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History Wireless Communication

Objectives

- Describe how wireless communications technologies are used today
- List various applications of wireless communications technology
- Outline the advantages and disadvantages of wireless communications technology
- List several types of wireless technologies and their purposes
- Mobile and Wireless Computing

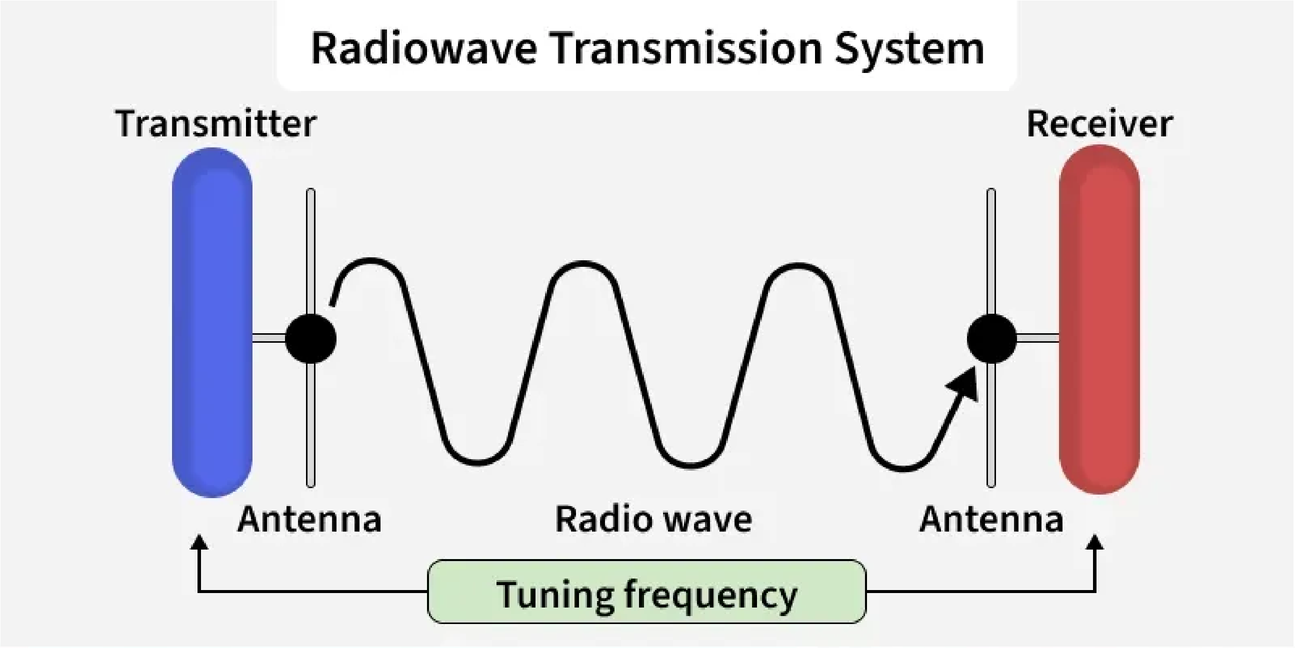
History of Wireless Communication

From Radio Waves to Mobile & Wireless Computing

Wireless communication enables information transfer **without physical conductors**

Based on **electromagnetic wave propagation**

Foundation of modern mobile, IoT, and cyber-physical systems



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What Is Wireless Communication?

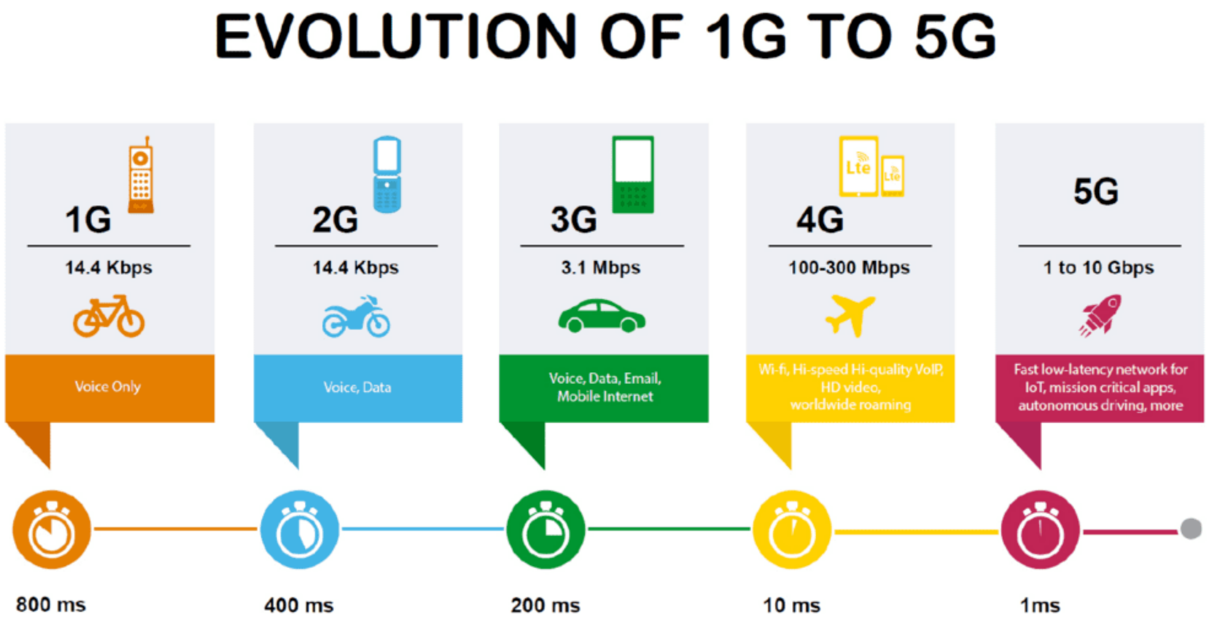
- Transmission of data using **electromagnetic waves**
- No physical cable between transmitter and receiver
- Key parameters:
  - ➢ Frequency
  - ➢ Bandwidth
  - ➢ Power
  - ➢ Propagation environment

Early History of Wireless Communication

- **1890s**: Radio wave theory validated
- **Marconi**: Wireless telegraphy
- Early systems:
  - Morse code
  - Point-to-point communication
- Used mainly for:
  - Maritime communication

Wireless Communication Milestones

- **1920s–1940s**: Radio broadcasting
- **1950s–1960s**: Television, radar, satellites
- **1980s**: 1G analog cellular
- **1990s**: 2G digital cellular (GSM)
- **2000s–today**: Wi-Fi, 3G–5G, IoT



https://www.rfpage.com/history-of-wireless-communication-morse-code-to-5g-technology/

Wireless Communications Today

Wireless technologies are **everywhere**:
- Smartphones & tablets
- Laptops & wearables
- Smart homes & cities
- Industrial automation
- Healthcare systems

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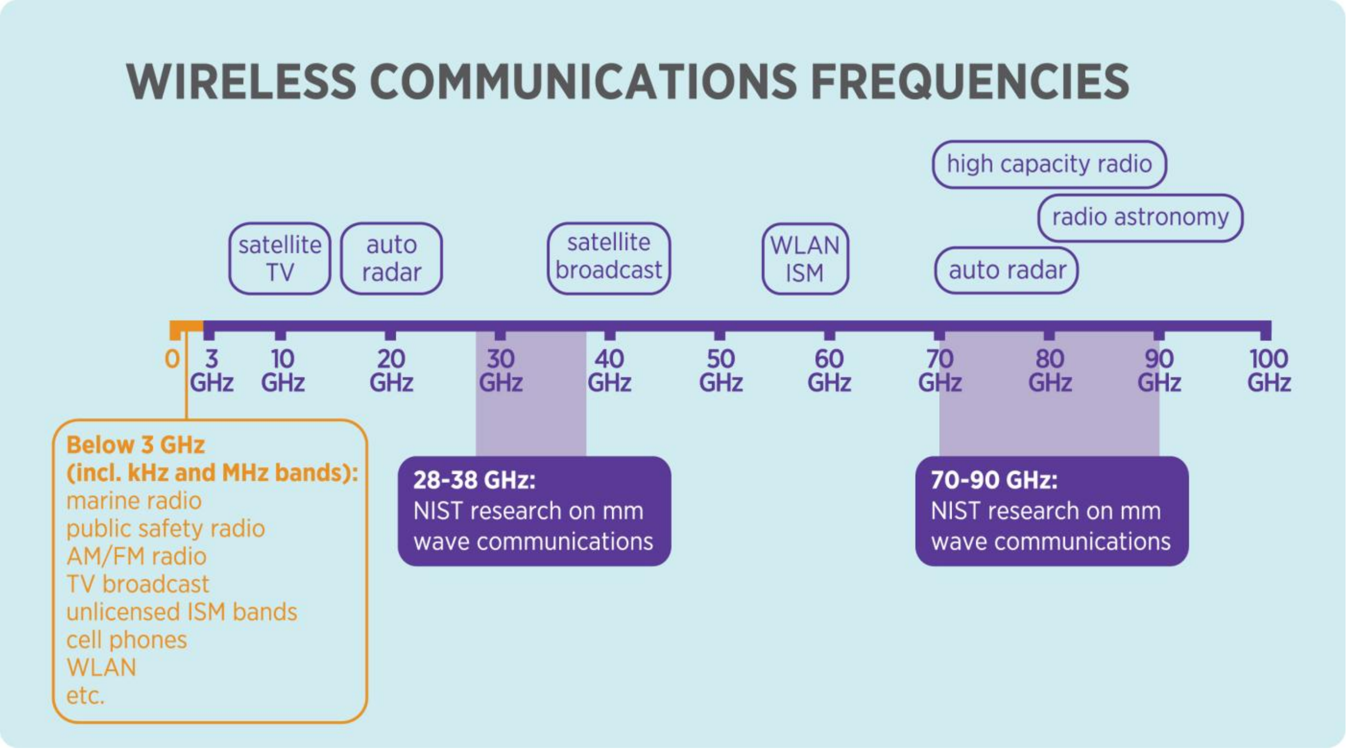
Applications of Wireless Communication

Major application areas:

- Mobile communication (voice, data)
- Internet access (Wi-Fi, cellular)
- Sensor networks (IoT)
- Transportation (V2X, GPS)
- Healthcare (remote monitoring)
- Defense & emergency services



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Advantages of Wireless Communication

- Mobility and flexibility
- Fast deployment
- Reduced cabling costs
- Scalable systems
- Enables portable and embedded devices
- **Engineering benefit:**
  Wireless enables **systems that could not exist with cables**

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Disadvantages of Wireless Communication

- Limited bandwidth
- Interference and noise
- Security vulnerabilities
- Power constraints (battery-operated devices)
- Unreliable links in harsh environments
- **Key engineering challenge:**
  Designing systems that are **robust despite uncertainty**

Types of Wireless Technologies

Attribute	Bluetooth® Low Energy Technology	Wi-Fi	Z-Wave	IEEE 802.15.4 (Zigbee, Thread)	LTE-M	NB-IoT	Sigfox	LoRaWAN
Range	10 m – 1.5 km	15 m – 100 m	30 m - 50 m	30 m – 100 m	1 km – 10 km	1 km – 10 km	3 km – 50 km	2 km – 20 km
Throughput	125 kbps – 2 Mbps	54 Mbps – 1.3 Gbps	10 kbps – 100 kbps	20 kbps – 250 kbps	Up to 1 Mbps	Up to 200 kbps	Up to 100 bps	10 kbps – 50 kbps
Power Consumption	Low	Medium	Low	Low	Medium	Low	Low	Low
Ongoing Cost	One-time	One-time	One-time	One-time	Recurring	Recurring	Recurring	One-time
Module Cost	Under $5	Under $10	Under $10	$8-$15	$8-$20	$8-$20	Under $5	$8-$15
Topology	P2P, Star, Mesh, Broadcast	Star, Mesh	Mesh	Mesh	Star	Star	Star	Star
Shipments in 2019 (millions)	~3,500	~3,200	~120	~420	~7	~16	~10	~45

Types of Wireless Technologies

Short-range

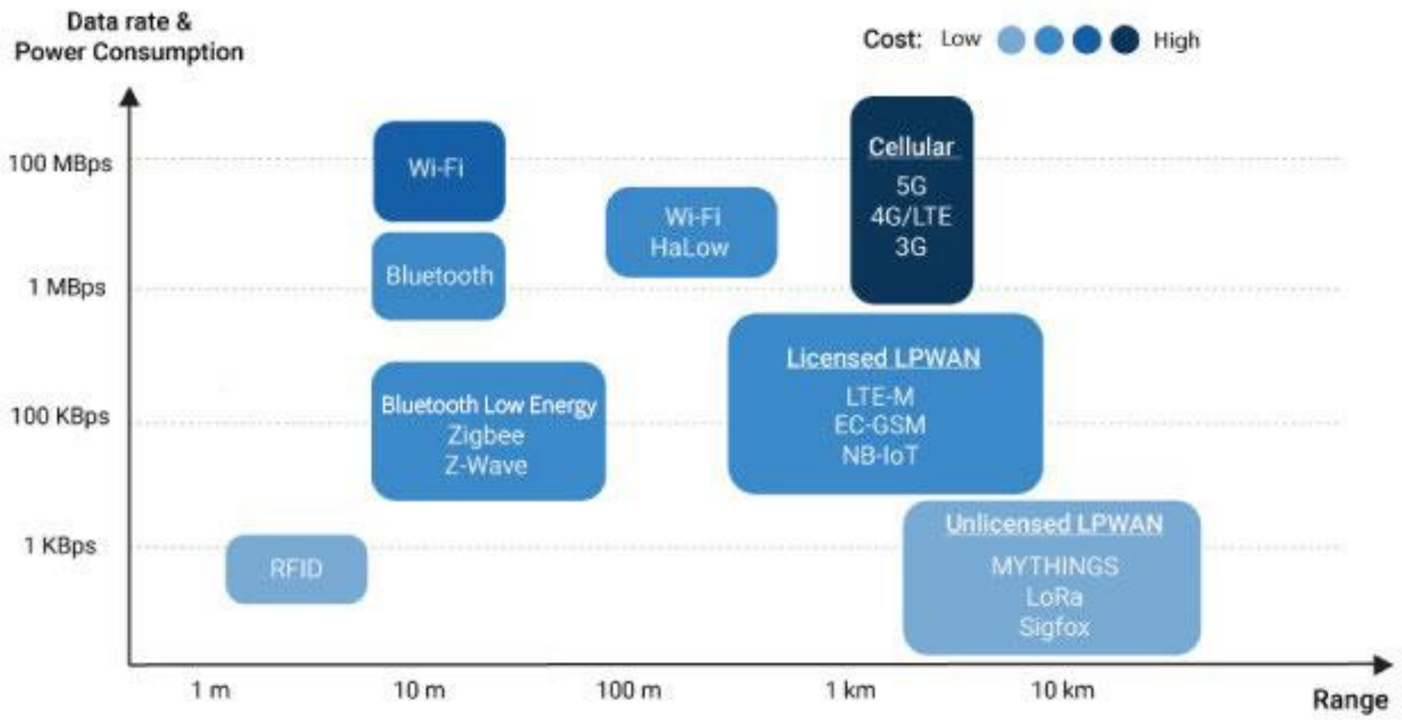
- Bluetooth
- NFC
- Zigbee

Medium-range

- Wi-Fi
- Private radio systems

Long-range

- Cellular networks
- LPWAN (LoRa, NB-IoT)
- Satellite communication



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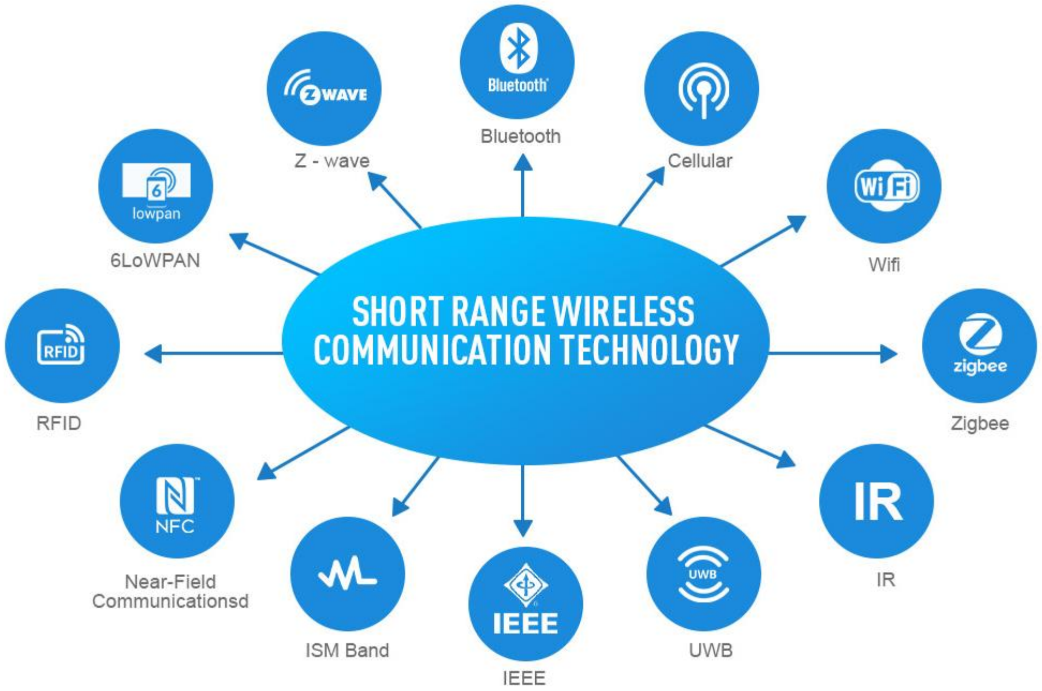
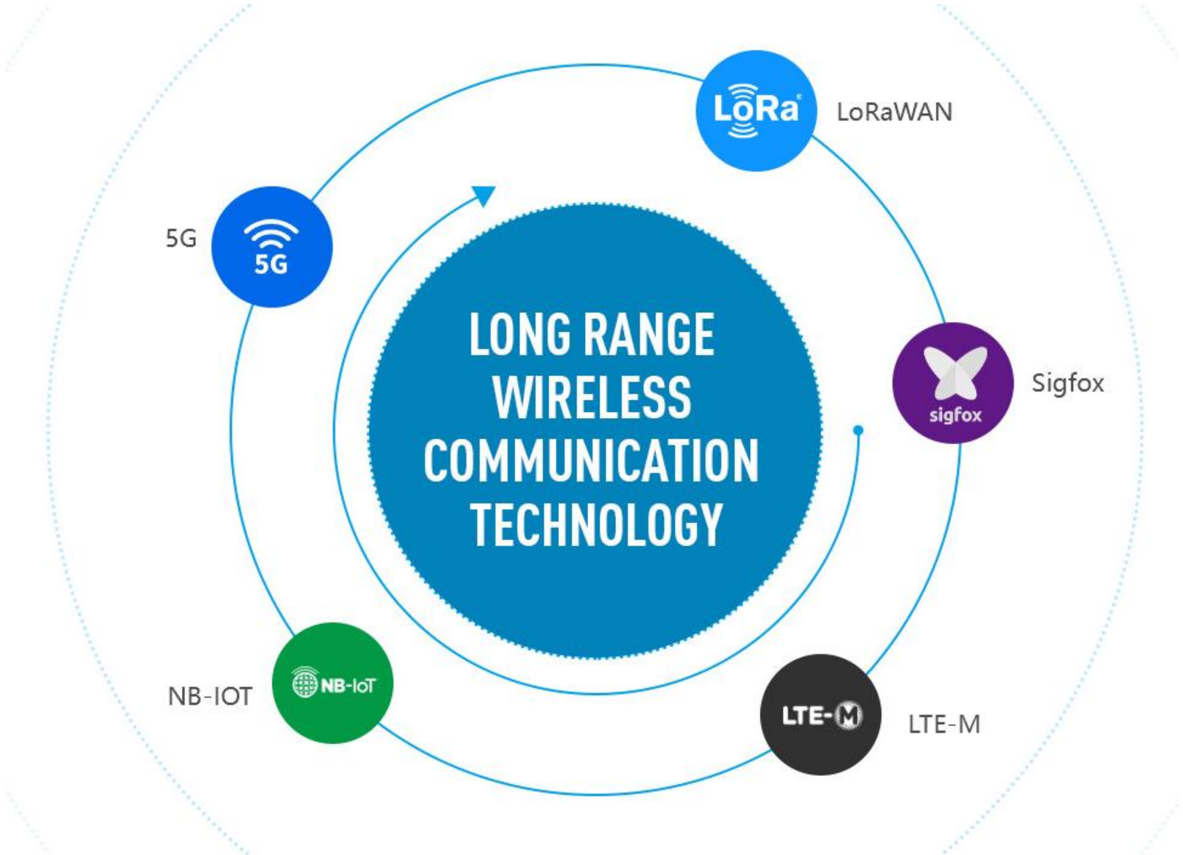
Types of Wireless Technologies





https://www.mokosmart.com/short-range-wireless-communication-technology-vs-long-range-wireless-communication-technology

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Purpose of Different Wireless Technologies

Technology Type	Primary Purpose
Bluetooth	Device-to-device communication
Wi-Fi	Local high-speed data
Cellular	Wide-area mobility
LPWAN	Low-power sensor networks
Satellite	Global coverage

Practical Mapping (Real Life)

- Bluetooth earbuds → **2.4 GHz**
- Home Wi-Fi → **2.4 / 5 GHz**
- Smart meter → **868 MHz**
- Smartphone data → **700 MHz – 3.5 GHz**
- GPS → **1.575 GHz**

Key Engineering Insight

- **Lower frequency** → longer range, better penetration
- **Higher frequency** → higher data rates, shorter range
- System design is always a **trade-off**

There is **no universal wireless solution.**

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Wireless Network Classifications

Wireless networks are commonly classified by:
•**Coverage area, Typical use case**, **Underlying standards**

Network Type	Coverage	Typical Frequency	Example
WPAN Wireless Personal Area Network	Personal	MHz – GHz	Bluetooth
WLAN Wireless Local Area Network	Local	2.4 / 5 / 6 GHz	Wi-Fi
WMAN Wireless Metropolitan Area Network	City	2–11 GHz	WiMAX
WWAN Wireless Wide Area Network	Wide	sub-GHz – GHz	LTE / 5G
LPWAN Low-Power Wide Area Network	Wide	sub-GHz	LoRaWAN
Satellite Networks	Global	GHz–tens of GHz	GPS

Why Wireless Matters for Engineers

Core skill in:
- IoT
- Embedded systems
- Automation
- AI at the edge

- Strong job-market relevance
- Interdisciplinary:
  - Electronics
  - Signal processing
  - Networking
  - Software

Summary

- Wireless communication has evolved for over 100 years
- Enables modern mobile and computing systems
- Comes with trade-offs and design challenges
- Multiple technologies serve different purposes
- Foundation of **Mobile & Wireless Computing**

Frequency Spectrum & ISM Bands

Electromagnetic Frequency Spectrum

- Wireless communication uses a **small portion** of the electromagnetic spectrum

- Frequency range for wireless:
  kHz → GHz
- Higher frequency → higher data rate potential
- Lower frequency → longer range, better penetration

- **Engineering view:**
  Frequency selection determines **range, data rate, antenna size, and power consumption**

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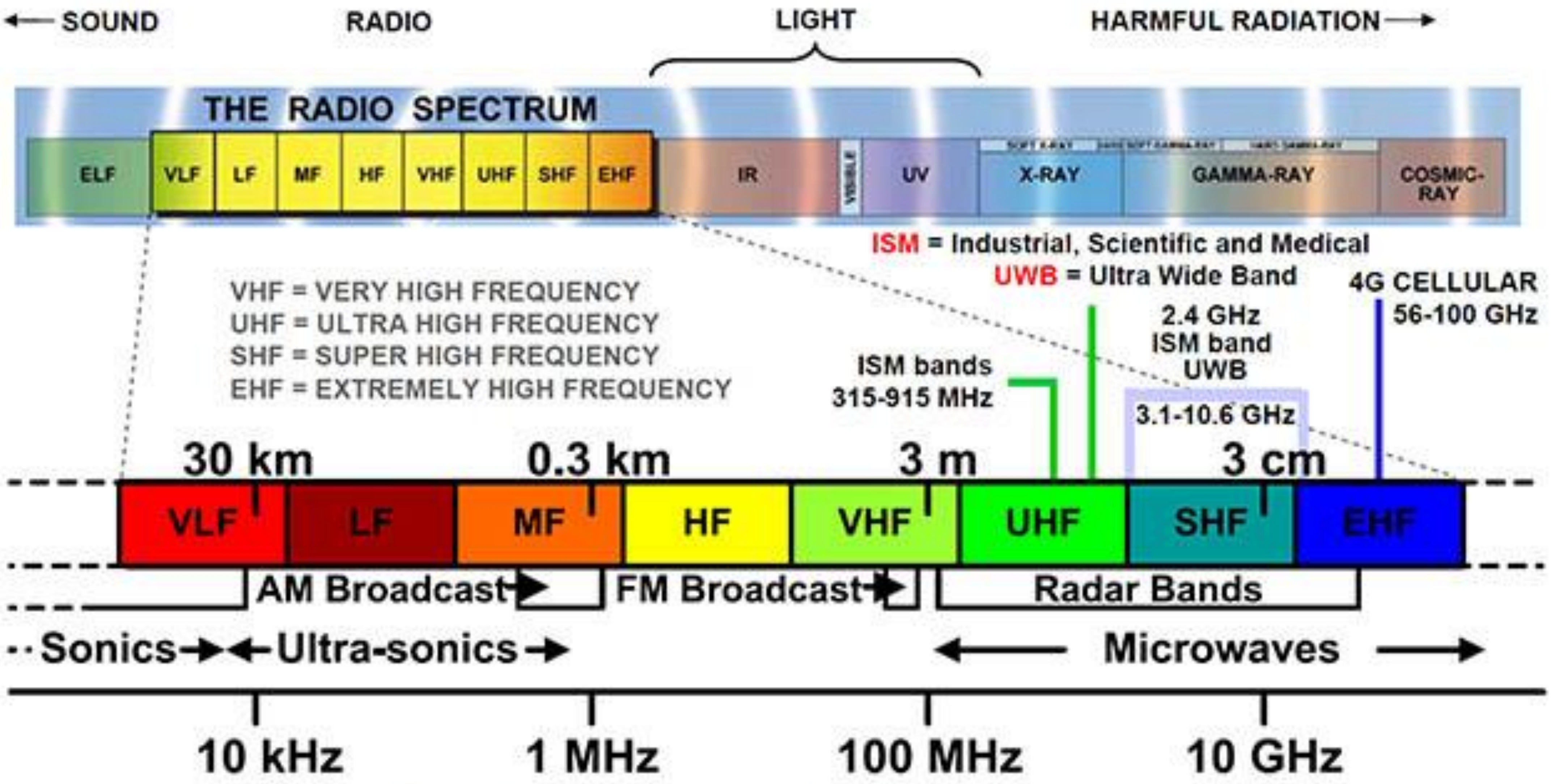
Electromagnetic Frequency Spectrum



Licensed vs Unlicensed Spectrum

- **Licensed spectrum**
  - Controlled by regulators
  - Used by cellular networks
  - Guaranteed quality of service
- **Unlicensed spectrum**
  - Free to use
  - Shared by many devices
  - Higher interference risk
- **Key trade-off:**
  Cost and control vs flexibility and accessibility

ISM Bands (Industrial, Scientific, Medical)

ISM Band Frequencies
6.765 - 6.795 MHz
13.553 - 13.567 MHz
26.957 - 27.283 MHz
40.66 - 40.70 MHz
83.996 - 84.004 MHz
167.992 - 168.008 MHz
433.05 - 434.79 MHz
886 - 906 MHz
2.400 - 2.500 MHz
5.725 - 5.875 MHz
24.0 - 24.25 GHz
61.0 - 61.5 GHz
122 - 123 GHz
244 - 246 GHz

Common ISM bands:

Band	Typical Use
433 MHz	Remote controls, sensors
868 MHz (EU)	IoT, LPWAN
915 MHz (US)	IoT
2.4 GHz	Wi-Fi, Bluetooth
5 GHz	Wi-Fi
24 GHz	Radar, sensing

ISM (Industrial, Scientific, and Medical) bands are **license-free** radio frequency bands reserved internationally for non-telecommunication purposes but widely used by wireless technologies such as Wi-Fi, Bluetooth, and IoT devices.

Important: ISM bands are **crowded by design.**

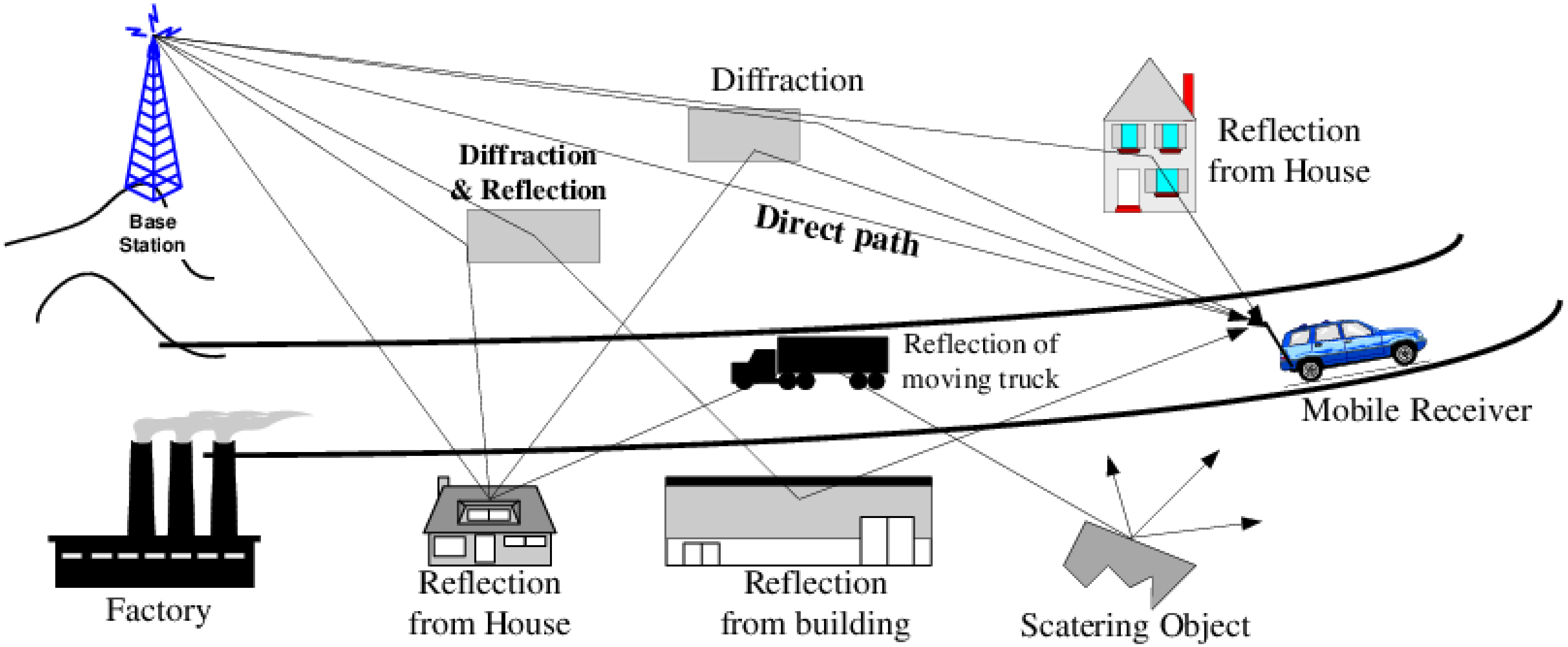
Signal Propagation Basics

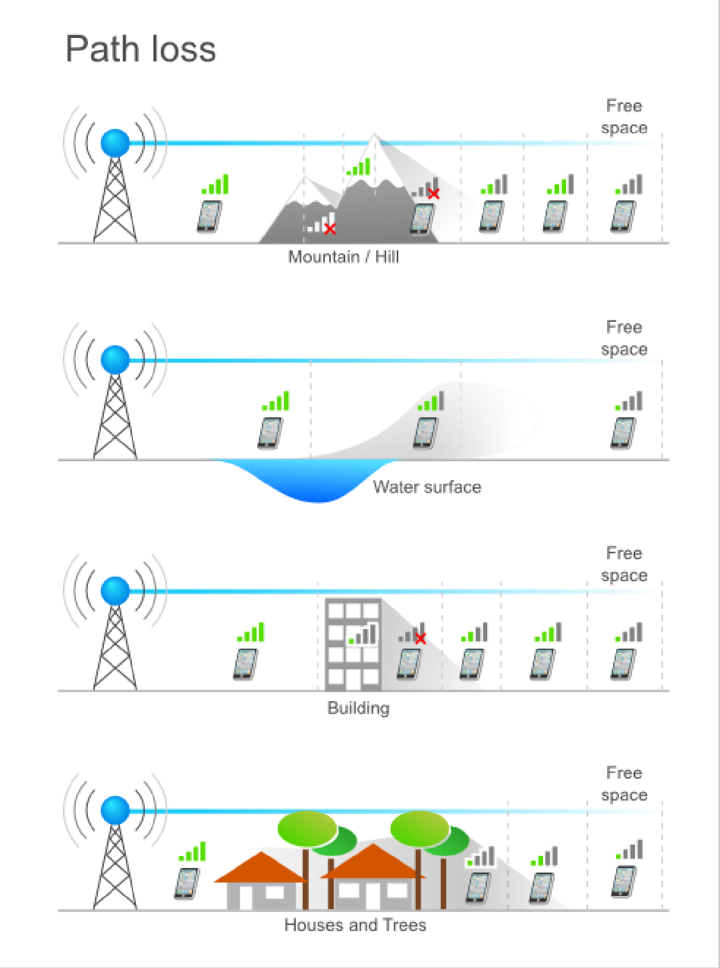
How Radio Waves Propagate

Wireless signals propagate via:

- Free-space propagation
- Reflection
- Diffraction
- Scattering

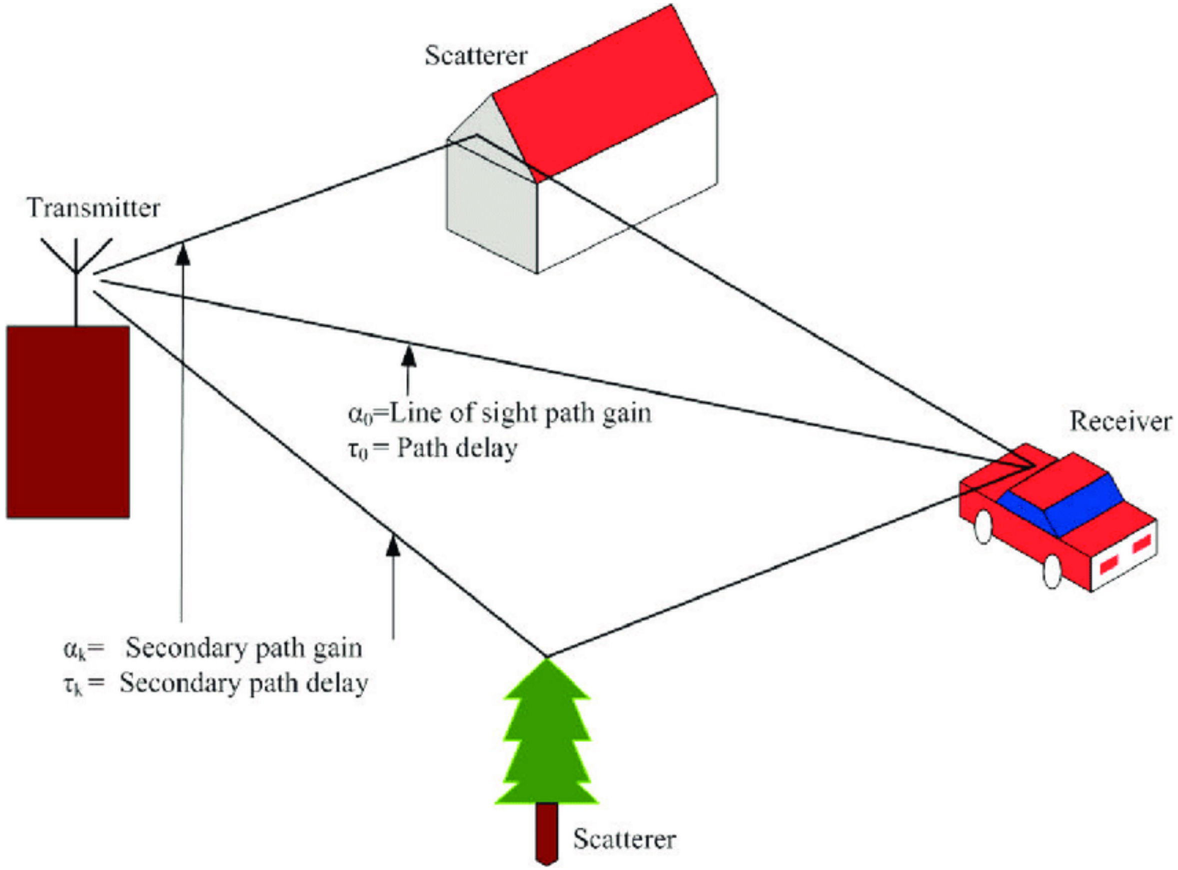
Real environments are **never ideal**





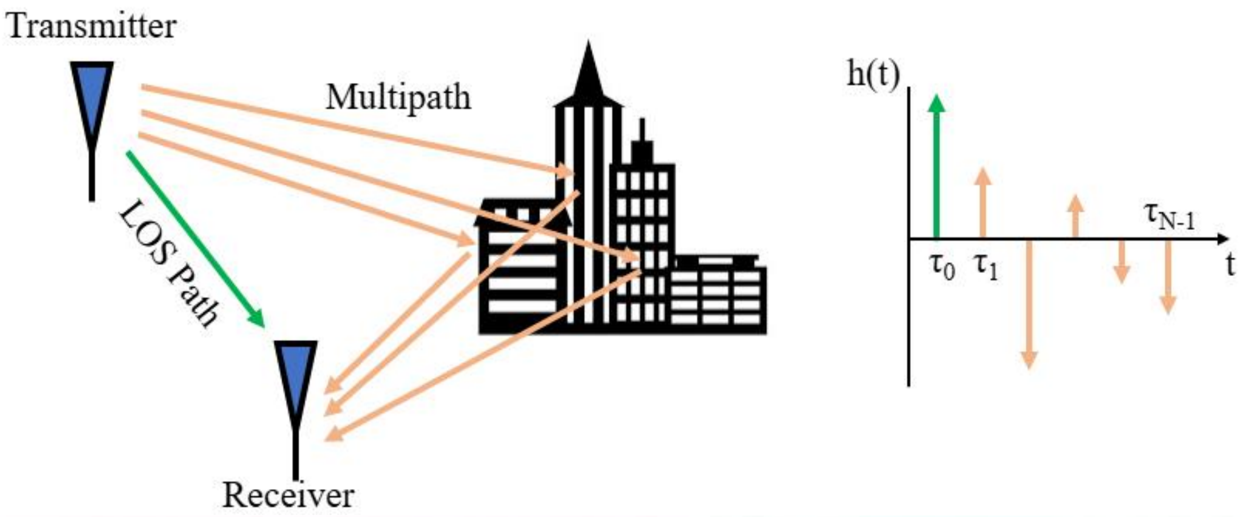
Line-of-Sight vs Non-Line-of-Sight

- **LOS (Line of Sight)**
  - Clear path between transmitter and receiver
  - Best signal quality
- **NLOS**
  - Obstacles block direct path
  - Multipath effects dominate
- **Applied example:** Indoor Wi-Fi is mostly **NLOS**



Multipath and Fading

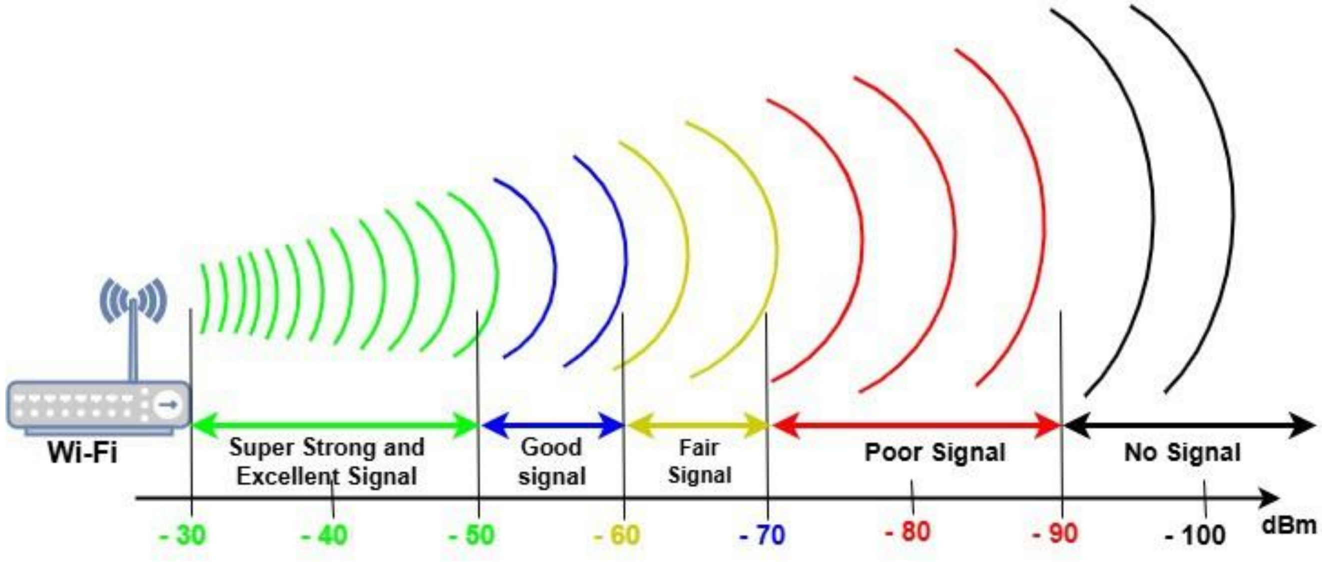
- Signals arrive via multiple paths
- Can interfere constructively or destructively
- Causes:
  - Signal fading
  - Fluctuating RSSI
  - Packet loss
- **Key concept:**
  Movement of just a few centimeters can change signal strength



RSSI, Noise, and Interference

RSSI (Received Signal Strength Indicator)

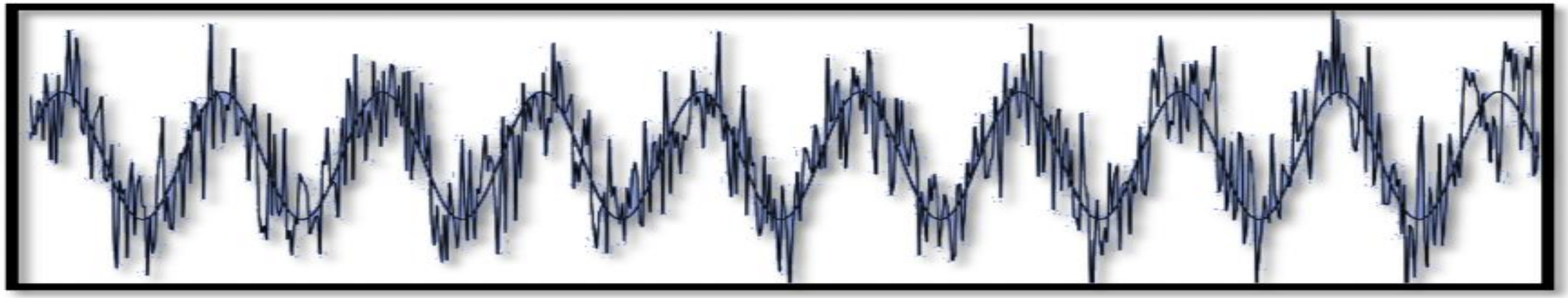
- Measurement of received signal power
- Typically expressed in **dBm**
- Example values:
  - −30 dBm → excellent
  - −60 dBm → good
  - −90 dBm → unreliable
- **RSSI ≠ Quality**
  It only measures **power**, not correctness



RSSI (Received Signal Strength Indicator) is a metric measuring the power of a wireless signal a device receives, indicating connection quality for Wi-Fi, Bluetooth, and cellular networks, expressed in dBm where closer to 0 (e.g., -30 dBm) is strong, and closer to -100 dBm is weak, helping devices decide when to connect, roam, or troubleshoot issues.

Noise in Wireless Systems

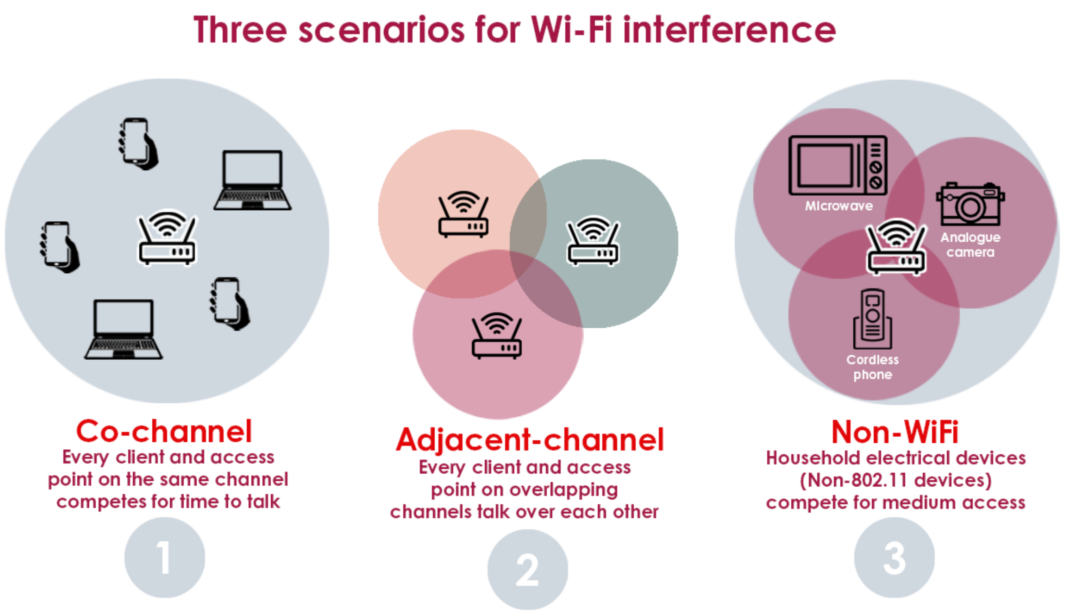
- Unwanted random signals
- Sources:
  - Thermal noise
  - Electronic components
  - Environmental noise
- Noise floor defines **minimum detectable signal**



Noise in wireless systems is any unwanted energy or disturbance that degrades a signal, impacting quality, speed, and reliability by obscuring data

Interference

- Caused by other transmitters
- Common in ISM bands
- Types:
  - Co-channel interference
  - Adjacent-channel interference
- **Engineering reality:**
  Interference is often the **main limiting factor**



Signal-to-Noise Ratio (SNR)

- SNR = Signal Power / Noise Power
- Higher SNR → better reliability
- Low SNR → errors, retransmissions
- **Practical takeaway:**
  A weaker signal with low noise can outperform a strong signal with high interference

SNR	Connection Quality	Performance
40+ dB	Excellent	Everything works - 4K streaming, massive file transfers, flawless VoIP
25-40 dB	Very Good	Solid performance for most apps, minimal packet loss
15-25 dB	Fair	Basic web browsing works fine; streaming gets dicey
10-15 dB	Poor	Barely functional - users will complain
Below 10 dB	Unusable	Frequent disconnects, time to troubleshoot

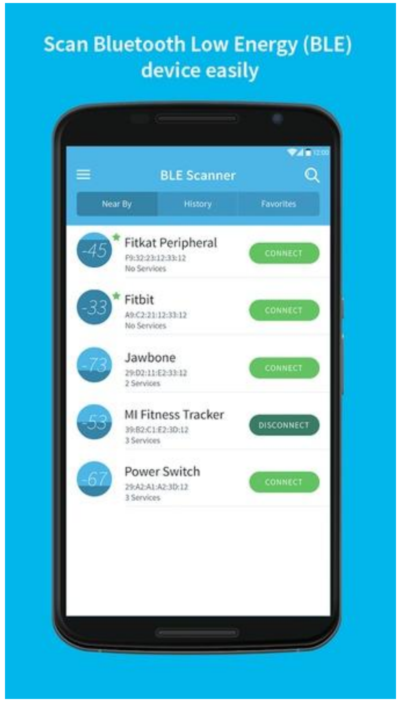
Practical Measurements with Smartphones

Why Smartphones Are Ideal Lab Tools

- Built-in radios
- Real environments
- Immediate feedback
- No extra hardware required

A modern smartphone is not a single radio device, but a co-located multi-radio system:

- Wi-Fi (2.4 / 5 / 6 GHz)
- Bluetooth / BLE (2.4 GHz)
- Cellular (sub-GHz to GHz)
- GNSS (L-band)
- NFC (13.56 MHz)

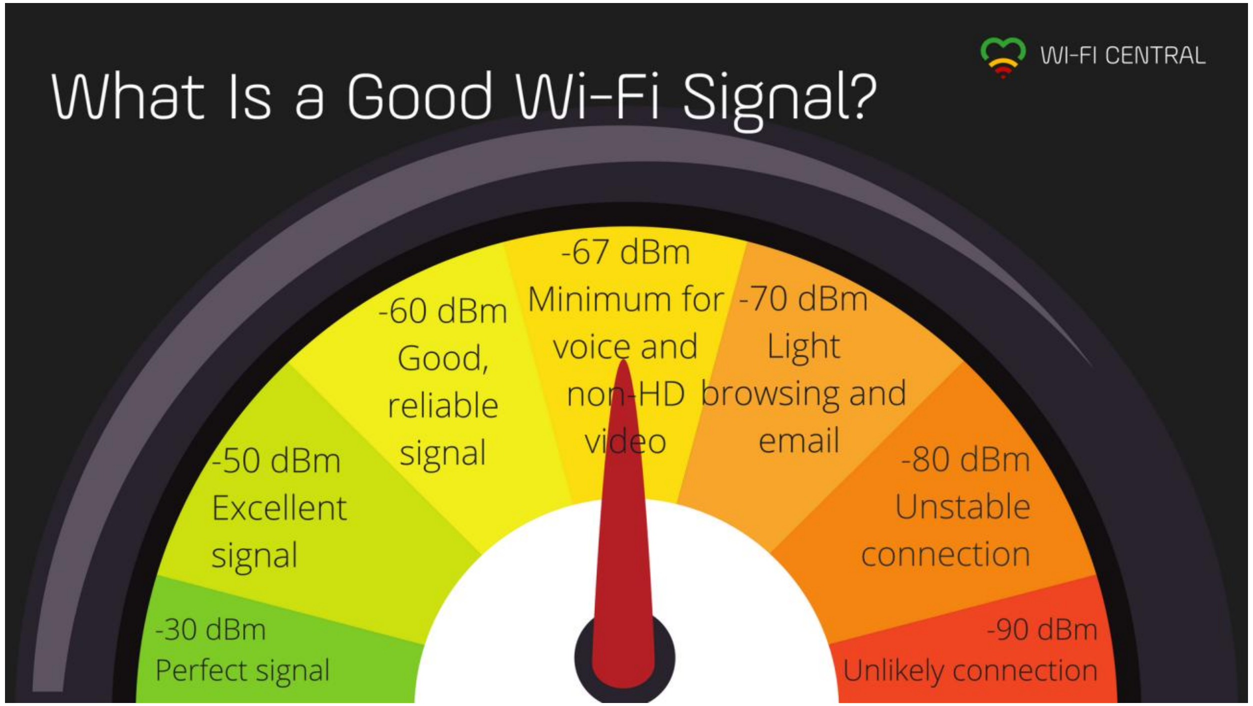


https://www.wilsonamplifiers.com/blog/how-to-read-cell-phone-signal-strength-the-right-way/?srsltid=AfmBOoqWAimKRMMdQR351rfRs71979ughT_eWiuM-VlvNOxAHN-HOjIt

Wi-Fi Measurements (Hands-On)

Can be measured:
•RSSI of access points
•Channel usage
•Signal stability over time

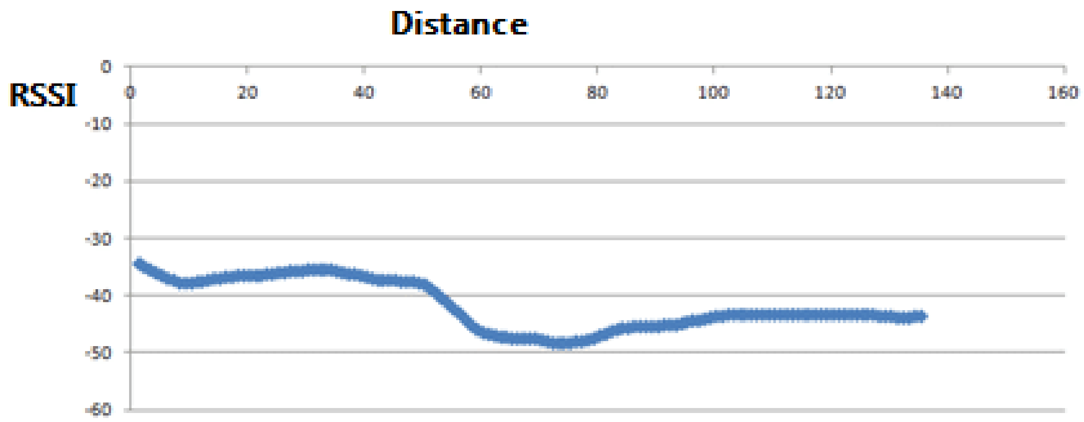
Typical observations:
•Strongest AP ≠ best performance
•2.4 GHz more crowded than 5 GHz



Bluetooth / BLE Measurements

Can be observed:
•Device discovery
•RSSI vs distance
•Advertising intervals
•Environmental effects

Insight:
BLE is optimized for **low power, not range or speed**



Experiment idea (Assignments):
1. Measure RSSI near transmitter
2. Move 5–10 meters away
3. Add obstacles (walls, people)
4. Compare readings

https://www.bluetooth.com/blog/proximity-and-rssi

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Summary

- Frequency choice defines system behavior
- ISM bands enable innovation but cause interference
- Signal propagation is environment-dependent
- RSSI alone is insufficient
- Smartphones are powerful measurement tools

https://www.bluetooth.com/blog/proximity-and-rssi