Quick Introduction to Communication Systems

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Why Modulate?

- Reduce noise and interference.
- Channel assignment.
- Multiplexing or transmission of several messages over a single channel.
- Overcome equipment limitation.
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Modulation

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

where \( \omega_c \) 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

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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.
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Binary Data Transmission

Principles of Communications, 5/E by Rodger Ziemer and William Tranter
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Quadrature Phase Shift Keying (QPSK)

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Synchronization

- Carrier synchronization.
- Bit synchronization.
- Frame or word synchronization.
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

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

(2)
The *information* sent from a digital source when the $j$th message was transmitted is given by

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

where $P_j$ is the probability of transmitting the $j$th message.
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.
**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.
Direct Sequence Spread Spectrum (DSSS)

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

To despread the signal, the received signal is multiplied by the same pseudorandom code (assuming perfect synchronization).
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.
The Mac layer is responsible for
- channel allocation,
- access procedures,
- protocol data unit addressing, and
- error checking.
The primary access protocol used in the 802.11 MAC layer is known as the Distributed Coordination Function (DCF) which is based on Carrier Sense Multiple Access/Collision Avoidance (CSMA/CS).
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.
The average path loss can be expressed as

\[ \overline{PL}(d) \propto d^{-\alpha} 10^{\eta/10}, \]  

(4)

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

\[
p(r) = \begin{cases} 
\frac{r}{r_r} \exp \left( -\frac{r^2}{2r_r^2} \right) & (0 \leq r \leq \infty), \\
0 & (r < 0),
\end{cases}
\]

(5)

where \( r_r \) 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.
SAW device

Fingers

Crystal substrate

Input piezo transducer

Output piezo transducer
Trade-Offs

- Bandwidth efficiency
- Power efficiency
- Performance
- System complexity
- Cost