# Introduction to Wireless Communication

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# Early History & Developments

- **Electro Magnetic (EM) waves**
  - **1678**: Huygens works on light reflection and refraction
  - **1819**: Fresnel demonstrates the wavelike nature of light
  - **1831:** Faraday demonstrates electromagnetic induction
    - Rotating electric coil -> magnetic field and vice versa
  - **1864:** J. Maxwell introduces the theory of electromagnetic fields, wave equations
  - **1886:** H. Hertz demonstrates experimentally the transmission and detection of an EM wave between two points a few meters apart

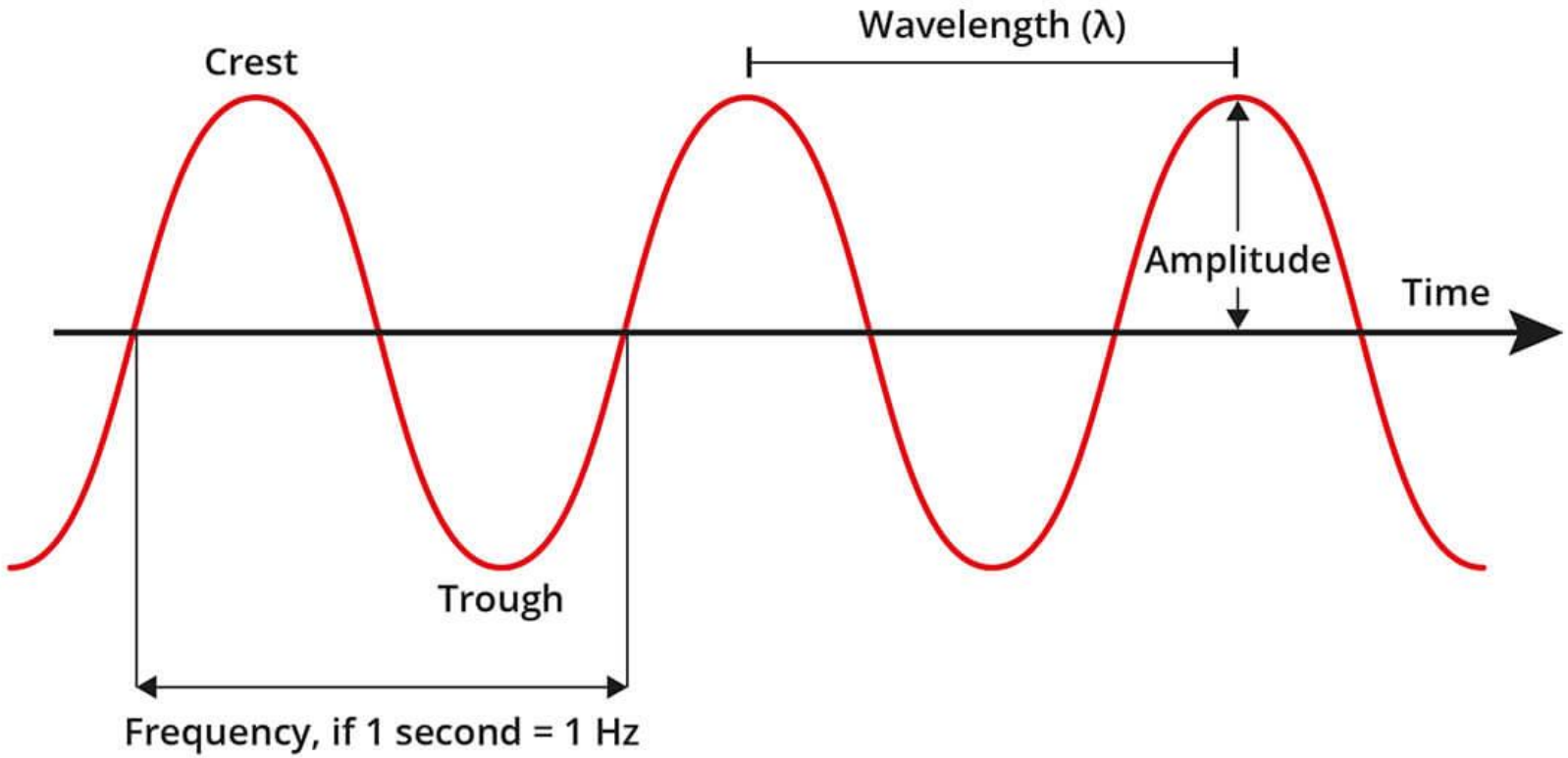
# What is Wireless Communication?

- Transmitting voice and data using **electromagnetic waves** in open space (atmosphere)

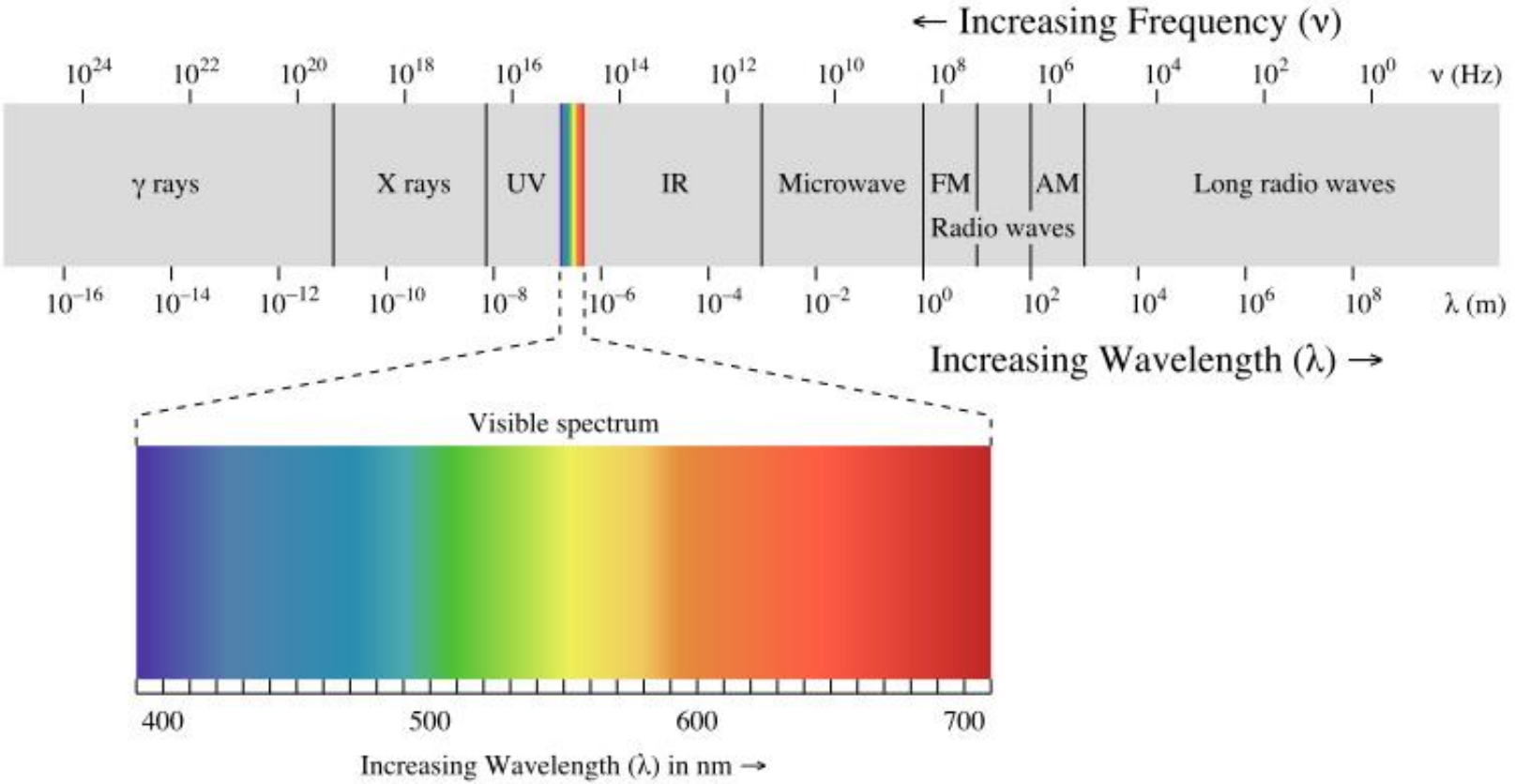
- **Electromagnetic waves**
  - Travel at **speed of light** (**c = 3x10$^8$ m/s**)
  - Has a **frequency (*f* )** and **wavelength** (**λ: *lambda***)

    **c = f x λ**
  - Higher frequency means higher energy
  - The higher the energy the more penetrating is the radiation

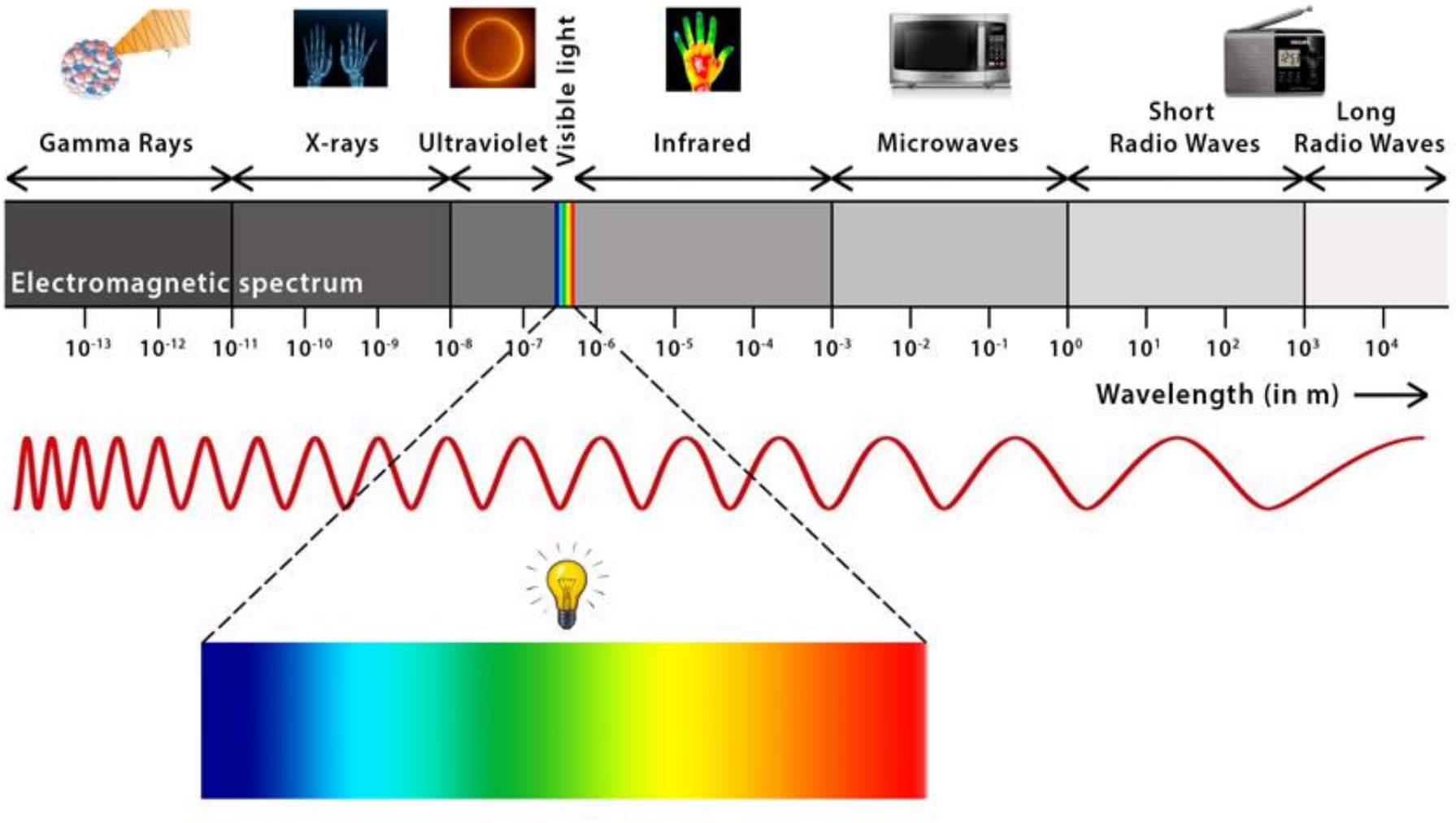
# Basics of Waves



# Electromagnetic Spectrum



# Electromagnetic Spectrum – Types



# Electromagnetic Carrier Selection

- Distance (between the sender and receiver) is short, e.g. TV box and a remote control
  - Infrared waves are used
- **Long range distances** (between sender and receiver), e.g. TV broadcasting)
  - **Microwaves** – good when large areas need to be covered and no obstacles exist in the transmission paths
- **Radio waves**
  - Can penetrate obstacles and also relatively large areas
  - Used for most wireless communications

# Wireless Communications: Advantages and disadvantages

- **Advantages**:
  - An ideal solution in areas where cables are impossible to install (e.g. hazardous areas, long distances etc.)
  - Easier to maintain
  - Supports Mobility

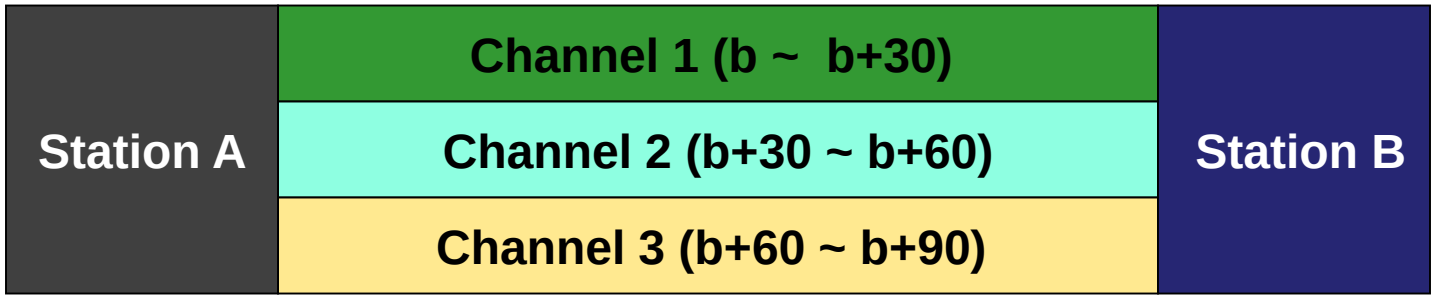
- **Disadvantages**:
  - Security vulnerabilities
  - High costs for setting the infrastructure
  - Influenced by physical obstructions, climatic conditions, interference from other wireless devices

# Frequency Carriers/Channels

- The information from sender to receiver is carrier over a well defined **frequency** band, often called **channel**
  - Similar it to a freeway or a city-water transmission
- Each channel has a fixed **frequency bandwidth** and capacity (bit-rate)
  - Similar to the width of a lane or tap
- Different **frequency bands (channels)** can be used to transmit information in parallel and independently

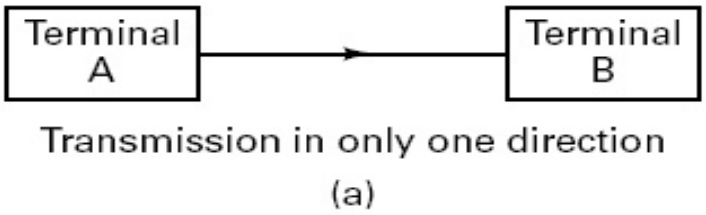
# Example of Frequency Channels

- Assume a **spectrum** of **90KHz** is allocated over a **base frequency b** for communication between **stations A and B**
- Assume each channel occupies **30KHz**.
- There are **3 channels**
- Each channel is **simplex**, i.e. only one-way transmission



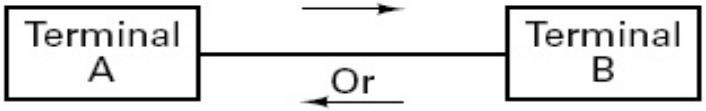
# Types of Communications

- **Simplex – one-way**
- **Half-duplex – two-way, but one-way at a time**
- **Duplex – always two-way**



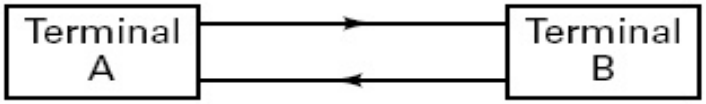

Transmission in only one direction

(a)



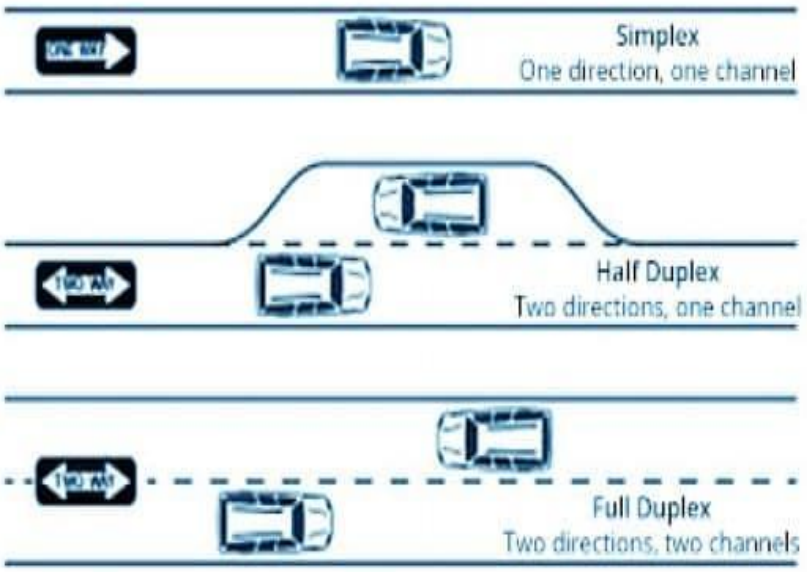

Transmission in either direction, but not simultaneously

(b)

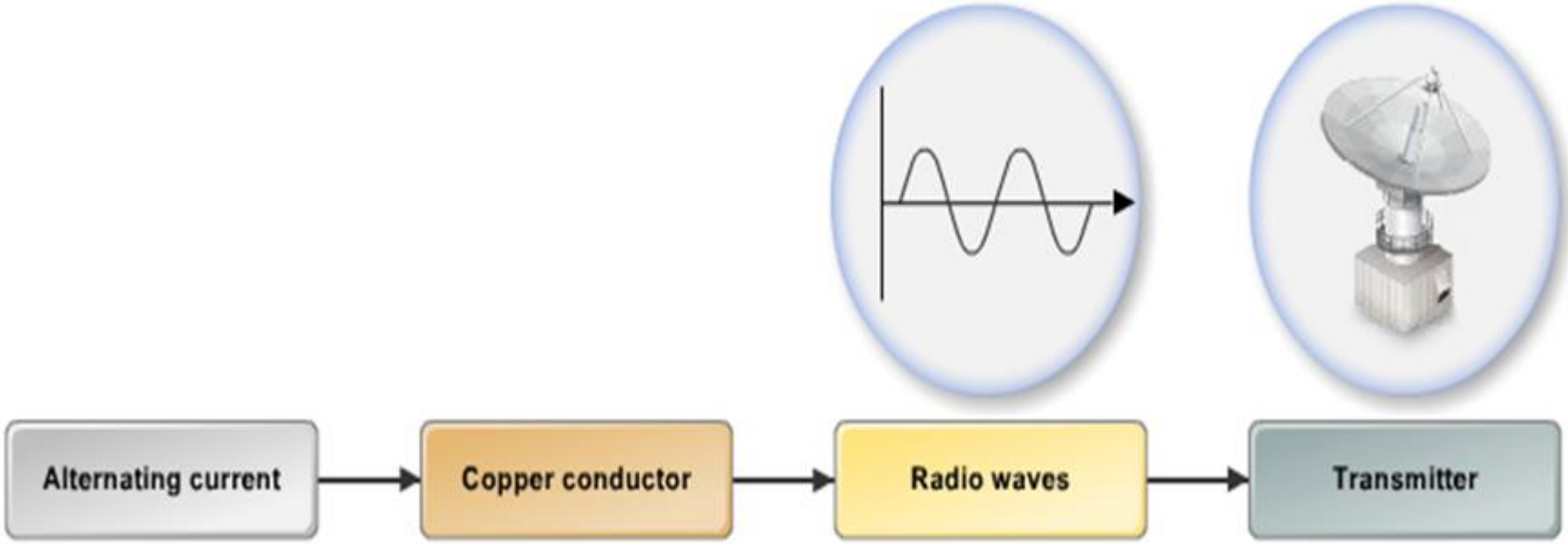



Transmission in both directions simultaneously

(c)



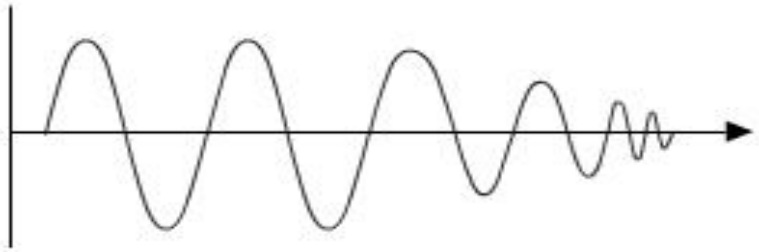
# Radio Waves – Generation




- A high-frequency alternating current (AC) is passed through a copper conductor – **Radio waves** are generated
- Transmitted using a transmitter (antenna)

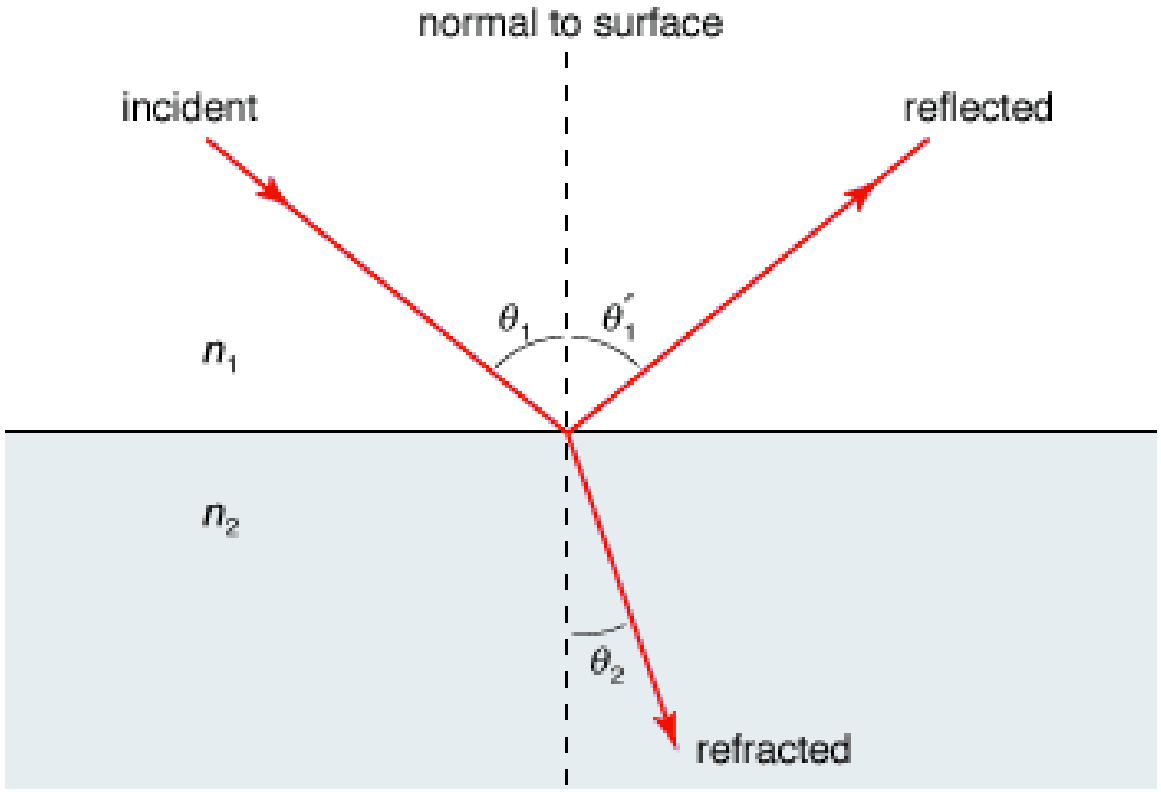
# Radio Wave Propagation (1)

- Propagate in **all directions** as a straight line
- Travel at **light velocity, i.e. 186,000 miles per second**
- Gets **weaker** as they travel a **long distance**



# Radio Wave Propagation (2)

- Properties similar to **visible light**
  - **Reflection and refraction**



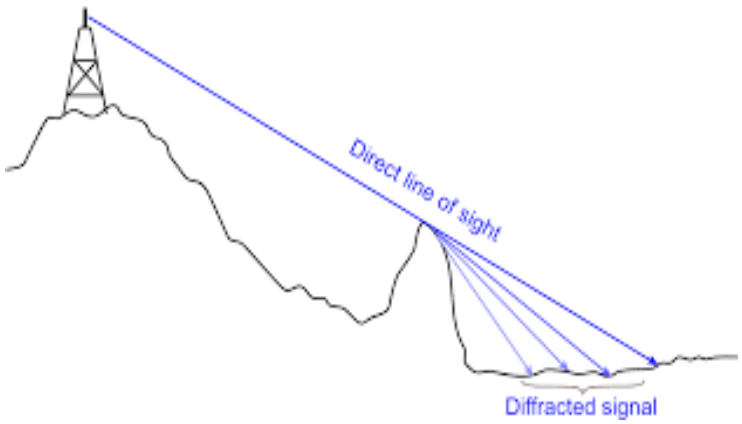

- **Law of Reflection**
  $\Theta_1 = \Theta`_1$

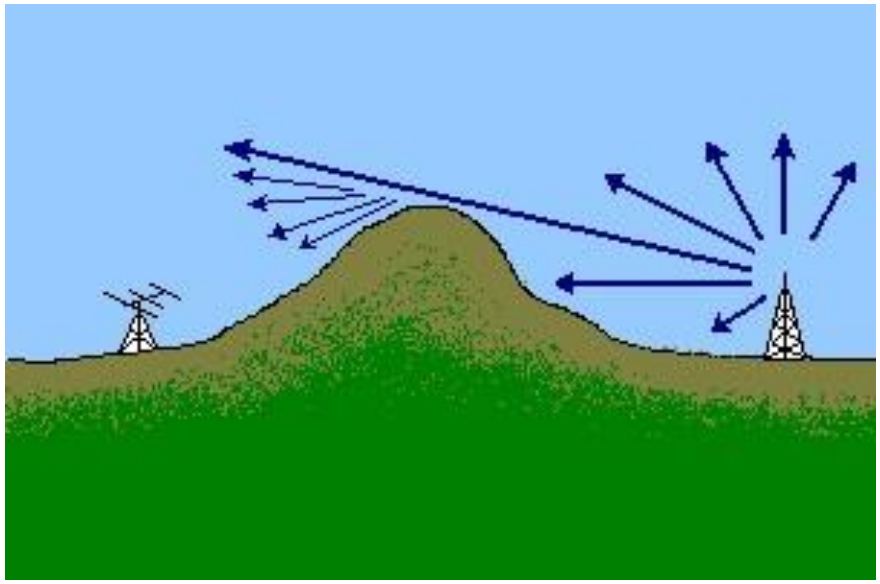
- **Law of Refraction**
  $\sin\Theta_1 / \sin\Theta_2 = R$

*(R is constant)*

# Radio Wave Propagation (3)

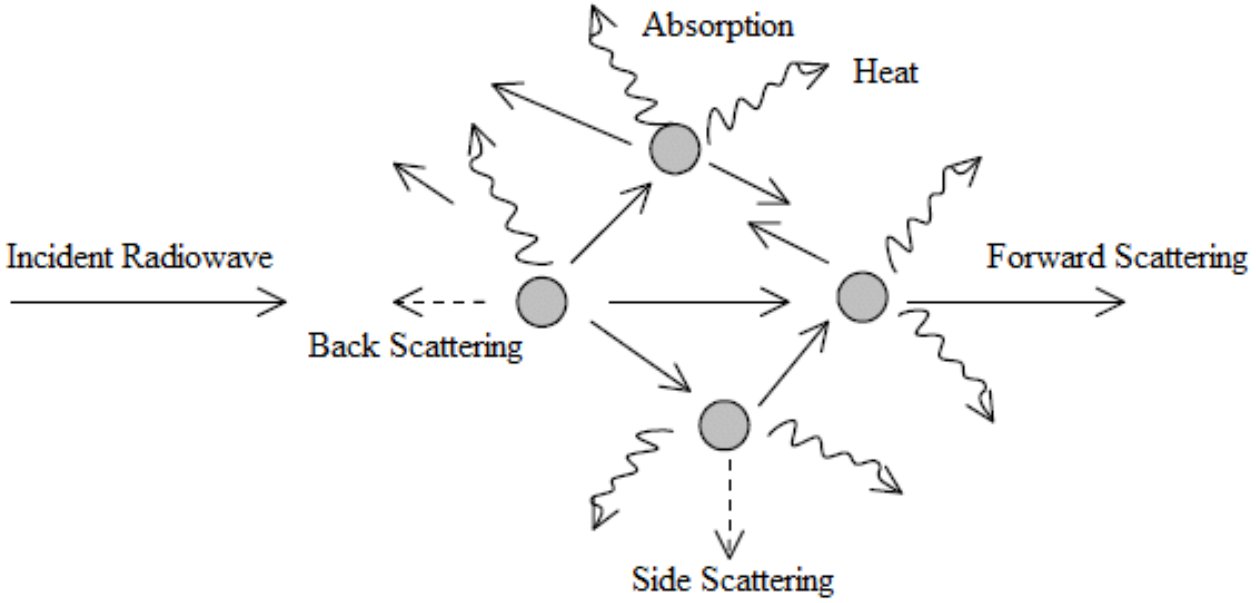
- **Diffraction**
  - Bending of waves around the corners of an obstacle or through an aperture into the region of geometrical shadow of the obstacle/aperture
  - Helps houses in shadows of hills to receive wireless signal (radio waves)



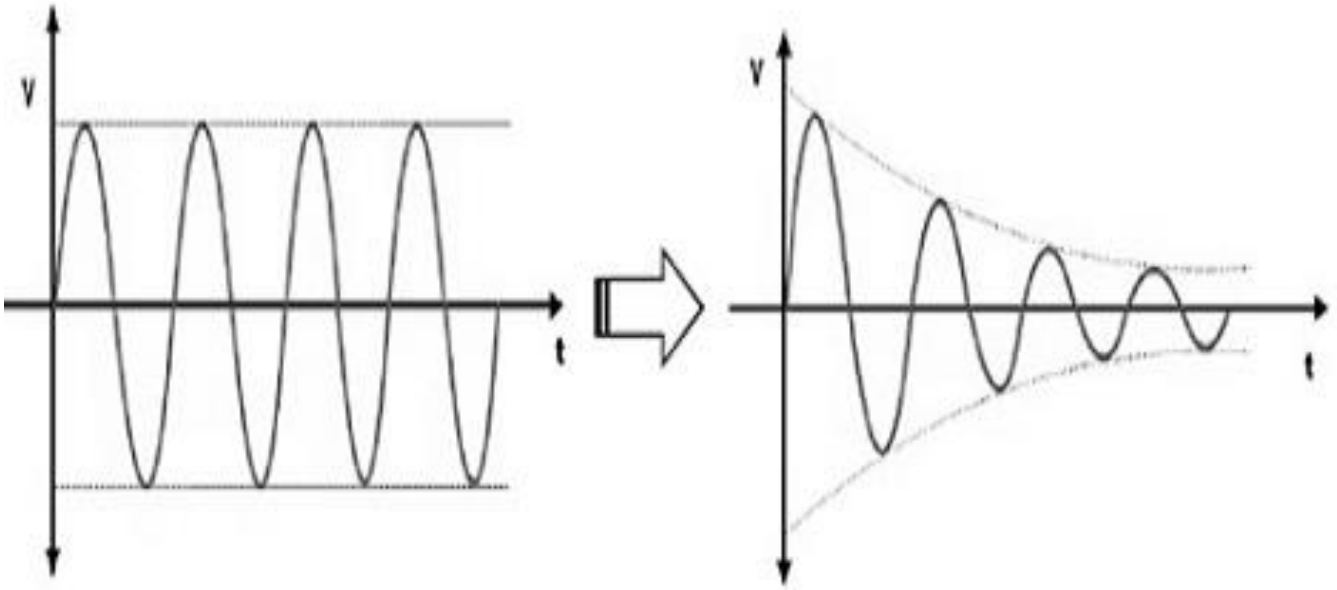
# Radio Wave Propagation (4)

- **Absorption,**
  - How matter (typically electrons) takes up a photon's energy — and so transforms electromagnetic energy into internal energy
- **Scattering**
  - Quanta of waves are forced to deviate from a straight trajectory by localized non-uniformities in the medium through which they pass



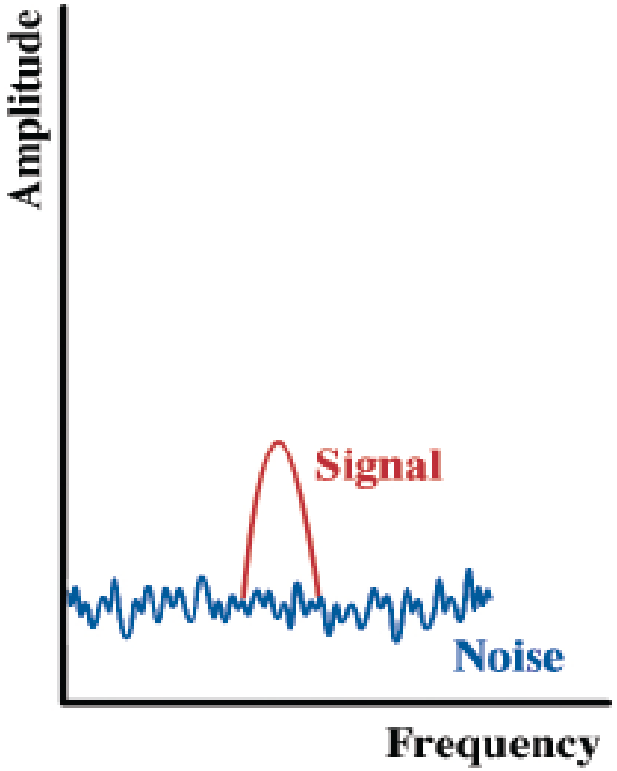
# Radio signal Attenuation (Path Loss)

- Signal's energy reduces (**attenuates**) as it travels
- Energy is lost in reflection, refraction, diffraction, scattering, *interference*, during propogation
- **Weak waves attenuates faster than strong waves**



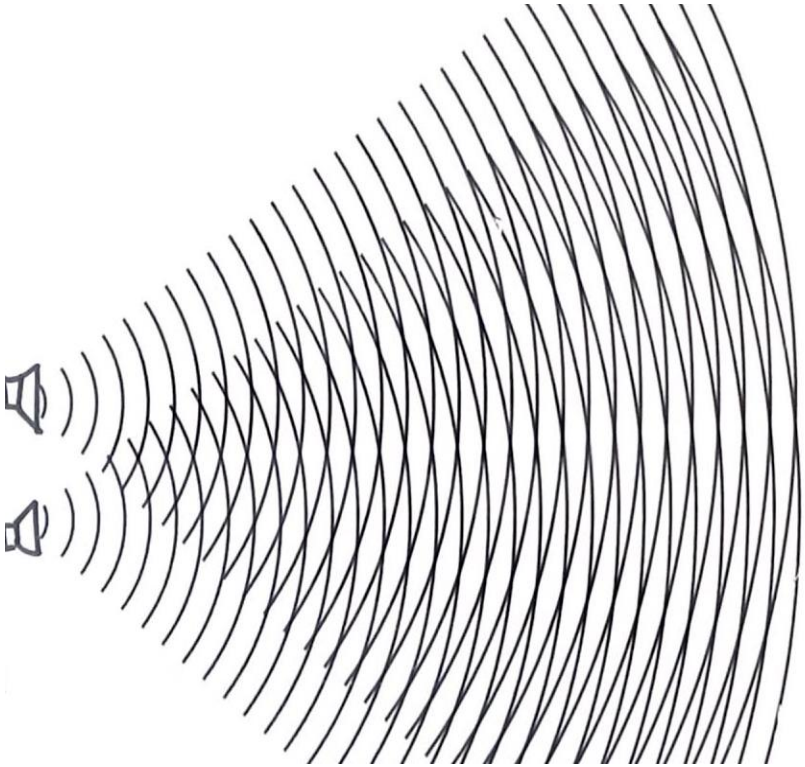
# Radio Frequency Noise

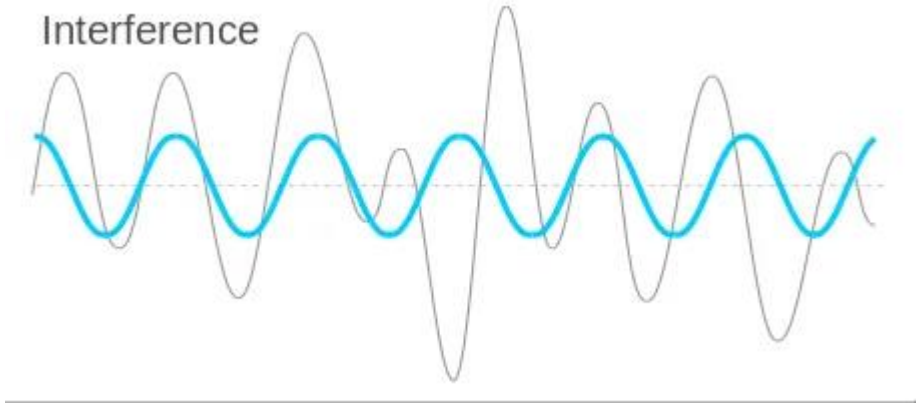
- Unfortunately, **any signal** can use the wireless medium
- Any signal **other than primary signal** is **noise**

# Radio Interference (1)

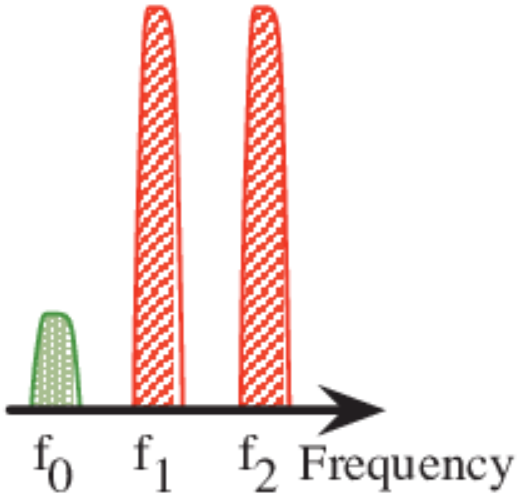
- Any other signal (e.g. noise) **interferes** with the primary signal
  - Interference disturbs and reduces the power of primary signal





# Radio Interference (2)

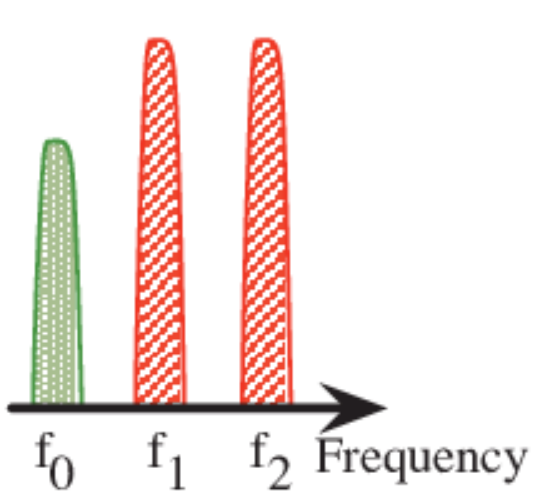
**Strong interferer**
**Weak Signal**




**High Performance**

(a)

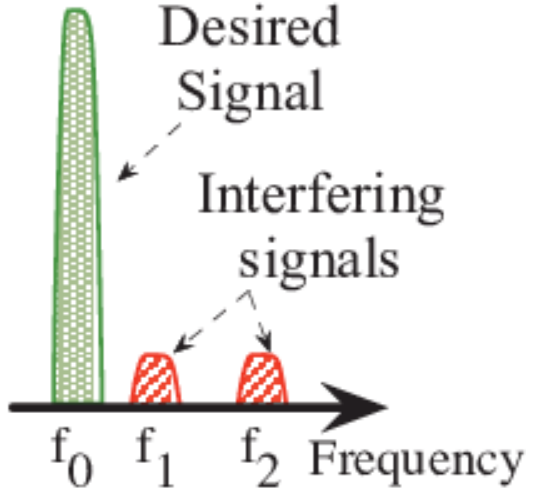
**Moderate interferer**
**Moderate Signal**




**Moderate Performance**

(b)

**Weak interferer**
**Strong Signal**

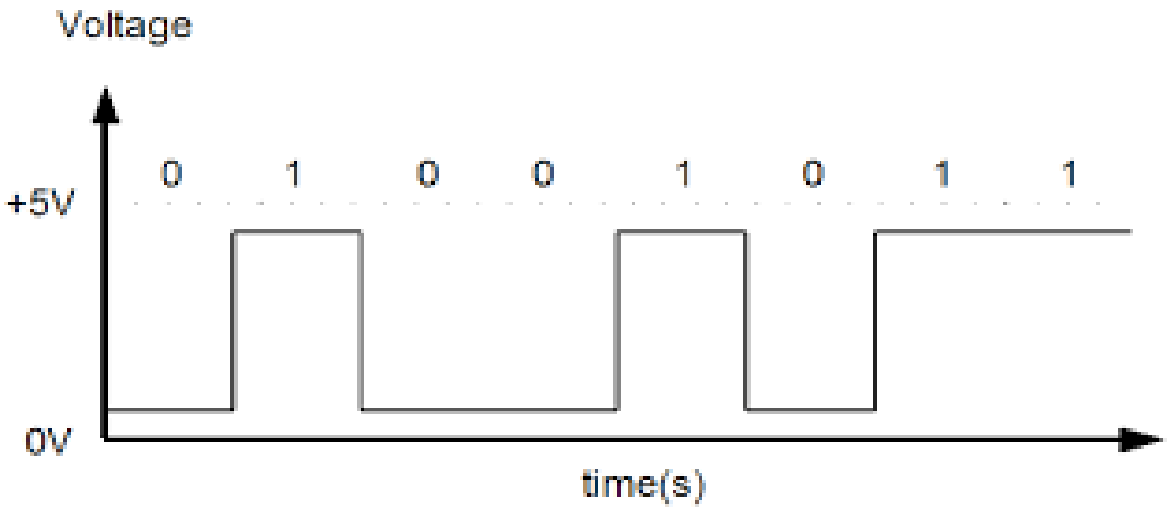



**Low Performance**

(c)

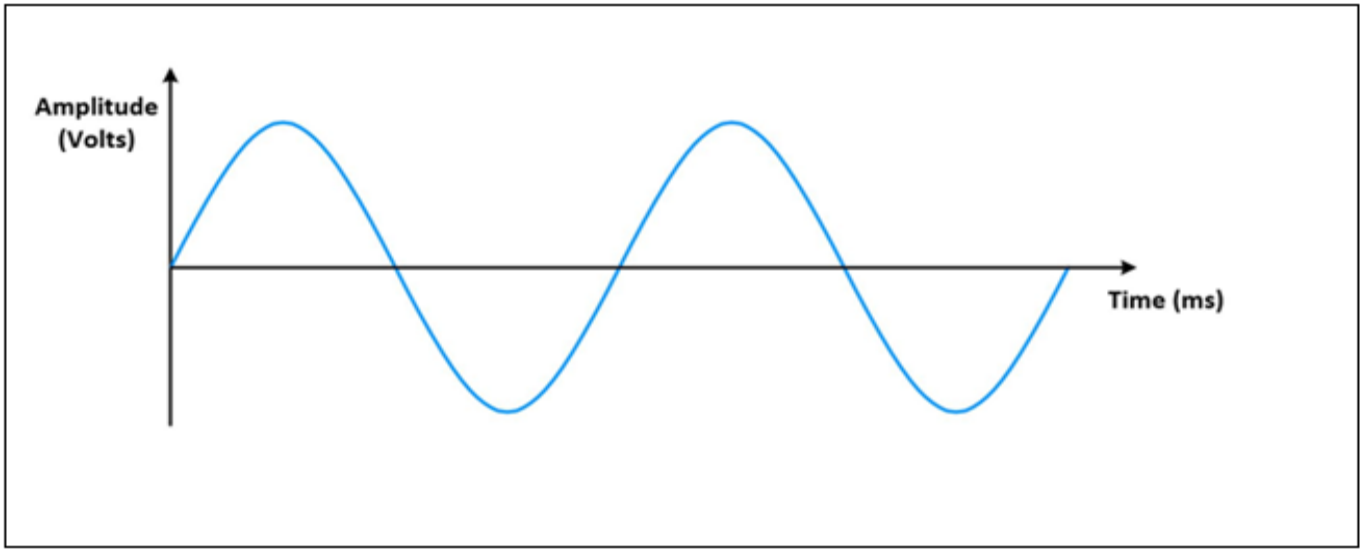
# Digital and Analog Signals (1)

- Digital messages are constructed with a finite number of symbols.
  - For example, a text file is a digital message, constructed from 50 symbols, consists of 26 letters, 10 numbers, space and several punctuation marks.
  - Messages are typically represented by sequence of 0 and 1



# Digital and Analog Signals (2)

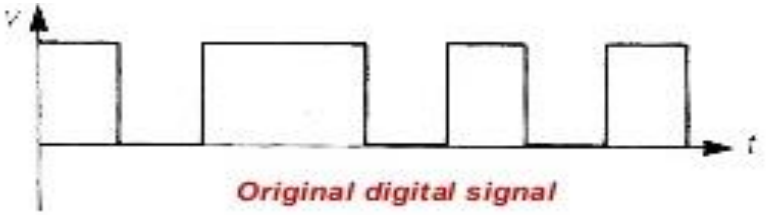
- **Analog Signal**
  - Characterized by data whose values vary over a continuous range.
  - For example, a speech waveform has amplitudes that vary over a continuous range.



# Advantages of Digital Signal (1)

## Noise Immunity

- **Digital signal**: Can be recovered without any error, as long as the distortion and noise are within limit.
- **Analog signal:** Even a slight distortion or interference in the waveform will cause an error in the received signal.

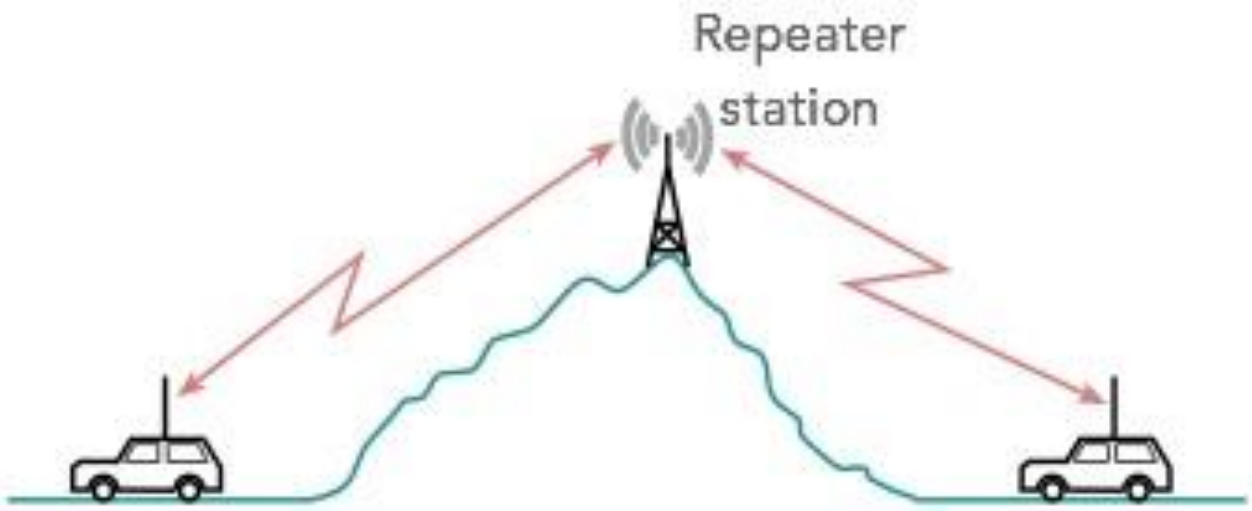





# Advantages of Digital Signal (2)

## Regenerative Repeaters

- During long distance signal transmissions, **regenerative repeaters** are placed at **short distances** to ensure that distortion remain within limit.
- These intermediate repeaters **recovers the original signal and boost up** the signal strength and transmits again along the same path**.**
- The viability of regenerative repeaters is the ***main reason for the superiority of digital systems over analog ones***.

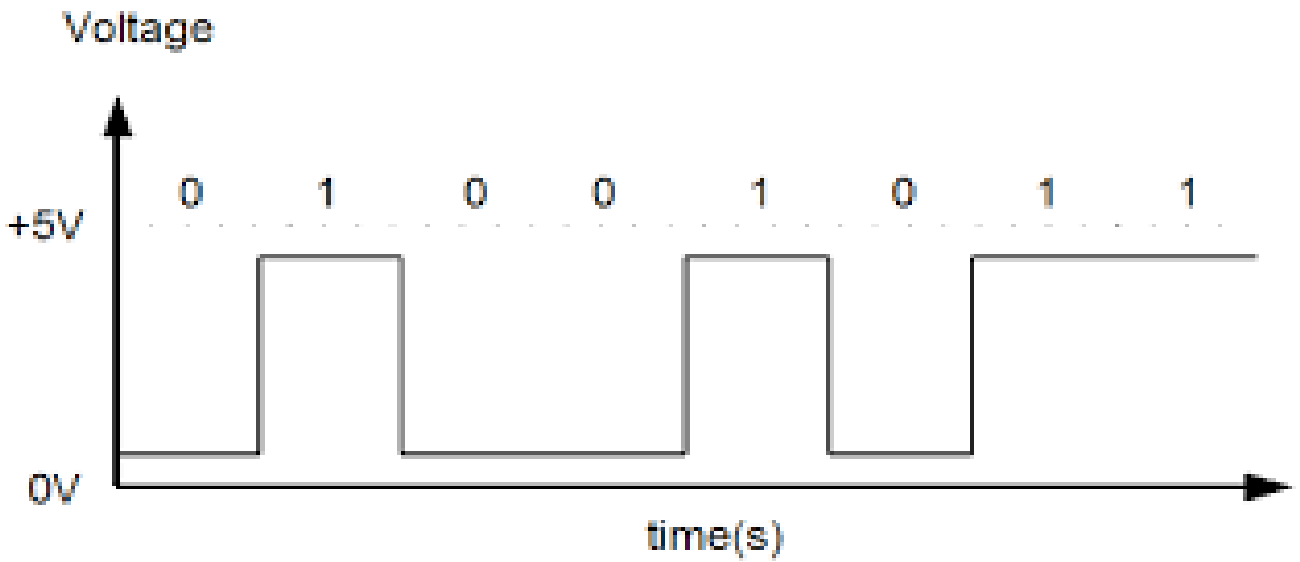


# Advantages of Digital Signal (3)

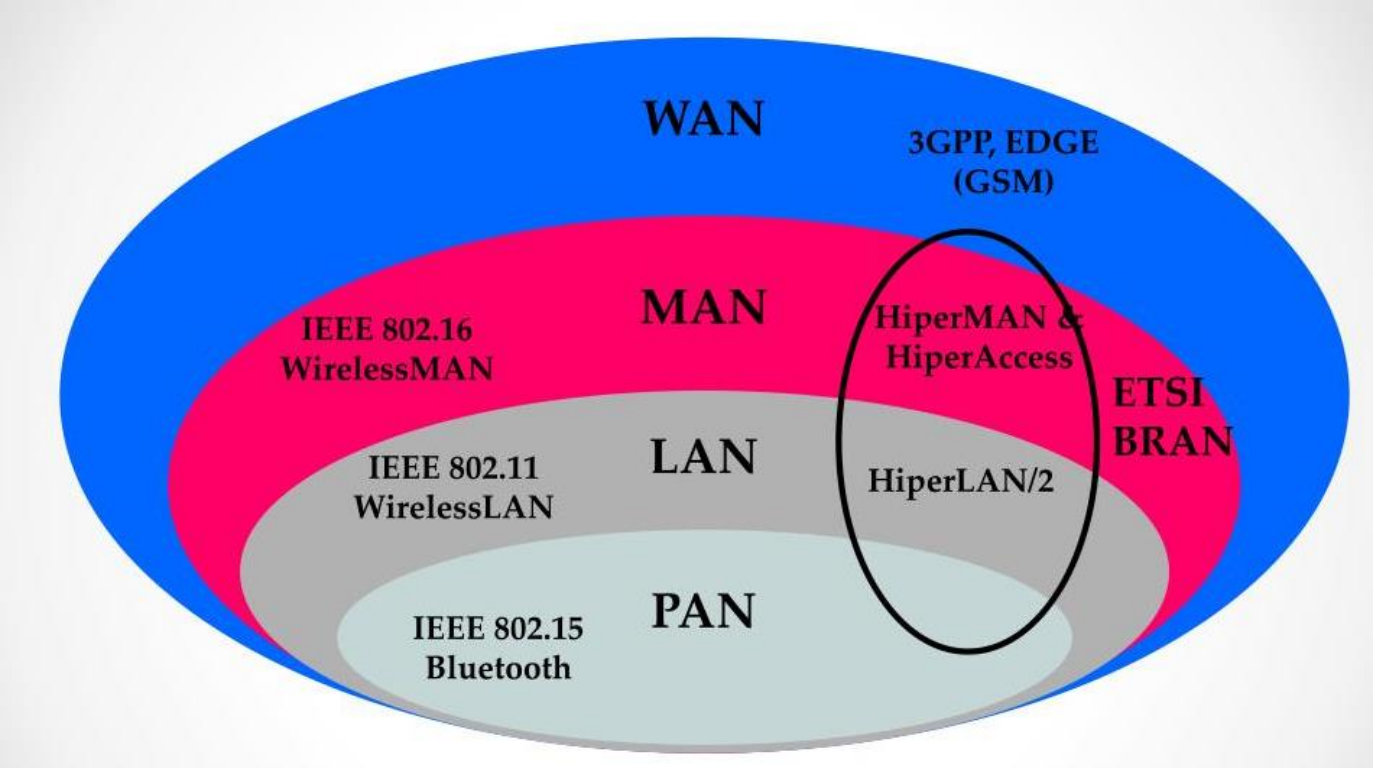
## Easy to Transmit Signal

- Communication can be carried on with only two symbols, i.e., by using a proper binary sequence.

- **Over last 20 years, digital communication has gradually replaced analog communications**



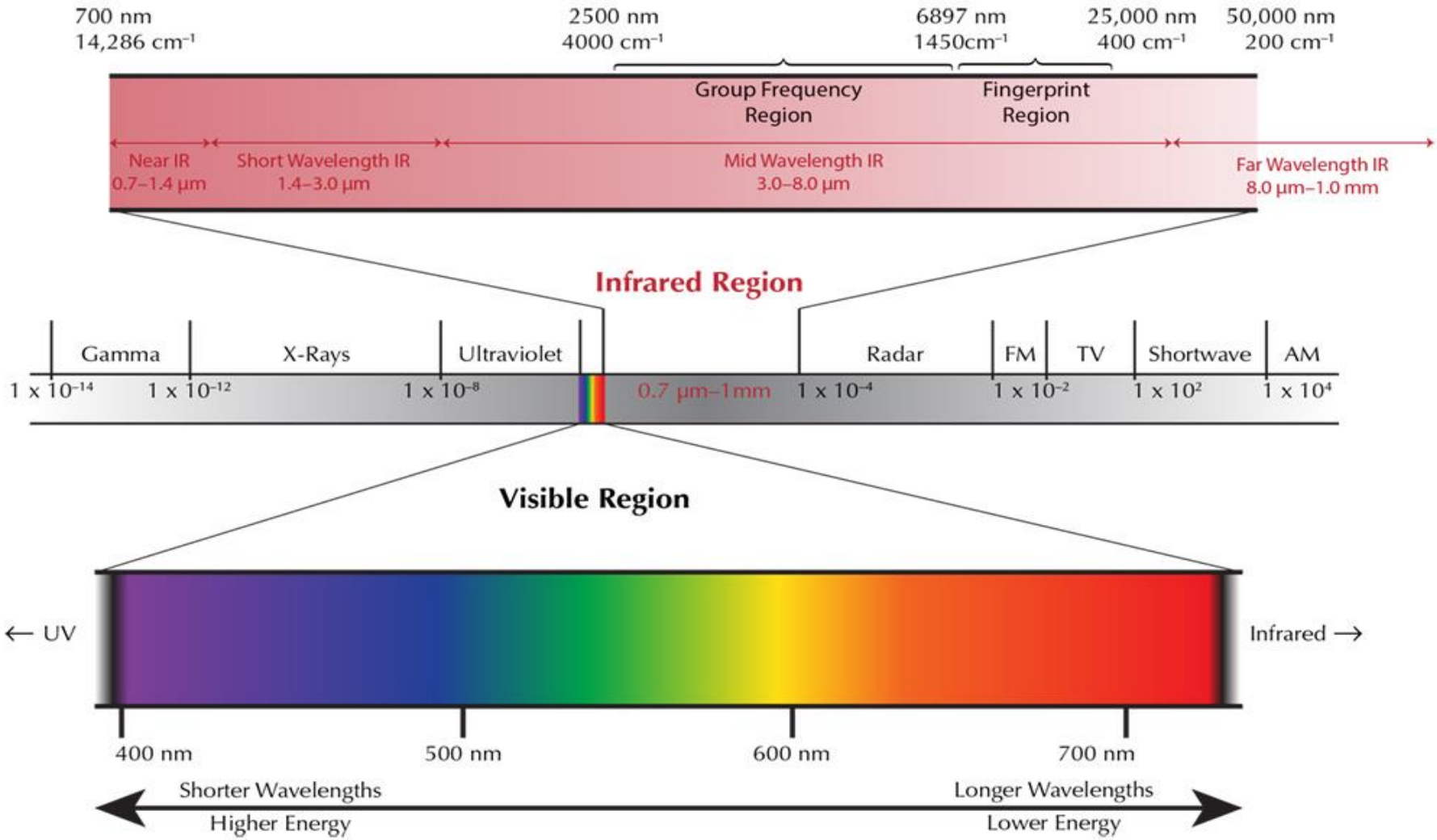
# Global Wireless Standards




1. **PAN: Personal Area Networks**
2. **LAN: Local Area Networks**
3. **MAN: Metropolitan Area Networks**
4. **WAN: Wide Area Networks**

# Personal Area Networks (PAN)

# Infra-Red (IR) Spectrum



# IR Wireless

- Uses beams of light in the **infrared spectrum**
  - Remote controls
- **Fairly reliable and low-cost**
- **IrDA – Infrared Data Association**
  - IrDA devices communicate using infrared LED's
  - Wavelength 875nm +-30nm
  - IrDA support data transmission of 1.15Mb/s and 4Mb/s

# IR Applications

- PDAs
- Phones
- Organizer
- Printers
- Cameras
- Laptops and Notebooks
- Other Applications



# IR – Advantages & Disadvantages

## Advantages

- Point-to-point
- Line of sight
- Transfer data up to 1m
- Security
- Low power consumption
- Low cost

## Disadvantages

- Line of sight
- One device at a time
- Transfer rate 4Mbps
- Needs stability during data transmission
- Essentially PANs – quite short range

# IEEE 802.15 (Bluetooth)

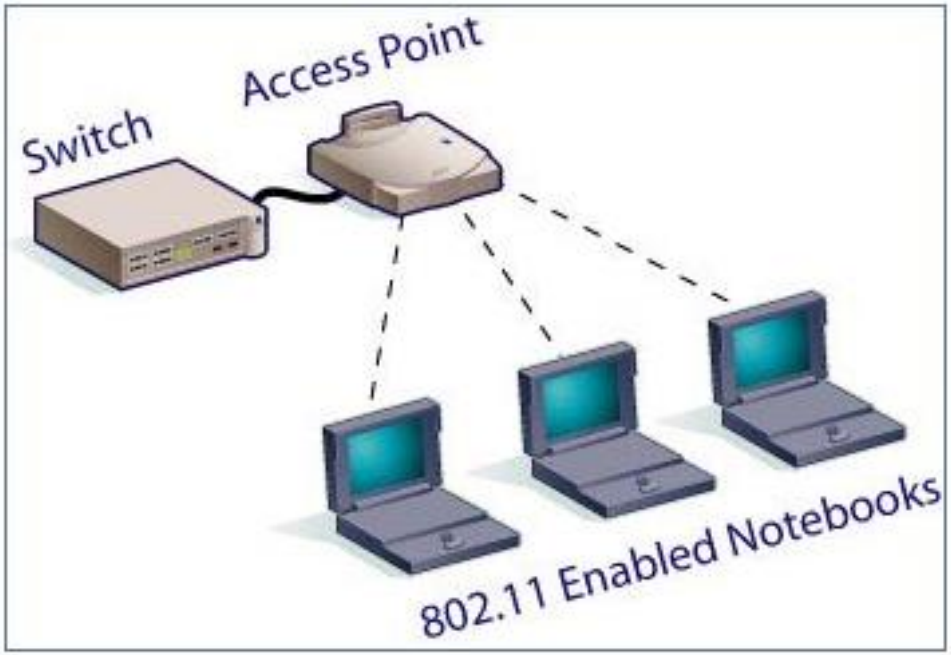
- **Special interest Group founded by Ericsson, IBM, Intel, Nokia, and Toshiba in 1998.**

- Open specification for short-range wireless connectivity between laptops, computers, cellular telephones etc.

- Use IR s

# Local Area Networks (LAN)

# Wireless Fidelity (Wi-Fi)




**Also referred as WLANs (Wireless Local Area Networks)**

# Wireless LANs

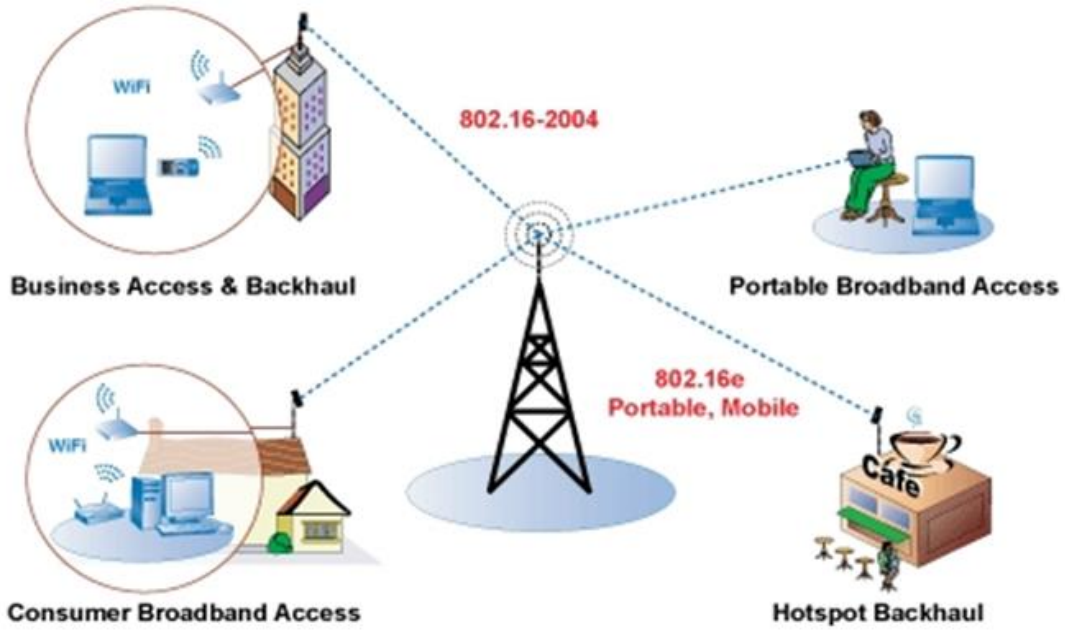
- **Advantages**:
  - Fast (11 Mbps)
  - Range (up to 1000 ft outdoors, 400 ft indoors)
  - Easy integration to wired networks
  - Advanced WLANs (802.11n/802.11ac/802.11ax) support hundreds of Mbps of data rates

- **Disadvantages**:
  - Speed often fluctuates a lot
  - Collision between carriers, originated from different clients
  - Only **local area networks** – limited mobility, indoor or need hotspots
  - **Doesn't** work in **outdoors** – need hotspots

# Metropolitan Area Networks (MAN)

# Worldwide Interoperability for Microwave Access (WiMAX)

- Commonly known as **WiMAX** – **IEEE 802.16 (2004)**
- Mobility is introduced in **802.16e** (Mobile WiMAX)



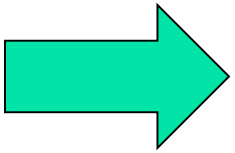
# WiMAX vs. WiFi

- WiMax eliminates most constraints of Wi-Fi.
- Unlike Wi-Fi, WiMax is intended to work outdoors over long distances.
- WiMax can handle important issues, like QoS guarantee, carrier-class reliability, NLOS.
- WiMax is not intended to replace Wi-Fi. Instead, the two technologies complement each other.

# Wide Area Networks (WAN)

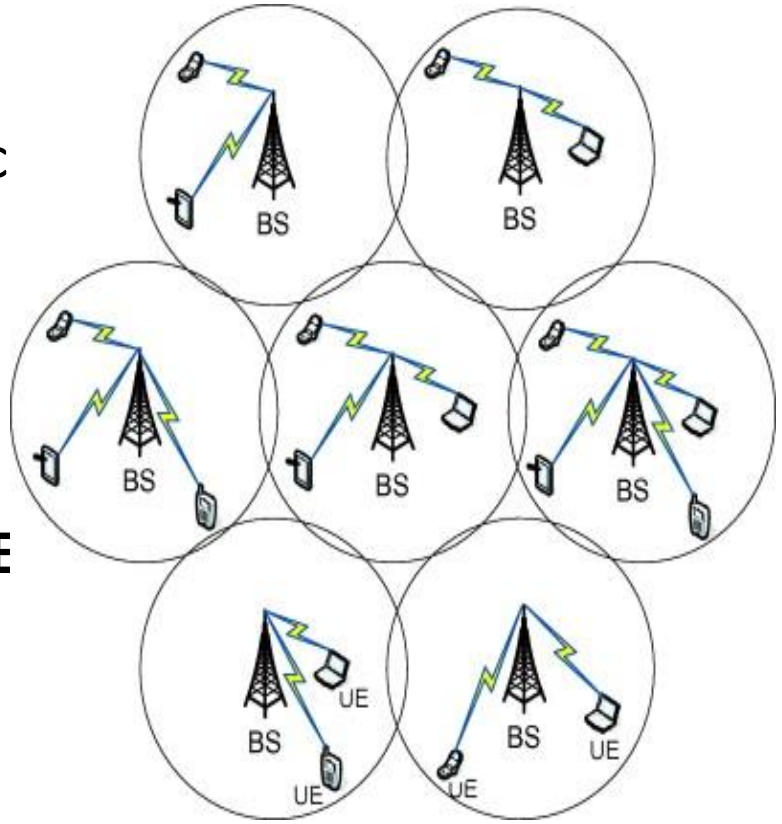
# Major Challenge – Mobility

- Remember: Traditional phones were wired
  - Do not support mobility!
  - Even WLANs and WPANs provide limited (short-range) mobility
- How to ensure moving with a phone?
  - The biggest challenge in 20th century's wireless communications



# Cellular Wireless

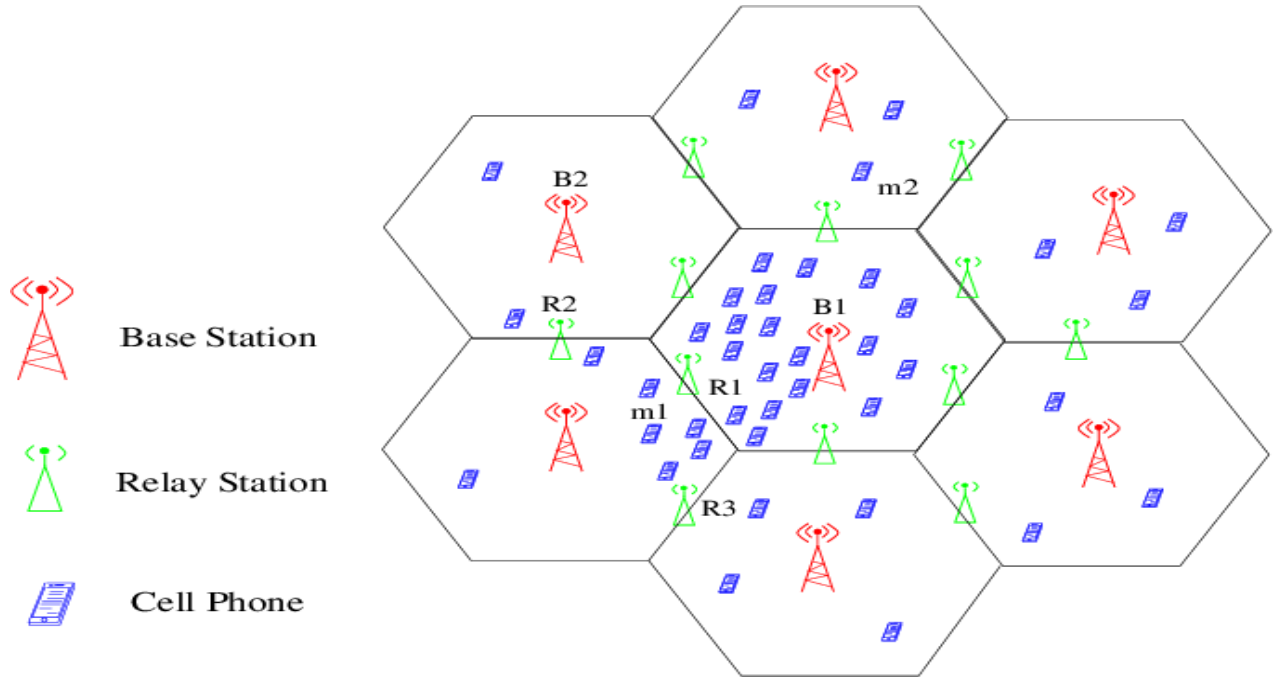
- Total area is divided into **many coverage areas** – termed **cells**
- A **tower** with **antenna** and **processing** c provided in each cell
- Tower is called **Base Station (BS)**
- Mobile phones or **User Equipments** (**UE** communicate with the **nearest BS**




- **Radio-based** technology and uses **radio waves** to communicate (**propagating** through **antennas in BS and UE**)

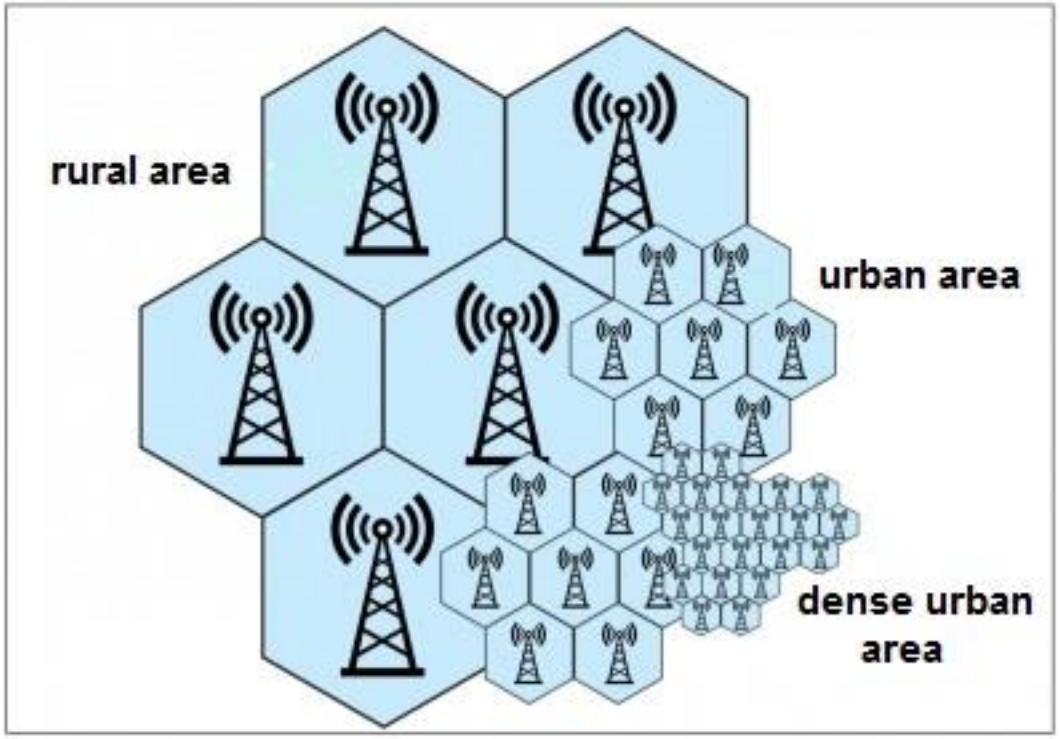
# Cellular Networks

- Multiple base stations can use the same spectrum
- **Relay nodes** are used to boost-up signal strength of digital electro-magnetic waves (Recap: digital communications)



# Different Types of Coverage

- Each BS can accommodate a maximum number of UEs
- Different seizes of coverage (cell) depending on density of UEs in the area, e.g. rural, urban, dense-urban



# Advantages of Cellular Networks

- Provides voice/data services even while moving
- Connects both fixed and wireless telephone users.
- Used in areas where cables can not be laid out due to its wireless nature.
- Easy to maintain and upgrade.
- Almost immediate connectivity as the phone is switched on.

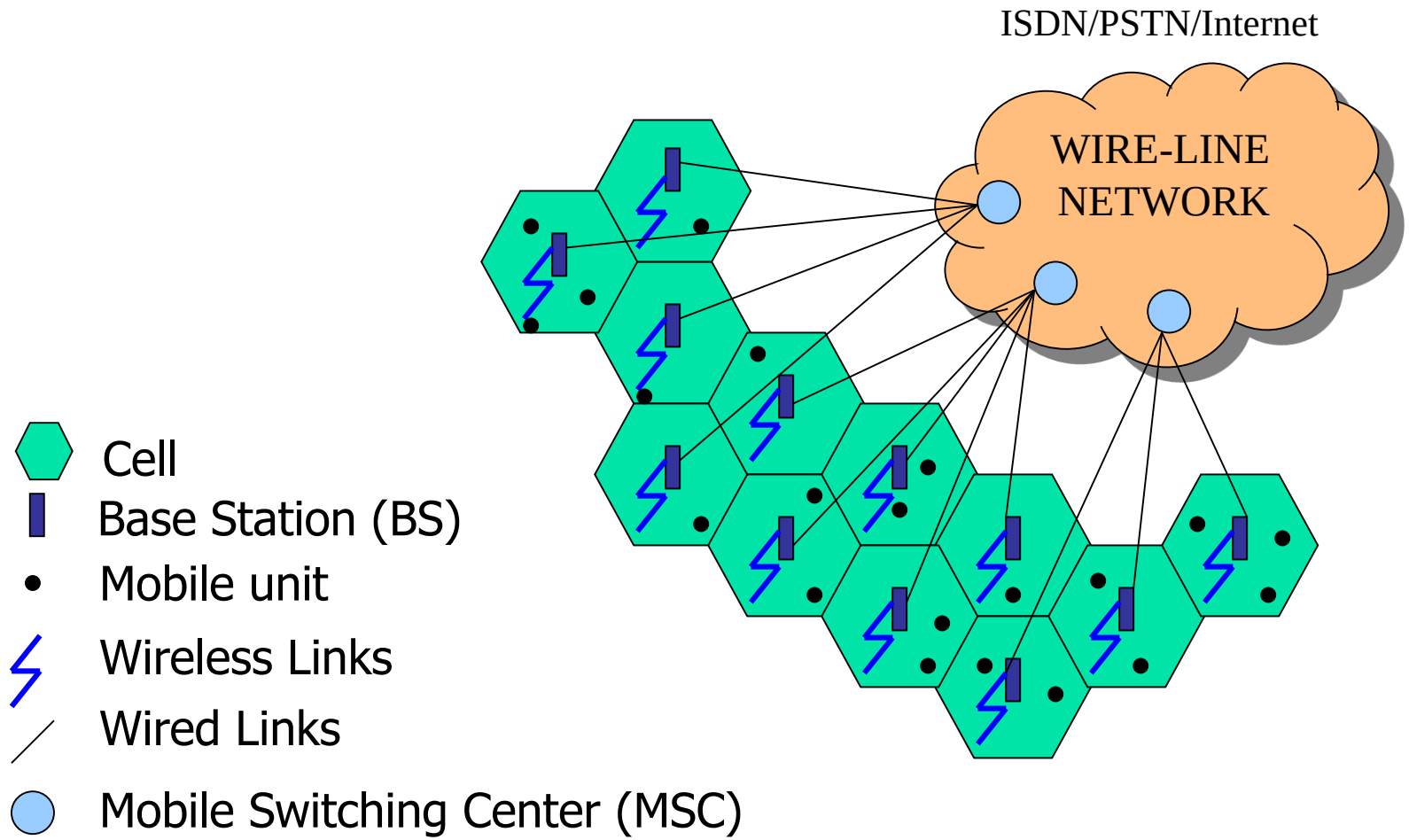
# Disadvantages of Cellular Networks

- Relatively less data rate compare to wired networks
- Data rates depend on type of cellular networks (2G/3G/4G/5G)
- Affected by challenges of EM waves (loss, attenuation, interference etc.)
- Capacity is lower and depends on channels.
- Security vulnerabilities, as communications is over the air
- Needs very high capital expenditure to set up the network
  - Many BSs and many processing equipments etc.

# Multiple Access Protocols

- Multiple Access Protocols in Cellular Networks
  - FDMA
  - TDMA
  - CDMA

# Cellular Architecture



# Types of Wireless Channels

1. **Control channels**

   - Carry information about coordination and management among different users or channels

   a) Forward (Downlink) control channel

   b) Reverse (Uplink) control channel

2. **Traffic channels**

   - Carry actual data traffic

   a) Forward (DL) traffic (data or information) channel

   b) Reverse (UL) traffic (data or information) channel

# Multiple Access Protocols (MAP)

- MAP allows multiple users to share a common channel.

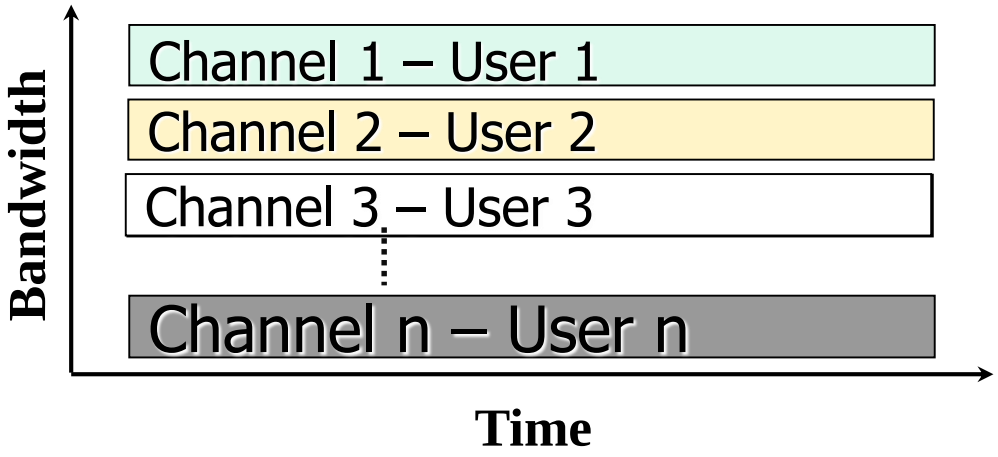
- Conflict-free protocols ensure successful transmission.
- Static conflict-free protocols –Current cellular mobile communications
  - FDMA
  - TDMA
  - CDMA

# Static Conflict-free protocols

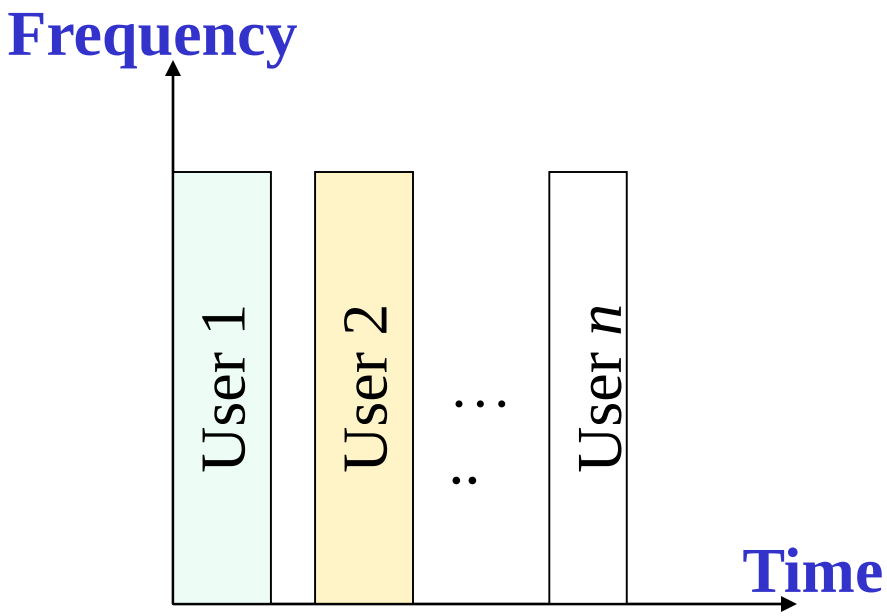
- Frequency Division Multiple Access (FDMA)
  - Fraction of the frequency range to each user for all the time
- Time Division Multiple Access (TDMA)
  - Entire frequency band to a single user for a fraction of time
- Code Division Multiple Access (CDMA)
  - A portion of bandwidth for a fraction of time

# Frequency Division Multiple Access (FDMA)

- **Channels** – assigned to user for the duration of a call.
- No other user access the channel during that time.
- When call terminates
  - Same channel can be re-assigned to another user
- 1st Generation (1G) mobile communication systems
  - AMPS (30 KHz channels), NMT, Japanese TACS/NTT



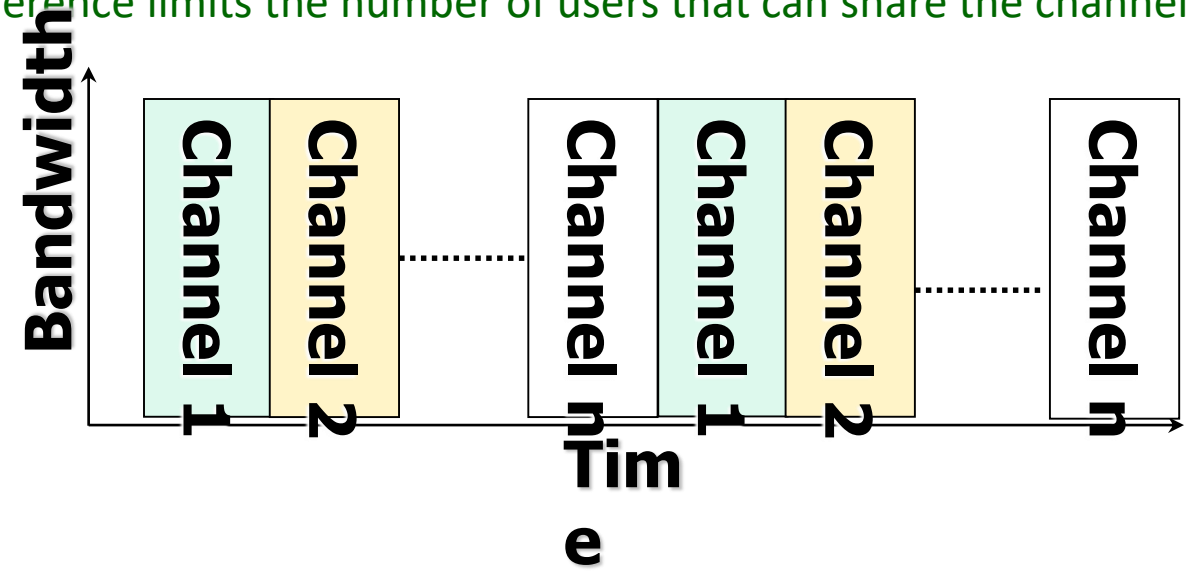
# Time Division Multiple Access (TDMA)



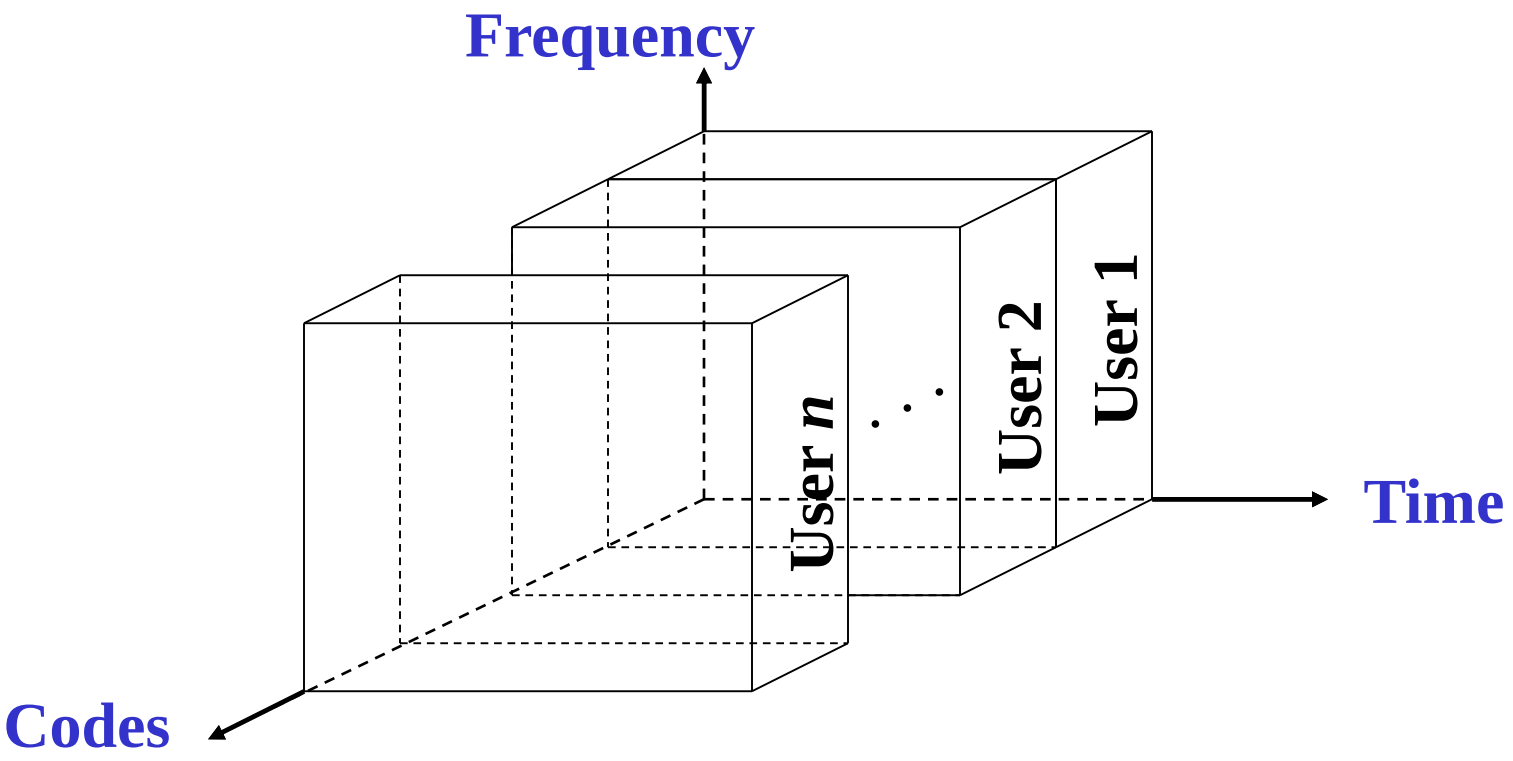

**Instead of dividing the frequency, split the time into small slots**

# Time Division Multiple Access (TDMA)

- The **whole channel** is assigned to each user for a **particular time slot**
  - Users – multiplexed over time during communication.
  - During that time slot, users use the entire frequency spectrum
- Channel Data rate: Sum of data rates of all the multiplexed transmissions
- Channel interference between transmission in two adjacent slots
  - Transmissions tend to overlap in time.
  - This interference limits the number of users that can share the channel

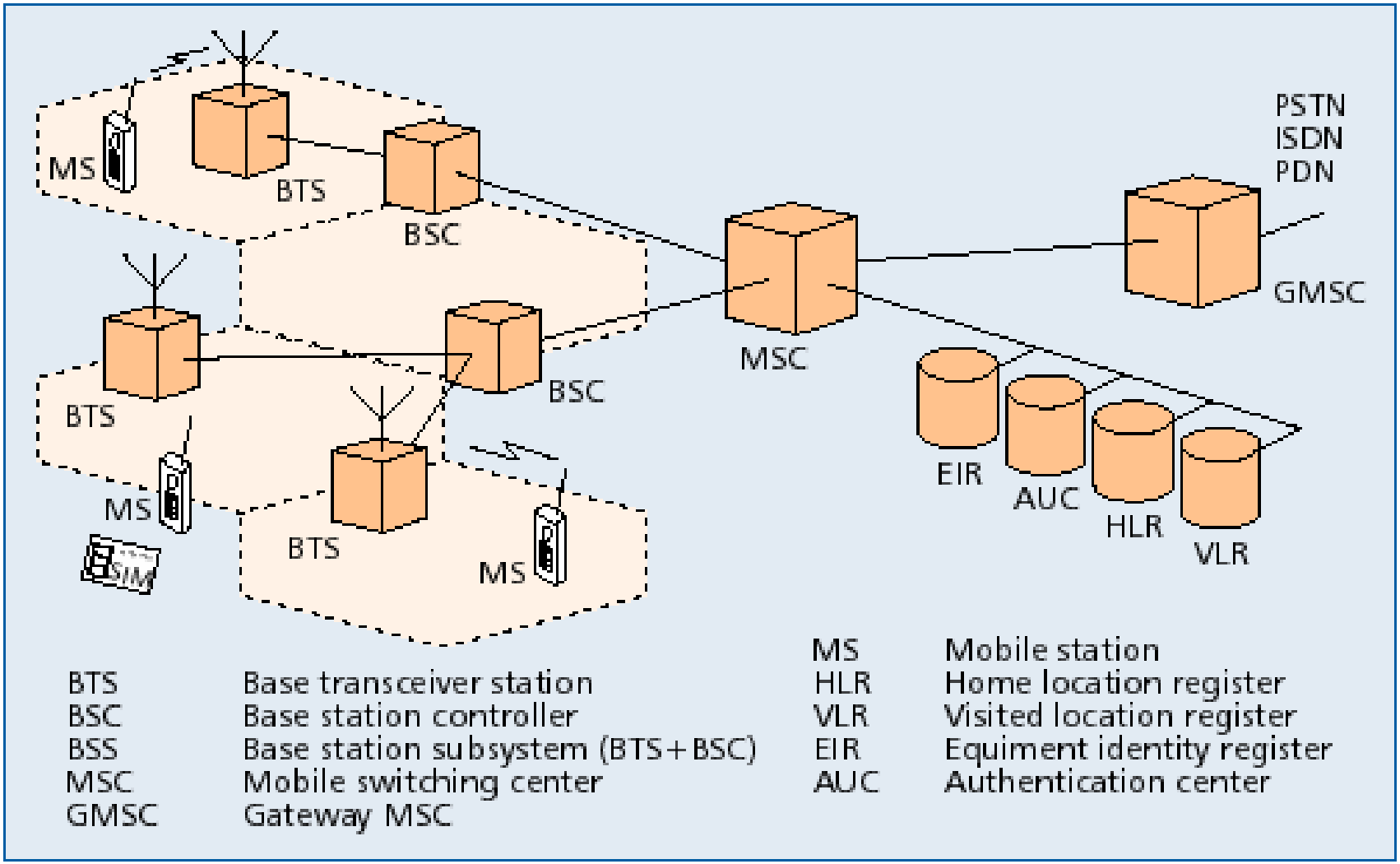


# Code Division Multiple Access (CDMA)




- **Users share bandwidth by using sequence of orthogonal codes**
- **No more division of frequency or time**

# GSM: System Architecture




| | | | |
|---|---|---|---|
| BTS | Base transceiver station | MS | Mobile station |
| BSC | Base station controller | HLR | Home location register |
| BSS | Base station subsystem (BTS+BSC) | VLR | Visited location register |
| MSC | Mobile switching center | EIR | Equiment identity register |
| GMSC | Gateway MSC | AUC | Authentication center |

# BTS and BSC

**BTS/BS**

- One per cell
- Consists of high speed transmitter and receiver
- Function of BTS
  - Provides two channels
    - Signalling &Data Channel
  - Performs error protection coding for the radio channel

**BSC**

- Controls multiple BTS
  - Performs radio resource management
    - Assigns and releases frequencies and time slots for all the MSs in its area
    - Reallocation of frequencies among cells
    - Hand over protocol is executed here

# Mobile Switching Centre (MSC)

- Switching node of a PLMN (Public Land Mobile Network)
- Allocation of radio resource (RR)
  - Handover
- Mobility of subscribers
  - Location registration of subscriber

## Databases of MSC

HLR - Home Location Register
For all users registered with the network
HLR keeps user profile

VLR - Visitor Location Register
VLR is responsible for a group of location areas, typically associated with an MSC

# Gateway MSC (GMSC)

- Connects mobile network to a fixed network
  - Entry point to a PLMN
- Usually one per PLMN
- Request routing information from the HLR and routes the connection to the local MSC

# Outgoing call setup

- User keys in the number and presses send
- Mobile transmits request on uplink signaling channel
- If network can process the call, BS sends a channel allocation message
- Network proceeds to setup the connection

- Network activity:
  - MSC determines current location of target mobile using HLR, VLR and by communicating with other MSCs
  - Source MSC initiates a call setup message to MSC covering target area

# Incoming call setup

- Target MSC initiates a paging message
- BSs forward the paging message on downlink channel in coverage area
- If mobile is on (monitoring the signaling channel), it responds to BS
- BS sends a channel allocation message and informs MSC

- Network activity:
  - Network completes the two halves of the connection

# Thank You!