

Lecture 13: Wireless Communications

ENGR 76 lecture notes — May 12, 2026

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1 Historical Perspective: The Pioneers

The engineering reality of wireless communication began with **Guglielmo Marconi**, who transitioned electromagnetic theory into practical engineering reality.

- **First Practical Link (1895):** Marconi successfully transmitted Morse code signals wirelessly over a distance of 3.2 km. This was the first practical demonstration of using electromagnetic waves as a communication carrier
- **Transatlantic Breakthrough (1901):** Marconi achieved the first transatlantic telegraphic radio transmission, sending the letter 'S' (three dots) from Cornwall, England, to Newfoundland, Canada. This experiment proved that radio waves could propagate around the curvature of the Earth, traversing the Atlantic Ocean.

2 The Cellular Wireless Revolution

Wireless connectivity has seen explosive growth, moving from niche industrial use to a global necessity.

- **Growth Scale:** Global mobile cellular subscriptions surged from **0.21** per 100 people in 1990 to **111.5** in 2025.
- **Total Increase:** This represents a **nearly 500x growth** in subscriptions over just 35 years.

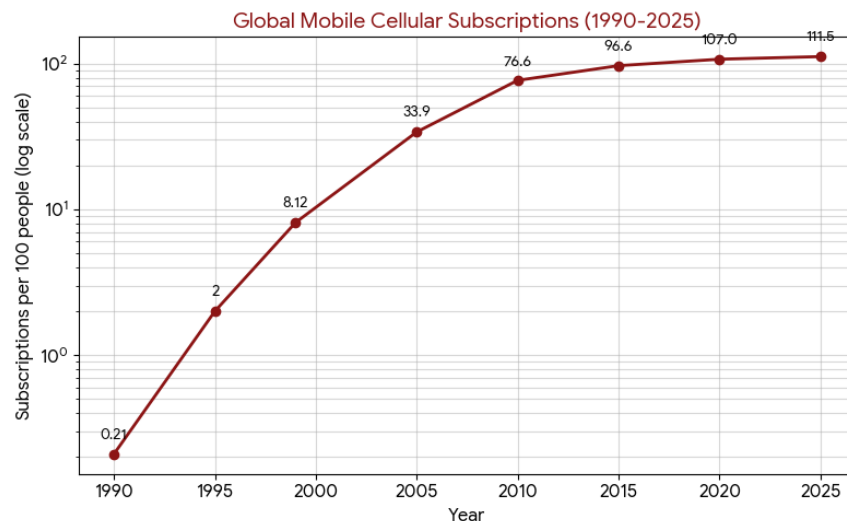


Figure 1: Global mobile cellular subscriptions per 100 people (log scale), 1990–2025.

3 FCC Frequency Spectrum Maps and Applications

Because wireless is a shared medium, the U.S. Frequency Allocations chart managed by the FCC regulates how different technologies utilize the spectrum to prevent interference.

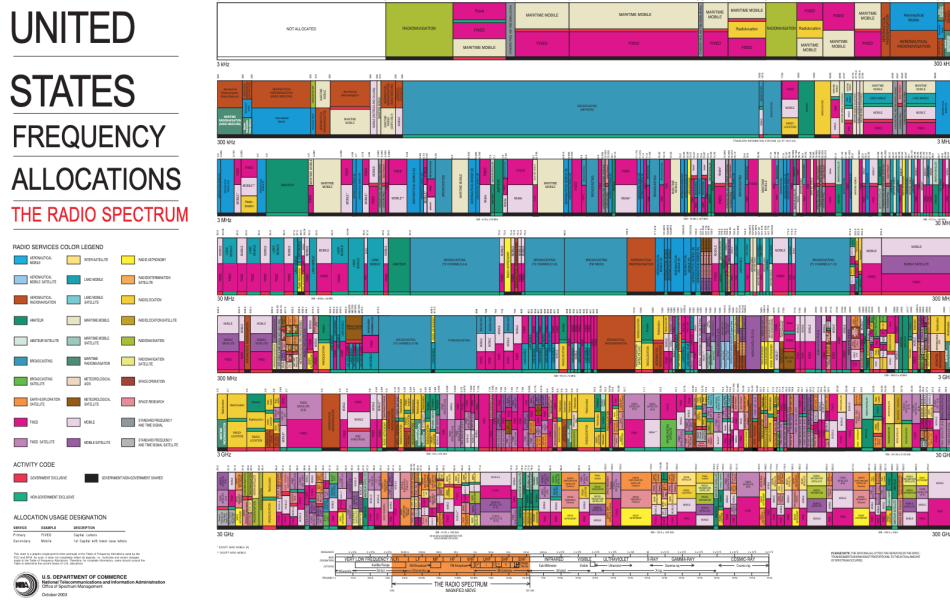


Figure 2: United States Frequency Allocations chart.

Modern technology utilizes these partitioned bands for various applications:

- **WiFi:** Operates in the 2.4 GHz, 5 GHz, and 6 GHz bands.
- **Bluetooth:** Operates in the 2.4 GHz band.
- **GPS:** Operates in the 1.2–1.5 GHz range.
- **Cellular:** Uses various bands including 600 MHz, 700 MHz, 850 MHz, and 5G bands at 2.5 GHz and 3.7–3.98 GHz.

4 Frequency vs. Time: The Mathematical Advantage

A fundamental question in networking is why we divide resources based on frequency bands rather than time slots. The answer lies in the signal's **insensitivity to time delay**.

Consider a signal $x(t) = \sin(2\pi ft - t_0)$ with an arbitrary initial time t_0 . After a channel delay Δ :

$$y(t) = \sin(2\pi f(t - t_0 - \Delta)) = \sin(2\pi ft + \phi) \quad (1)$$

The received frequency remains exactly f regardless of the initial time t_0 or the delay Δ . This proves that **synchronization across different applications is not required** when dividing by frequency.

5 Project 2 System Architecture

Project 2 focuses on building a functional acoustic wireless link using a modular pipeline.

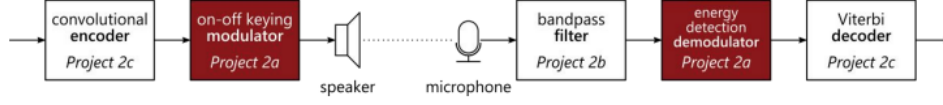


Figure 3: System Diagram for Project 2.

6 Baseband Communication

We define the baseband signal $x(t)$ using amplitude V and bit duration T_b .

- $\{b_m\}$: Bitstream sequence.
- V : Amplitude.
- T_b : Bit duration.
- $R_b = \frac{1}{T_b}$: Bit rate.

$$x(t) = \begin{cases} V & t \in [(m-1)T_b, mT_b] \text{ if } b_m = 1 \\ 0 & \text{if } b_m = 0 \end{cases} \quad (2)$$

7 Simulated Channel

In development, the physical environment is replaced by `channel.py`, a Python program that simulates propagation and noise. The channel exhibits a specific frequency response characterized by peaks and nulls.

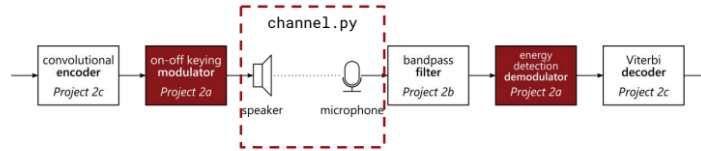


Figure 4: Channel simulated by a Python program.

8 Multipath Analysis and Interference

Why does the frequency response changes with frequency? Answer: multipath. Multipath interference occurs when a signal reaches the receiver via different paths with delays Δ_1, Δ_2 .

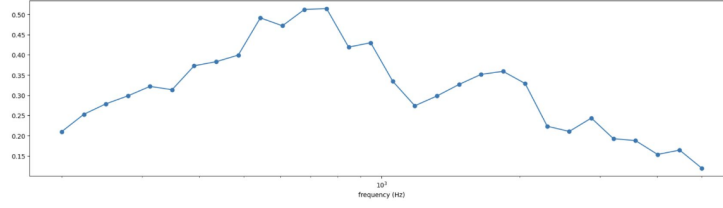


Figure 5: Channel frequency response showing peaks and nulls.

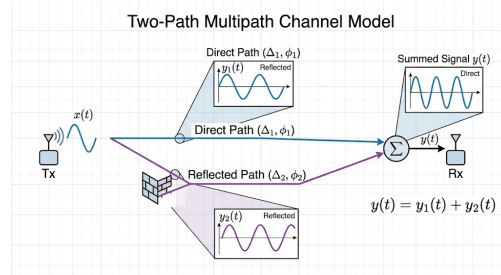


Figure 6: Multipath channel diagram between laptops.

The sum of two sinusoids at frequency f is another sinusoid at the same frequency f , but with amplitude $A(f)$ that depends on the frequency:

$$y(t) = \underbrace{[2 \cos(\pi f(\Delta_2 - \Delta_1))]}_{A(f)} \cdot \sin(2\pi f t - \pi f(\Delta_1 + \Delta_2)) \quad (3)$$

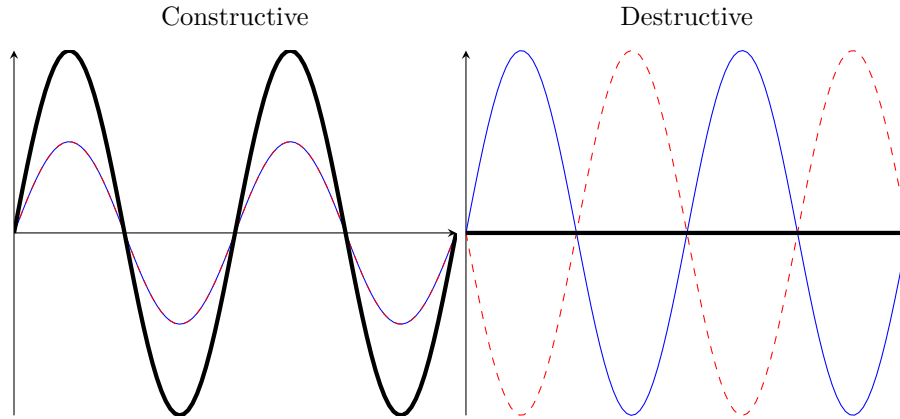


Figure 7: Constructive and Destructive interference based on phase shift.

You may remember this phenomenon from your high school physics days!

9 Passband Communication

To optimize transmission, we modulate $x(t)$ onto a carrier frequency f_c optimized for the strongest channel response: $s(t) = x(t) \sin(2\pi f_c t)$.

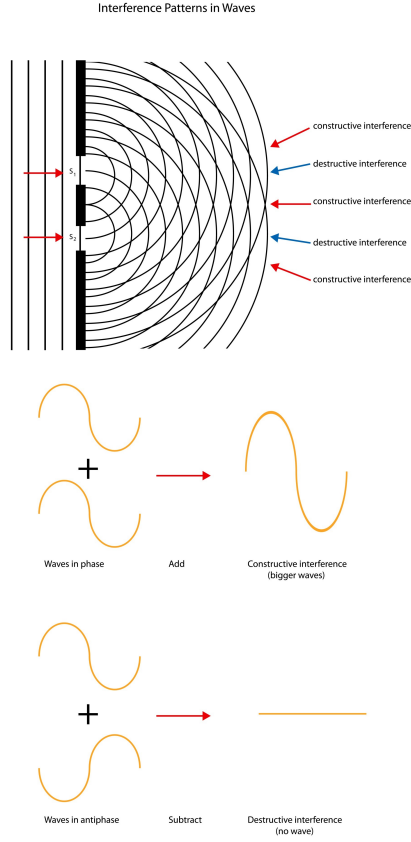


Figure 8: Constructive and Destructive interference from a classic high school physics experiment.

10 Demodulation: Energy Detection

Integrating the raw passband signal fails because $\int \sin \approx 0$. Instead, we use an **Energy Detection Demodulator** by integrating the squared signal:

$$P = \frac{1}{T_b} \int_0^{T_b} y^2(t) dt \quad (4)$$

If $b_m = 1$, $P \approx V^2/2$; if $b_m = 0$, $P \approx 0$. The receiver uses a threshold (e.g., $V^2/4$) to determine the bit's value.