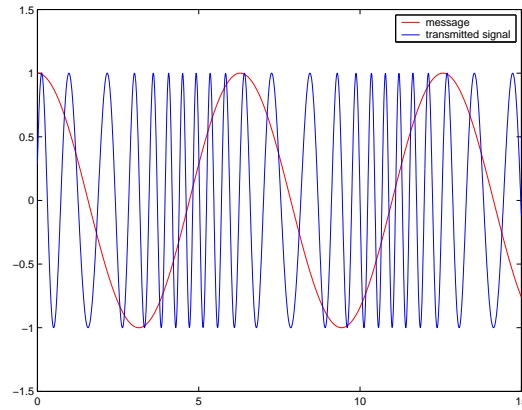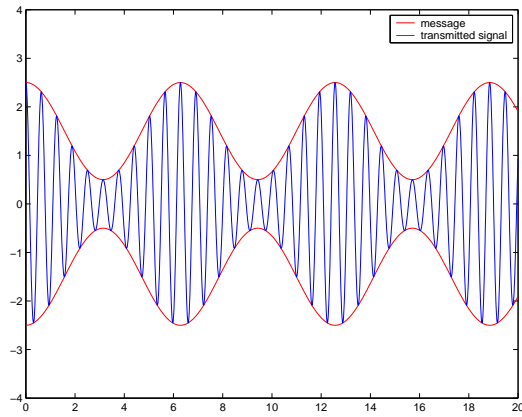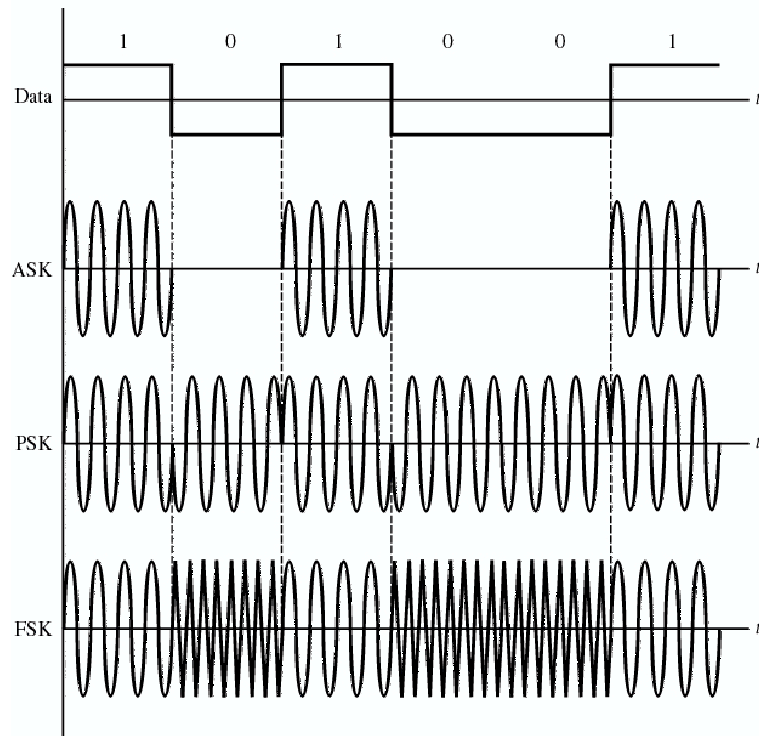
Why Digital Communication?

- Inexpensive digital circuits may be used.

- Privacy by using data encryption.

- Greater dynamic range.

- In long-distance systems, noise does not accumulate from repeater to repeater.

- Errors may be corrected.

Binary Data Transmission
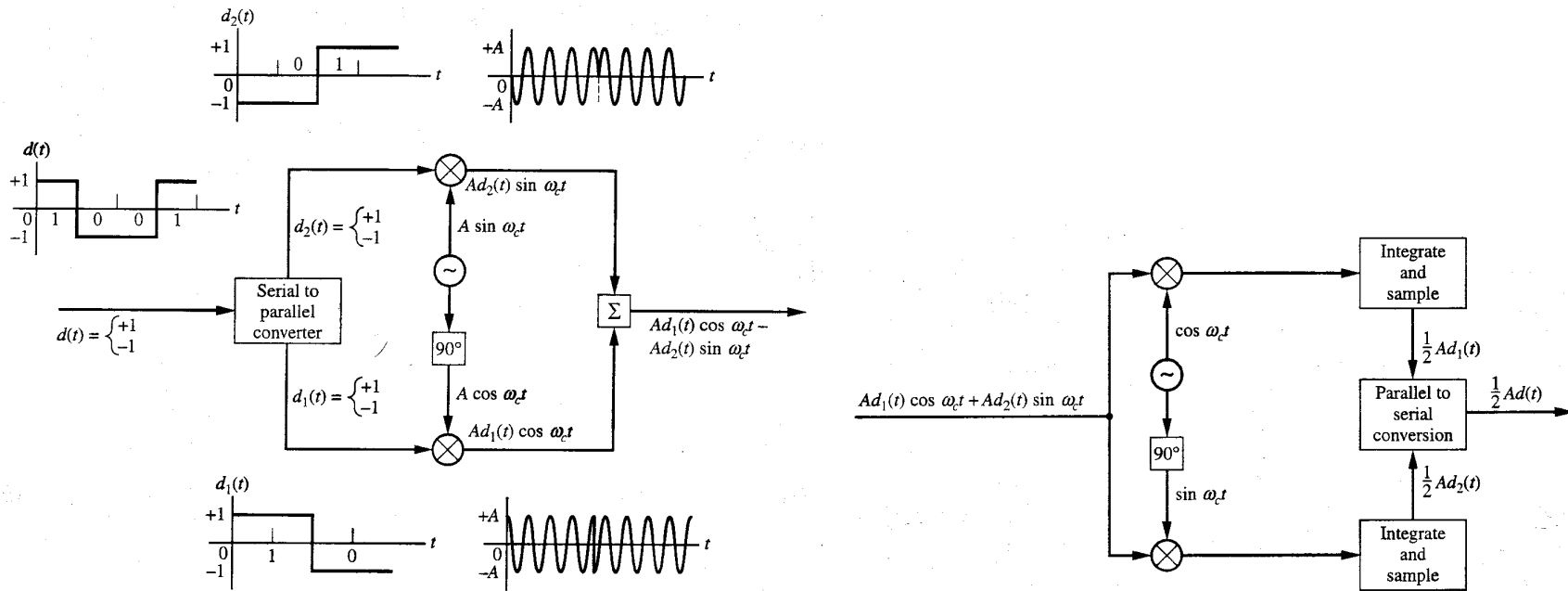
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Synchronization

- Carrier synchronization.

- Bit synchronization.

- Frame or word synchronization.

Information Capacity

What is the bandwidth required to convey the information?

In 1948, Claude Shannon proved that the information capacity of a communication channel was related to the bandwidth, and signal-to-noise ratio in the channel by the equation

$$\text{capacity} = \text{bandwidth} \times \log_2\left(1 + \frac{P_{\text{signal}}}{P_{\text{noise}}}\right) \tag{2}$$

Information Measure

The *information* sent from a digital source when the jth message was transmitted is given by

$$I_j = \log_2\left(\frac{1}{P_j}\right) \text{ bits} \tag{3}$$

where P_j is the probability of transmitting the jth message.

Coding

- *Automatic repeat request (ARQ)*
  When a receiver detects parity errors in a block of data, it sends a request for the data to be retransmitted.

- *Forward error correction (FEC)*
  The transmitted data are encoded so that the receiver can detect and correct errors.

FEC

- *Block codes*
  A Block code is a memoryless device that maps k input binary symbols to n output binary symbols, where $n > k$.

- *Convolutional codes*
  A convolutional code is produced by a coder that has memory.

Multiplexing

FDMA

Power

Time

Frequency

TDMA

Power

Time

Frequency

CDMA

Power

Time

Frequency
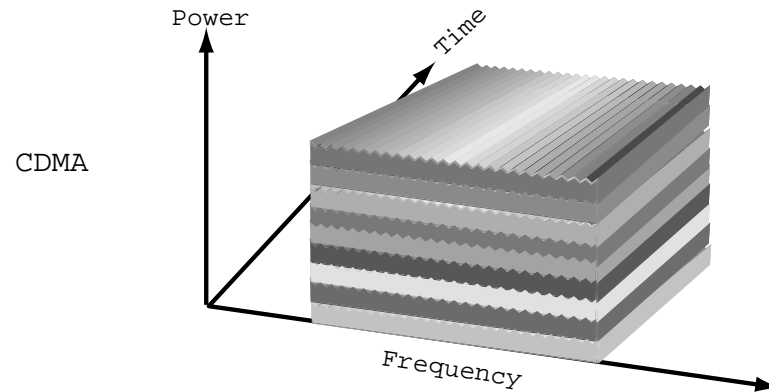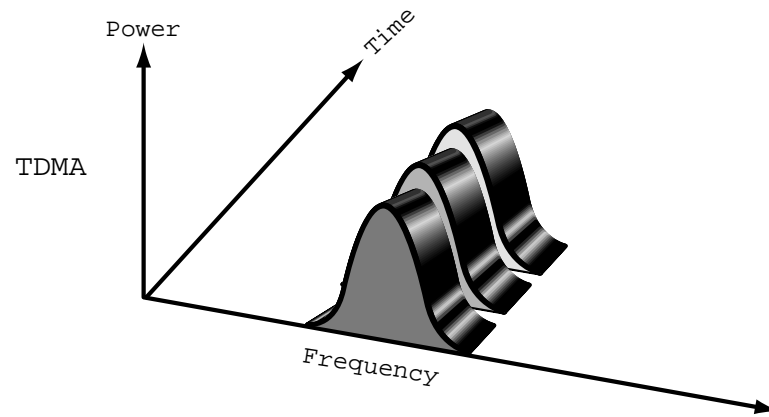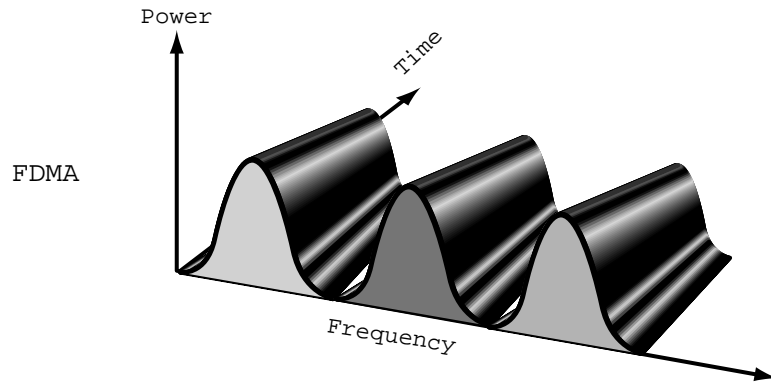
Direct Sequence Spread Spectrum (DSSS)

- The signal is spread to occupy a wider bandwidth and is buried among noise-like signals.

(a)   (b)
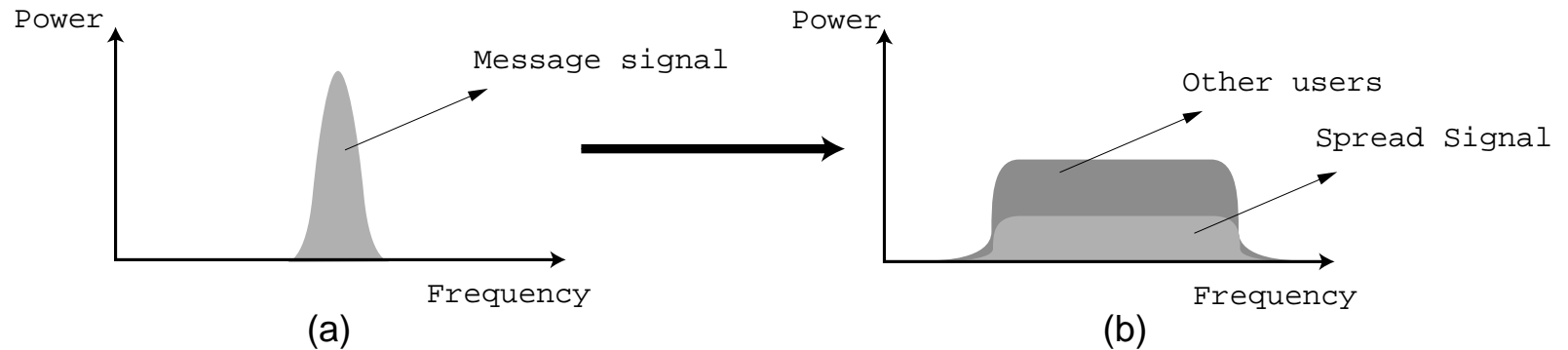
- To despread the signal, the received signal is multiplied by the same pseudorandom code (assuming perfect synchronization)

IEEE Standards

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`http://standards.ieee.org/wireless/overview.html`
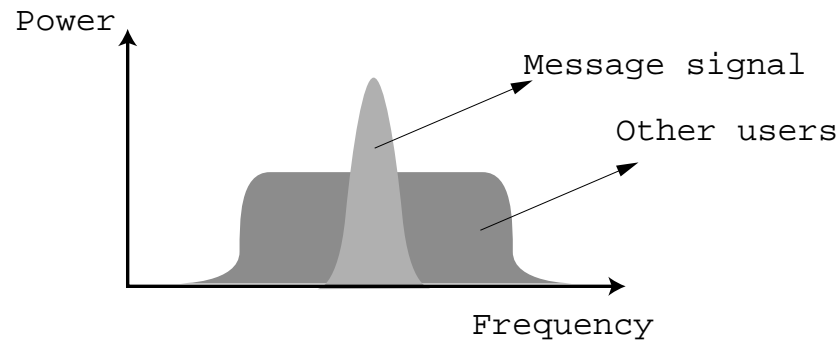
- **802.11** Wireless Local Area Networks.

- **802.15** Wireless Personal Area Networks.

- **802.16** Broadband Wireless Access.

- **1451** Wireless Sensor Standards.

IEEE 802.11

- Standard for Wireless Local Area Networking (WLAN) in the US.

- Specifies the Physical (PHY) layer and the Medium Access Control (MAC) layer.

- Offers two variations of PHY, namely, DSSS and FSSS.

MAC layer

The Mac layer is responsible for
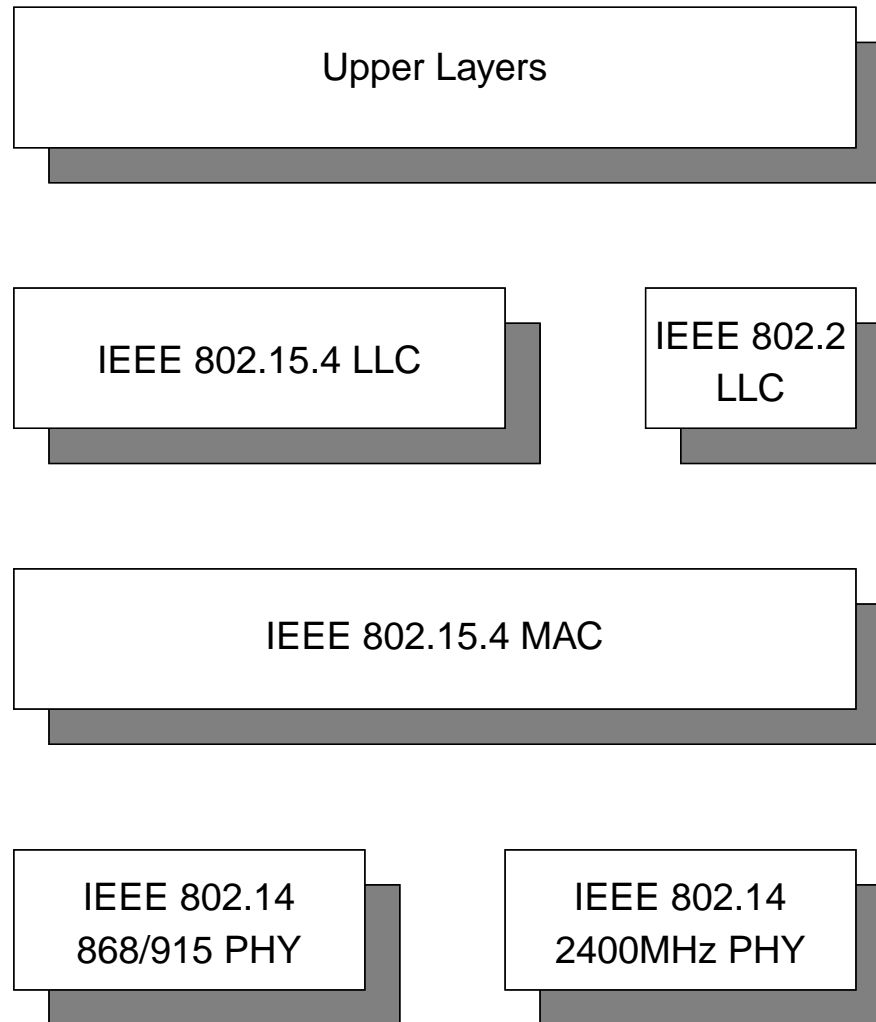
- channel allocation,
- access procedures,
- protocol data unit addressing, and
- error checking.

ZigBee/IEEE 802.15.4

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- ZigBee is a technology that addresses the market needs for cost effective wireless networking solutions based on IEEE 802.15.4 standard.

- IEEE 802.15.4: Wireless MAC and PHY specifications for low-rate wireless personal area networks (WPANs).
  `http://www.ieee802.org/15/pub/TG4Expert.html`

  - Data rates of 250 kbps, 40 kbps, and 20 kbps.

  - CSMA-CA channel access.

  - Automatic network establishment by the coordinator.

  - Fully handshaked protocol for transfer reliability.

  - Power management to ensure low power consumption.

  - 16 channels in the 2.4GHz ISM band, 10 channels in the 915MHz I and one channel in the 868MHz band.

IEEE 802.15.4 Architecture

Upper Layers

IEEE 802.15.4 LLC

IEEE 802.2 LLC

IEEE 802.15.4 MAC

IEEE 802.14 868/915 PHY

IEEE 802.14 2400MHz PHY

Radio Transmission

- *Very low frequency (VLF)* ($f_0 < 0.3 MHz$): The earth and the ionosphere form a waveguide for the electromagnetic waves.

- *Medium frequency (MF)* ($0.3 < f_0 < 3 MHz$): Waves propagate as ground waves up to a distance of 160km.

- *High frequency (HF)* ($3 < f_0 < 30 MHz$): The waves are reflected by the ionosphere at an altitude that may vary between 50 and 400km.

- *Very high frequency (VHF)* ($30 < f_0 < 300 MHz$): The signal propagate through the ionosphere with small attenuation.

- *Ultra high frequency (UHF)* ($300 MHz < f_0 < 3 GHz$)

Mobile Radio Propagation

Large-scale fading It represents the average signal power attenuation or path loss over large distances.

In practice, the environment between the transmitter and the receiver is changing due to the different terrain contours such as forests, hills, buildings, etc., between the transmitter and the receiver. This is known as *shadowing*.

Base Station   Buildings   Mobile station

Mobile Radio Propagation (cont.)
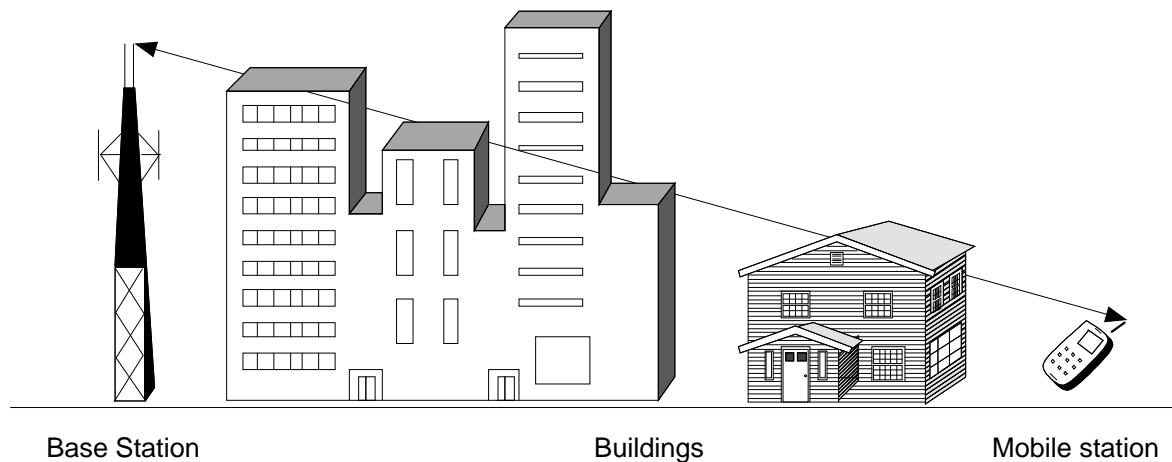
The average path loss can be expressed as

$$\overline{PL}(d) \propto d^{-\alpha} 10^{\eta/10}, \tag{4}$$

where $\overline{PL}(d)$ is the average path loss as a function of distance, α is the path loss exponent usually taken to be 4, η is a normally distributed variable with zero mean and variance σ_s^2. The value of σ_s^2, which is affected by the configuration of the terrain, ranges from 5 to 12, with 8 as a typical value.

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Small-scale fading is caused by multipath reflection of the transmitted wave by local scatters such as man-made structures. The small-scale fading is usually Rayleigh distributed. Rayleigh distribution has a probability density function given by

$$p(r) = \begin{cases} \frac{r}{\sigma_r} \exp\left(-\frac{r^2}{2\sigma_r^2}\right) & (0 \leq r \leq \infty), \\ 0 & (r < 0), \end{cases} \tag{5}$$

where σ_r is the rms value of the received voltage signal, and $r(t)$ is the complex envelope of the received signal.

Glossary

- **Baud**: Measure of data rate.

- **FCC**: Federal Communications Commission. The U.S. government agency responsible for allocating radio spectrum for communication services.

- **Latency**: Measure of how much time it takes for a packet of data to get from one point to another.

- **SAW**: Surface acoustic wave devices. These devices use the piezoelectric effect inherent in a crystal to transform EM energy to acoustic energy and back. Fingers specially placed on a surface of a SAW devices act as wave energy filters yielding bandpass filter effects that can't be obtained with RCL filters.

- **Throughput**: Measure of the number of useful data characters sent, received, and processed per second.

Trade-Offs

- Bandwidth efficiency

- Power efficiency

- Performance

- System complexity

- Cost