

Chapter 5: Communication Theory

1- Motivation

- **IoT Data Transport:** IoT involves more than just sensor data; it requires understanding and designing data transport from remote sensors to the cloud using various technologies and data paths.
- **Increased Demand for Wireless Technologies:** The growing IoT demand emphasizes the importance of understanding RF fundamentals for proper application and implementation of wireless systems.
- **Focus on Wireless RF Signals:** The text suggests starting with a review of wireless RF signals and factors affecting signal quality, such as limitations, interference, models, bandwidth, and range.

2- Radio Frequency (RF)

- Wireless Transmissions:

- Radio frequency (RF) signals travel based on propagation characteristics.
- Signals are transmitted from an antenna, modulated at the source and demodulated at the receiver

- Frequency Range:

- RF oscillates between 20 kHz and 300 GHz.
- Transmission range and power are critical factors in protocol selection.

- Transmission Range:

- Determined by the distance between antennas, transmission frequency, and power.
- Ideal transmission is line-of-sight, though real-world conditions include obstructions and noise.

- Propagation Characteristics:

- Frequency, wavelength, and amplitude define RF signal behavior.
- Frequency impacts the data-carrying capacity and range.

- Frequency Regulation:

- Frequencies are governed by regulatory bodies like the FCC.
- Common bands include 900 MHz, 2.4 GHz, and 5.8 GHz.

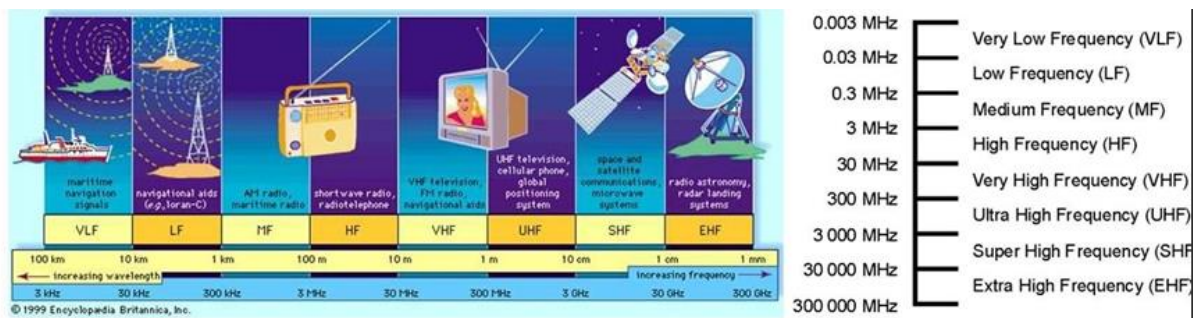
- Wavelength:

- Inversely proportional to frequency.
- Calculated by dividing the speed of light by frequency.
- Essential for antenna design.

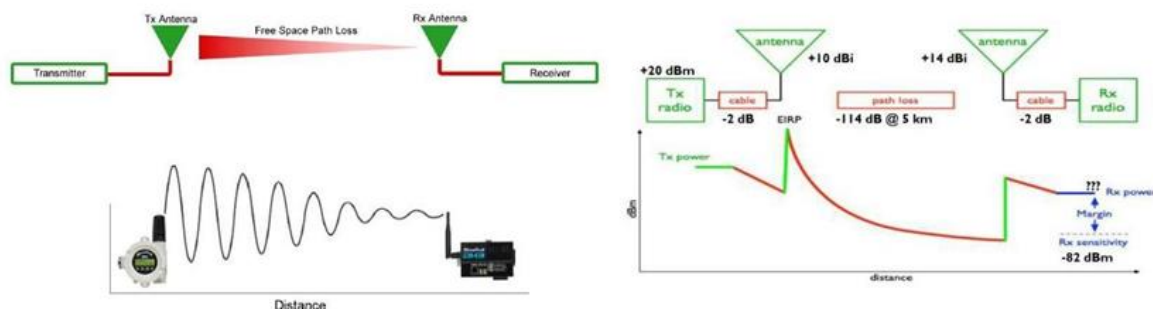
- Amplitude:

- Represents the height or peak of a wave.
- Higher amplitude indicates more power.

3- General RF Spectrum



4- Link Budget



- Essential for determining the feasibility of a wireless system.
- Accounts for all gains and losses from the transmitter through various mediums to the receiver.
- **Link Budget Equation:** Received Power (dBm) = Transmitted Power (dBm) + Gains (dB) - Losses (dB)
- **Components of Link Budget:**
 - Gains include factors like antenna gains.
 - Losses include attenuation due to propagation, connectors, antennas, open air, etc.
- **Signal Strength:**
 - Expressed in dBm (decibels relative to a milliwatt).
 - Signal strengths range from approximately -30 dBm to -110 dBm.
 - Closer to 0 dBm indicates a stronger signal; better than -85 dBm is generally usable.
 - dBm is a logarithmic expression of signal power.

5- Sensitivity

- Measures the lowest power level at which a receiver can detect and demodulate an RF signal.
- Comparable to being able to hear and understand a conversation, even at low volumes.
- Lower power level (more negative dBm) indicates better sensitivity.
- A receiver with -110 dBm sensitivity can detect signals half as strong as one with -107 dBm sensitivity. The larger the absolute value of the negative number, the better the sensitivity.

6- Link Budget

- **Transmitter Output Power:**

The transmitter output power depends on the technology and deployment region.

Lower output power is used to save energy in battery-powered networks, while higher power is used in systems like licensed radio.

Example: 30 dBm.

- **Transmitter Loss:**

Losses occur from the transmitter to the antenna due to connectors, cables, and other components.

Important to consult specifications for minimizing loss.

Example: 4.3 dB of loss.

- **Antenna Gain:**

Antennas convert electrical currents to radio waves and vice versa.

Gain is specified in dBi, referring to a hypothetical isotropic antenna.

Example: 3 dBi gain.

- **Free Space Path Loss (FSPL):**

Signal power decreases over distance due to geometric spreading.

FSPL is calculated based on distance and frequency.

Example: 110 dB loss for 5 miles at 900 MHz.

- **Receiver Antenna Gain:**

Gain at the receiver's end improves signal strength. Example: 3 dBi gain.

- **Receiver Loss:**

Similar to transmitter loss, it includes losses in the receiver's components.

Example: 4.3 dB of loss.

- **Received Signal Strength:**

The final signal strength at the receiver after all gains and losses.

Example: -82.6 dBm.

- **Receiver Sensitivity:**

The minimum signal power the receiver can detect.

Lower sensitivity values (more negative dBm) are better.

Example: -110 dBm.

- **Fade Margin:**

Margin between received signal and receiver sensitivity to account for obstacles and interference.

Recommended margin: 20 dB for reliable performance.

7- Transmitter

- A transmitter can be a separate device or an electrical circuit within another device, used for radio communication of information over a distance.
- Information is provided to the transmitter as an electronic signal (e.g., audio, video, digital signals).
- The transmitter combines the information signal with a radio frequency signal called the carrier signal through a process called modulation.
- Information can be added to the carrier in various ways:
 - Amplitude Modulation (AM) changes the amplitude of the radio signal.
 - Frequency Modulation (FM) changes the frequency of the radio signal.
 - Other types of modulation are also used for different applications.

8- Modulation/Demodulation

- **Modulation:** The process of mixing a signal with a sinusoid to produce a new signal. It combines a low-frequency signal with a high-frequency carrier signal. This is beneficial over an unmodulated signal.
- **Basic components of RF communication:**
 - **Carrier wave:** The high-frequency signal used to carry the data.
 - **Information sent (data):** The actual data to be transmitted.
- **Demodulation:** The process at the receiver end where the modulated signal is extracted and converted back into the original information (data).
 - **Transmitter (Tx)** sends a modulated signal.
 - **Receiver (Rx)** receives and demodulates the signal to recover the information.

9- Sampling

- **Sampling:**
 - Sampling involves transmitting a few samples of an analog signal instead of the whole signal.
 - These samples are observed at the receiving end to determine the actual signal.
- **Sampling Rate:**
 - According to Nyquist's theorem, a periodic signal must be sampled at a rate more than twice the highest frequency of the signal to capture it accurately.
 - For example, to record audio with frequencies ranging from 20 Hz to 20,000 Hz, the signal must be sampled at least at 40,000 Hz. Standard CDs use a sampling rate of 44,100 Hz (44.1 kHz).

10- BIT error Rate

- **Definition:** BER measures the number of bit errors in a transmission over a communication channel. It is expressed as a ratio or percentage.
- **Example Calculation:**
 - Original sequence: 1 0 1 0 1 1 0 1 0 0
 - Received sequence: 0 0 1 0 **1** 0 1 **0** 1 0 (differences in bold)
 - $BER = 5 \text{ errors} / 10 \text{ bits transferred} = 50\%$
- **Factors Affecting BER:** Channel noise, interference, multipath fading, and attenuation.
- **Improving BER:**
 - Increase transmission power.
 - Improve receiver sensitivity.
 - Add redundant data (forward error correction, FEC).
- **FEC Technique:**
 - Adds extra data to transmissions to correct errors.
 - Basic FEC methods include adding triple redundancy and using a majority vote algorithm.
 - Reduces bandwidth by up to three times.