Lecture 2:

Wireless Transmission Fundamentals

- Signals
- Analog and Digital Data Transmission
- Channel Capacity
- Transmission Media
- Signal Strength and Decibels
Signals for Conveying Information

- **Electromagnetic Waves:**
  - Means to transmit information
  - Physical representation of data

- **Function of time**

- **Can also be expressed as a function of frequency**
  - Signal consists of components of different frequencies
Time-Domain Concepts

- Analog signal - signal intensity varies in a smooth fashion over time
  - No breaks or discontinuities in the signal, e.g. speech
- Digital signal - signal intensity maintains a constant level for some period of time and then changes to another constant level, e.g., binary 1’s and 0’s
Time-Domain Concepts

- Periodic signal - analog or digital signal pattern that repeats over time
  \[ s(t + T) = s(t) \quad -\infty < t < +\infty, \quad T \text{ is the period of the signal} \]

- Aperiodic signal - analog or digital signal pattern that doesn't repeat over time
Time-Domain Concepts

- **Signal Parameters**
  - **Peak amplitude** \( (A) \) - maximum value or strength of the signal over time; typically measured in volts
  - **Frequency** \( (f) \) - Rate, in cycles per second, or Hertz (Hz) at which the signal repeats
  - **Period** \( (T) \) - amount of time it takes for one repetition of the signal
    - \( T = 1/f \)
  - **Phase** \( (\phi) \) - measure of the relative position in time within a single period of a signal
  - **Wavelength** \( (\lambda) \) - distance occupied by a single cycle of the signal
    - \( \lambda = v.T = v/f \), \( v \) is the velocity, e.g. speed of light in free space: \( 3 \times 10^8 \)
Signal Parameters

General sine wave

\[ s(t) = A \sin(2\pi ft + \phi) \]

A = ?, f = ?, T=?, \phi = ?
A = 1, f = 1, T=1, \phi = 0

A = ?, f = ?, T=?, \phi = ?
A = 0.5, f = 1, T=1, \phi = 0
Signal Parameters

\[ A = ?, \quad f = ?, \quad T = ?, \quad \phi = ? \]  
\[ A = 1, \quad f = 2, \quad T = 0.5, \quad \phi = 0 \]  

\[ A = ?, \quad f = ?, \quad T = ?, \quad \phi = ? \]  
\[ A = 1, \quad f = 1, \quad T = 1, \quad \phi = \pi/4 \]
Any electromagnetic signal can be shown as a collection of periodic analog signals (sine waves) at different amplitudes, frequencies, and phases.

The period of the total signal is equal to the period of the fundamental frequency.
Frequency Domain Concepts

- **Fundamental frequency** - when all frequency components of a signal are integer multiples of one frequency, it’s referred to as the fundamental frequency.

- **Spectrum** - range of frequencies that a signal contains.

- **Absolute bandwidth** - width of the spectrum of a signal.

- **Effective bandwidth (or just bandwidth)** - narrow band of frequencies that most of the signal’s energy is contained in.

![Graph showing frequency domain concepts](image-url)
Analog and Digital Signaling

- Both analog and digital data can be represented, and hence propagated by digital and analog signals.

Advantages and Disadvantages of Digital Signaling

+ Generally cheaper than analog signaling
+ Less susceptible to noise interference
- Suffer more from attenuation, needs repeaters
Analog and Digital Signaling of Analog and Digital Data

Analog Signals: Represent data with continuously varying electromagnetic wave

Analog Data (voice sound waves)  →  Telephone  →  Analog Signal

Digital Data (binary voltage pulses)  →  Modem  →  Analog Signal (modulated on carrier frequency)
Digital Signals: Represent data with sequence of voltage pulses

Analog Signal → Codec → Digital Signal

Digital Data → Digital Transmitter → Digital Signal
Impairments, such as noise, can corrupt a signal and limit data rate that can be achieved

- Noise - unwanted signals that combine with the intended signal and hence distort the signal
- Other impairments will be studied in the next lecture

**Question:** For digital data, to what extent do impairments limit data rate?

**Channel Capacity** – the maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions.
Concepts Related to Channel Capacity

- **Data rate** - rate at which data can be communicated (bps)
- **Bandwidth** - the bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium (Hertz)
- **Noise** - average level of noise over the communications path
- **Error rate** - rate at which errors occur
  - Error = transmit 1 and receive 0; transmit 0 and receive 1

Aim: Efficient use of limited bandwidth and get as high a data rate as possible at a particular limit of error rate
Nyquist Bandwidth

- Consider the case of a channel that is noise free.
  - Limitation: Bandwidth of the signal.

- A formulation of this limitation, due to Nyquist:
  - If the rate of a signal transmission is $2B$, then a signal with frequencies no greater than $B$ is sufficient to carry the signal rate.
  - Or, given a bandwidth of $B$, the highest signal rate that can be achieved is $2B$.

- For binary signals (two voltage levels)
  - $C = 2B$

- With multilevel signaling
  - $C = 2B \log_2 M$
    - $M =$ number of discrete signal or voltage levels

- Conclusion: For a given bandwidth, the data rate can be increased by increasing the number of signal elements?
Signal Strength and Decibels

• As the signal propagates along a transmission medium, it attenuates or loses strength.

• It is customary to represent losses and gains in logarithmic unit decibels, because:
  • Signal strength often falls exponentially.
  • The net loss/gain can be calculated in simple addition/subtraction operations.

• Decibel is a measure of the ratio between two signal levels, and the decibel gain is expressed as:

\[ G_{dB} = 10 \log_{10} \frac{P_{out}}{P_{in}} \]

\[ G_{dB}: \text{gain in decibels} \]

\[ P_{in}: \text{input power level} \]

\[ P_{out}: \text{output power level} \]

\[ L_{dB} = -10 \log_{10} \frac{P_{out}}{P_{in}} = 10 \log_{10} \frac{P_{in}}{P_{out}} \]

• Decibels refer to relative magnitudes.

• Decibel-Watt \( Power_{dBW} = 10 \log_{10} \frac{Power_{W}}{1W} \)

\[ 1000W = 30dBW \]

\[ 1mW = -30dBW \]
Signal-to-Noise Ratio

- Ratio of the power in a signal to the power contained in the noise that’s present at a particular point in the transmission
- Typically measured at a receiver
- Signal-to-noise ratio (SNR, or S/N)

\[
(SNR)_{dB} = 10 \log_{10} \left( \frac{\text{signal power}}{\text{noise power}} \right)
\]

- A high SNR means a high-quality signal, low number of required intermediate repeaters
- SNR sets upper bound on achievable data rate
Shannon Capacity Formula

Equation:

\[ C = B \log_2 (1 + SNR) \]

Represents theoretical maximum that can be achieved
In practice, only much lower rates achieved

- Formula assumes white noise (thermal noise)
- Impulse noise is not accounted for
- Attenuation distortion or delay distortion not accounted for
Transmission Medium

- Physical path between transmitter and receiver

Guided Media

- Waves are guided along a solid medium
- E.g., copper twisted pair, copper coaxial cable, optical fiber

Unguided Media

- Provides means of transmission but does not guide electromagnetic signals
- Usually referred to as wireless transmission
- E.g., atmosphere, outer space
- Transmission and reception are achieved by means of an antenna
  - Directional
  - Omnidirectional
Frequencies for communication

VLF = Very Low Frequency
LF = Low Frequency (Submarines)
MF = Medium Frequency (AM Radio)
HF = High Frequency (FM Radio)
VHF = Very High Frequency (Analog TV)
UHF = Ultra High Frequency (DAB, AMPS, GSM, UMTS)
SHF = Super High Frequency (directed microwave, satellite services)
EHF = Extra High Frequency
UV = Ultraviolet Light (directed links – laser)
Frequencies for mobile communication

- VHF-/UHF-ranges for mobile radio
  - simple, small antenna for cars
  - deterministic propagation characteristics, reliable connections

- SHF and higher for directed radio links, satellite communication
  - small antenna, focusing
  - large bandwidth available

- Wireless LANs use frequencies in UHF to SHF spectrum
  - some systems planned up to EHF
  - limitations due to absorption by water and oxygen molecules (resonance frequencies)
    - weather dependent fading, signal loss caused by heavy rainfall etc.
Frequencies and regulations

ITU-R holds auctions for new frequencies, manages frequency bands worldwide (WRC, World Radio Conferences)

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