# Wireless Communications

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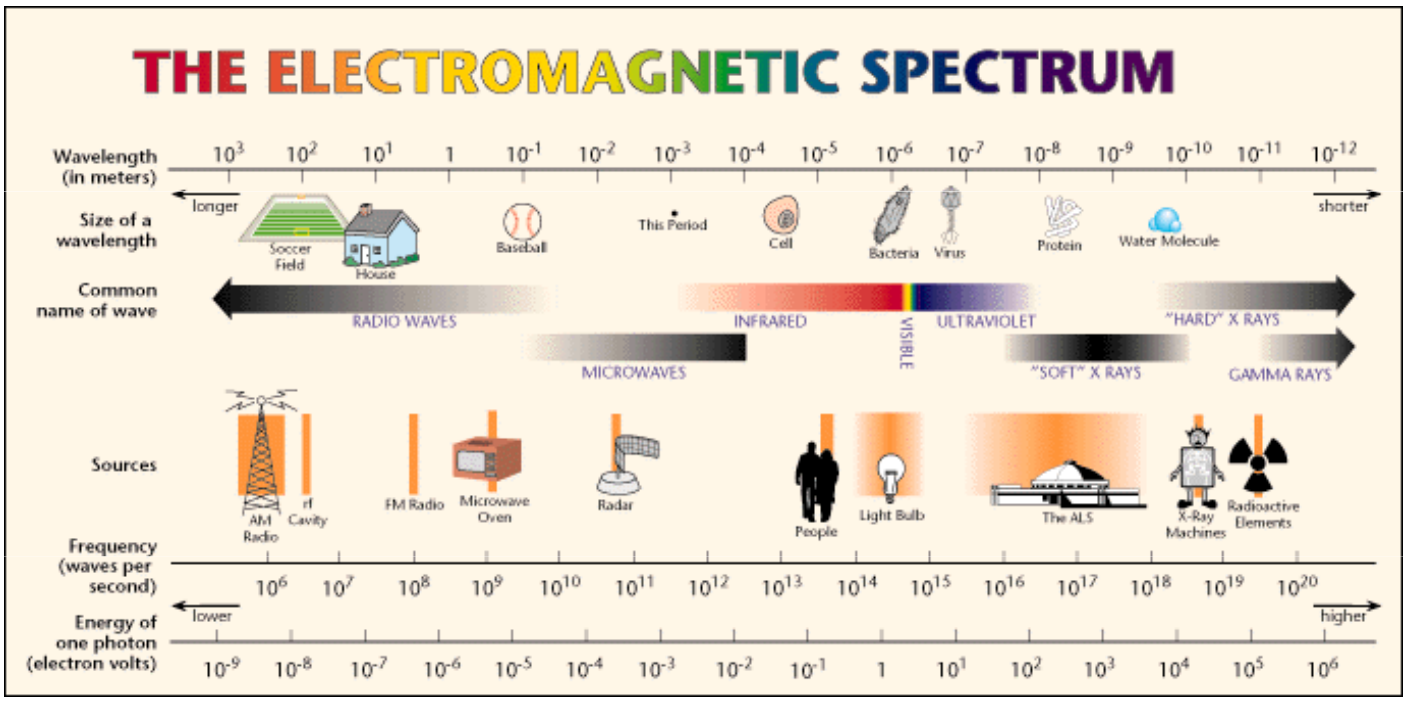
## The Technology: Radio Spectrum

- **Radio Spectrum: from 30 KHz to 3 GHz**
  - **AM radio: 540KHz – 1800 KHz**
  - **FM radio: 88 MHz – 108 MHz**
  - **Cellular (e.g. AMPS): 824 – 849, 869 – 894 MHz**
  - **Cellular (e.g. GSM): 890 – 915, 935 – 960 MHz**
  - **PCS frequencies: 1800 – 2200 MHz**
- **Microwaves: from 3 GHz to 300 GHz**
- **Infrared Spectrum: from 300 GHz to 300 THz**






# Issue: Spectrum is a scarce resource!

## Possible Solutions:

- Frequency reuse (cells)
- Multiplexing

# How wireless frequencies are allocated

- Garage door openers, alarm systems, etc. – 40MHz
- Cordless phones: 40-50MHz, 900MHz, 2.4GHz, 5.8GHz
- Baby monitors: 49MHz
- Radio controlled toys: 27-75MHz
- Wildlife tracking collars: 215-220MHz
- MIR space station: 145-437MHz
- Cell phones: 824-849MHz, 869-894MHz, 1850-1990MHz
- Public safety (fire, police, ambulance): 849-869MHz
- Air traffic control radar: 960MHz-1.215GHz
- Global Positioning System: 1.227-1.575MHz
- Satellite radio: 2.3GHz
- WiFi/802.11b/g and Bluetooth: 2.4GHz
- Zigbee/802.15.4: 868MHz, 915MHz, 2.4GHz
- Microwave ovens: 2.4Ghz
- TV: 54-216 (VHF 2-13), 470-806MHz (UHF 14-69)
- Ultra-wide-band: 3.1-10.6GHz
- ISM (industrial, scientific, medical): 900MHz, 1.8GHz, 2.4GHz, 5.8GHz



# Considerations in choosing a carrier frequency

- Carrier frequency
  - Signal that is modulated to carry data
  - Frequency is not equal to bandwidth
- Ability to carry data (modulation rate)
- Availability of devices to transmit and receive signals
- Interference from other devices in same band
  - ISM bands limit power output
- Interactions of radiation with environment
  - absorption by water, metal, building materials, foliage
- Reflection and multi-path properties
  - constructive/destructive interference patterns (e.g., nulls)

# Radio Protocols for Wireless Networks

- UHF (300-1000MHz)
  - Mote radio
- WiFi (2.4GHz)
  - Wireless LAN

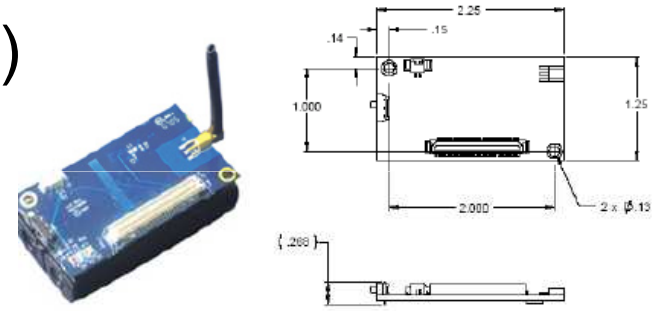



**Figure 2-1.** *Photo of the XM2110—IRIS with standard antenna*

- Bluetooth (2.4GHz)
  - Common in many consumer devices (PDAs, cell phones, etc.)
- Zigbee (850-930MHz)
  - Next generation radio for sensor networks and consumer devices



# Wireless Network Evolution

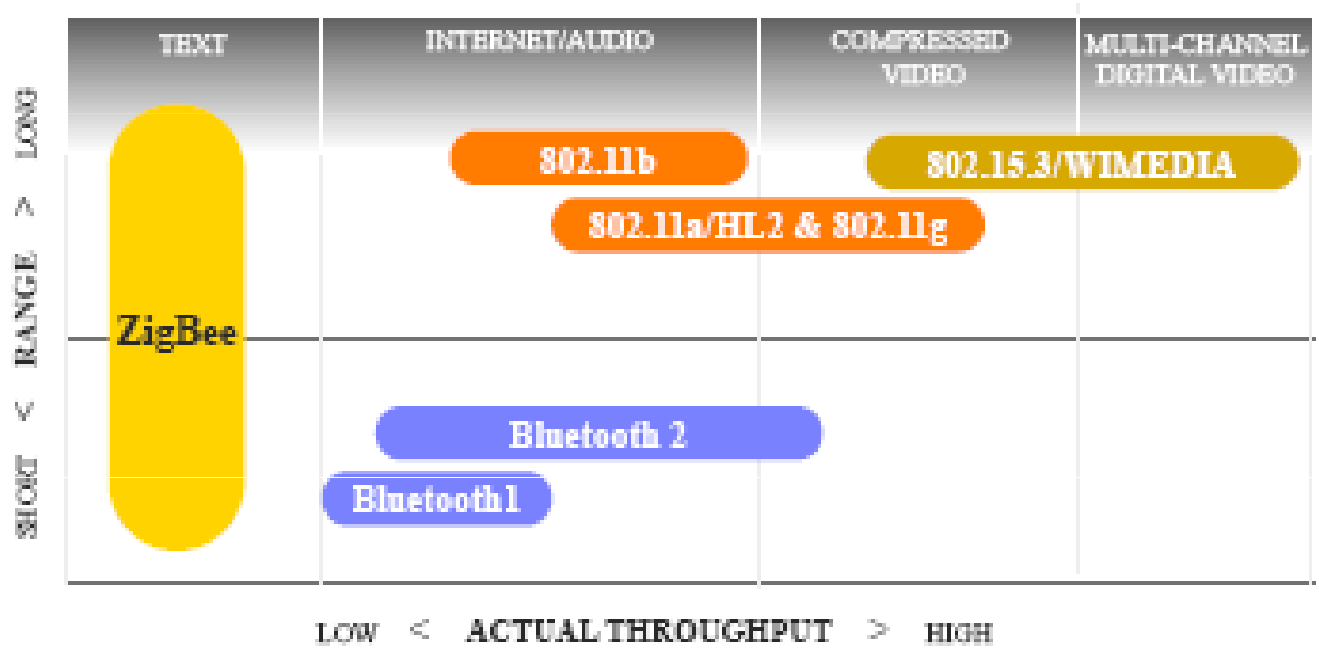
- Point-to-point
  - Simple wire replacement (Virtual Wire, Bluetooth)
- Star pattern (single base-station)
  - Centralized routing and control point (WiFi, GSM)
- Multi-hop/Mesh (wireless sensor networks)
  - Multiple paths for data
  - Self-configuring

# Comparison of Major Protocols

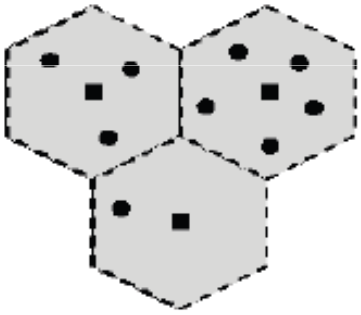
| Feature(s) | IEEE 802.11b | Bluetooth | ZigBee |
|---|---|---|---|
| Power Profile | Hours | Days | Years |
| Complexity | Very Complex | Complex | Simple |
| Nodes/Master | 32 | 7 | 64000 |
| Latency | Enumeration upto 3 seconds | Enumeration upto 10 seconds | Enumeration 30ms |
| Range | 100 m | 10m | 70m-300m |
| Extendability | Roaming possible | No | YES |
| Data Rate | 11Mbps | 1Mbps | 250Kbps |
| Security | Authentication Service Set ID (SSID) | 64 bit, 128 bit | 128 bit AES and Application Layer user defined |



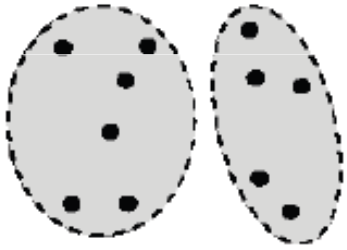
# The Wireless Market



# Wireless Network Configurations



Cellular system



Conventional
ad Hoc System

Scatternet



# Radio Specification

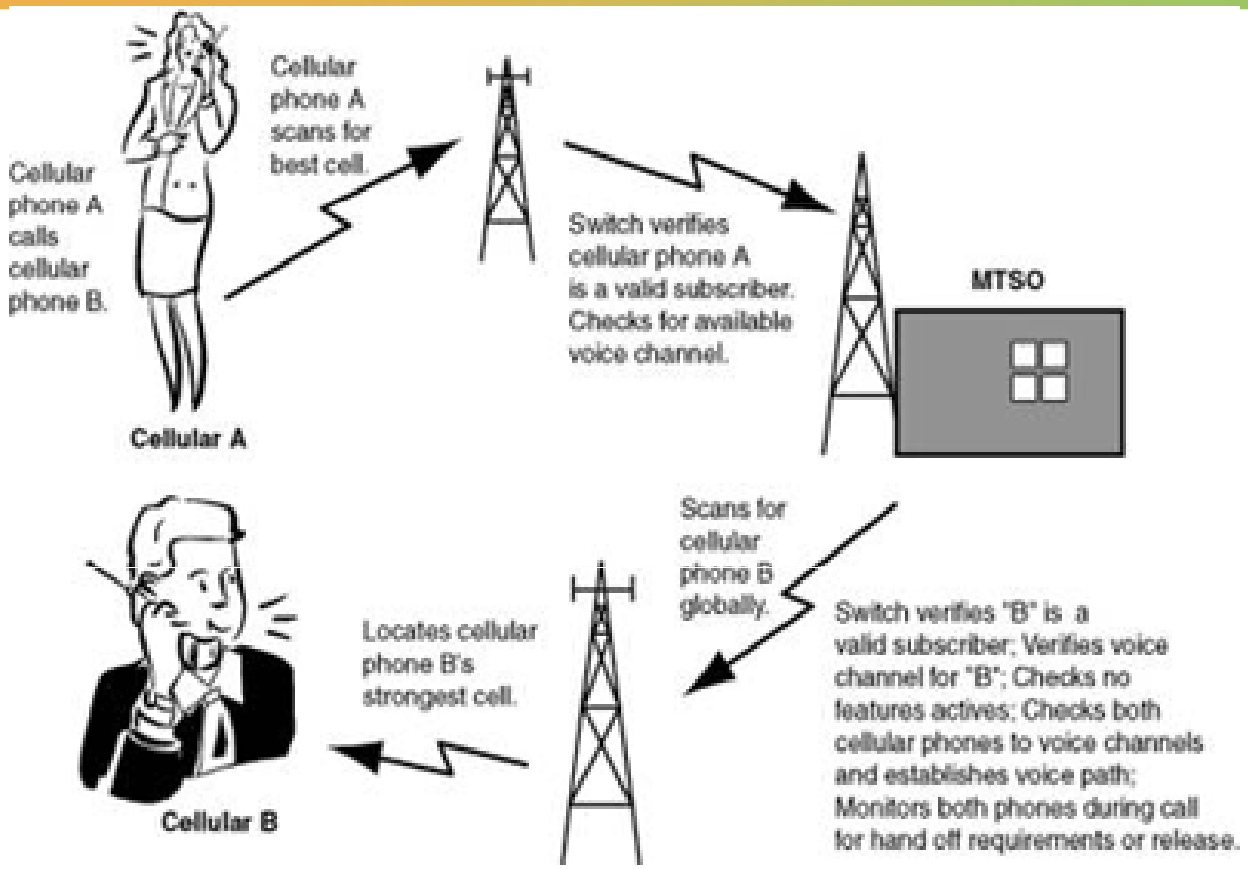
- Classes of transmitters
  - Class 1: Outputs 100 mW for maximum range
    - Power control mandatory
    - Provides greatest distance
  - Class 2: Outputs 2.4 mW at maximum
    - Power control optional
  - Class 3: Nominal output is 1 mW
    - Lowest power

# WIRELESS COMMUNICATIONS

- Wireless telephony
- Wireless LANs
- Location-based services

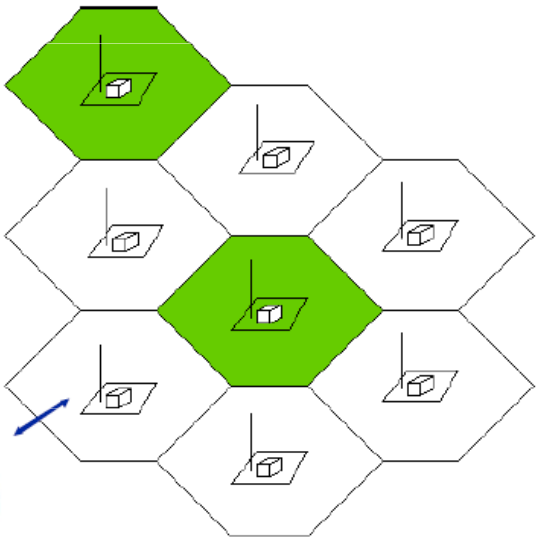


## How a cell phone works



# Cellular Phone Networks

- Frequency reuse
- Handoff





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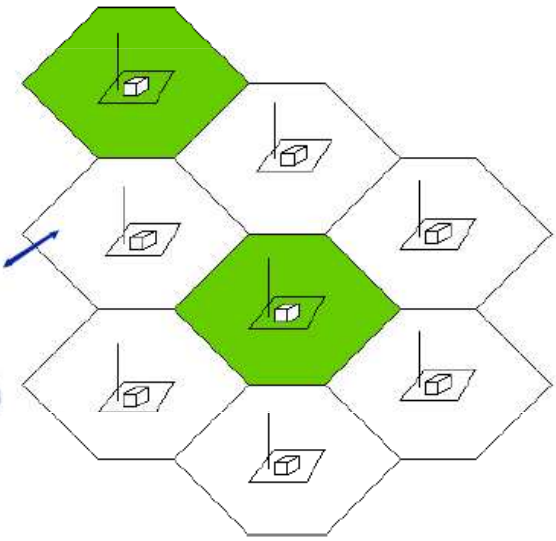

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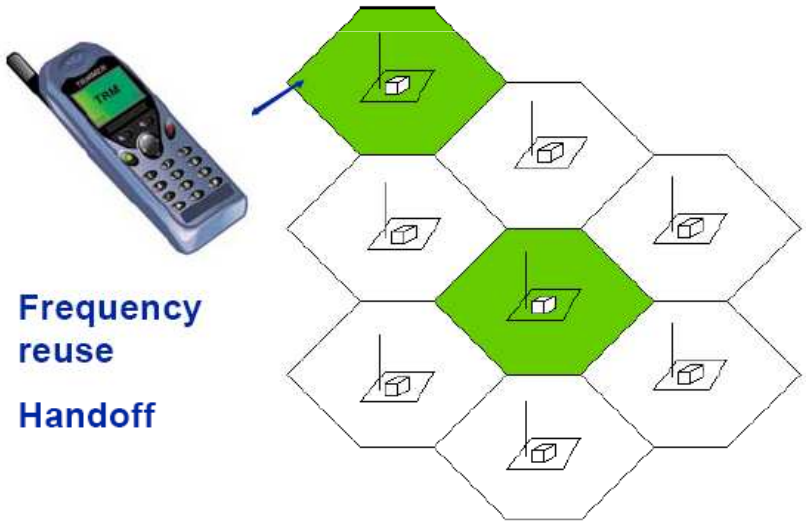
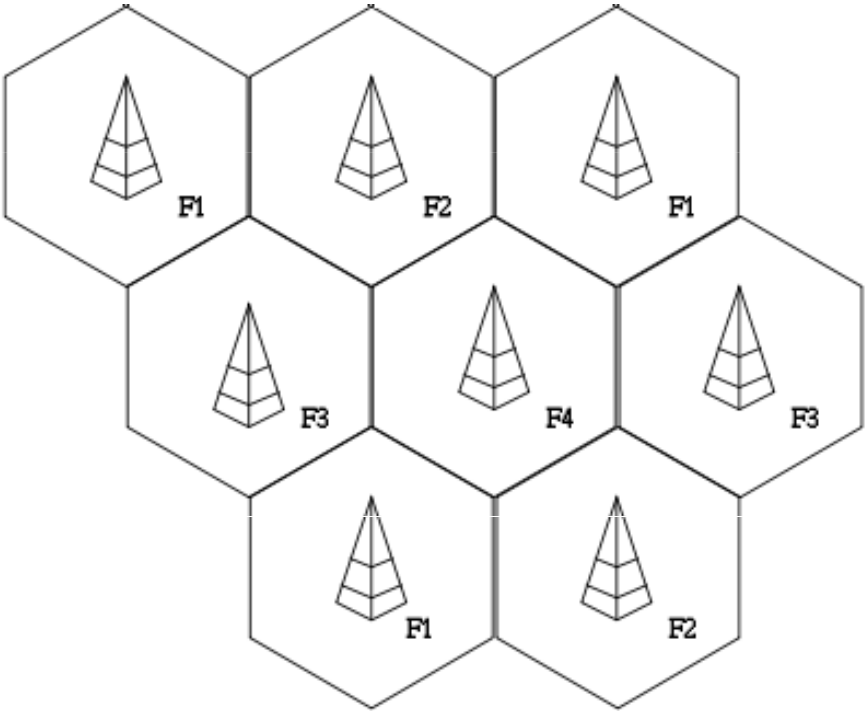


- Frequency reuse
- Handoff



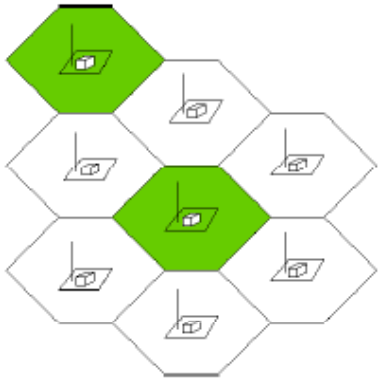
# Example of frequency reuse factor or pattern 1/4




http://en.wikipedia.org/wiki/Cellular_network

# Problem: Reuse not good enough!

- Radio waves attenuate at a rate proportional to the square of distance ($1/r^2$)
- This means that faraway cells are irrelevant but we still can have interference from adjacent cells
- Therefore, a cell cannot reuse the same channels as its 6 immediate neighbors
- This means that each cell can only use $1/7^{th}$ of the spectrum allocation…
- Example: AMPS system
  - Each operator was given 416 2-way channels but could only use about 416/7 ~ 60 channels at any given cell

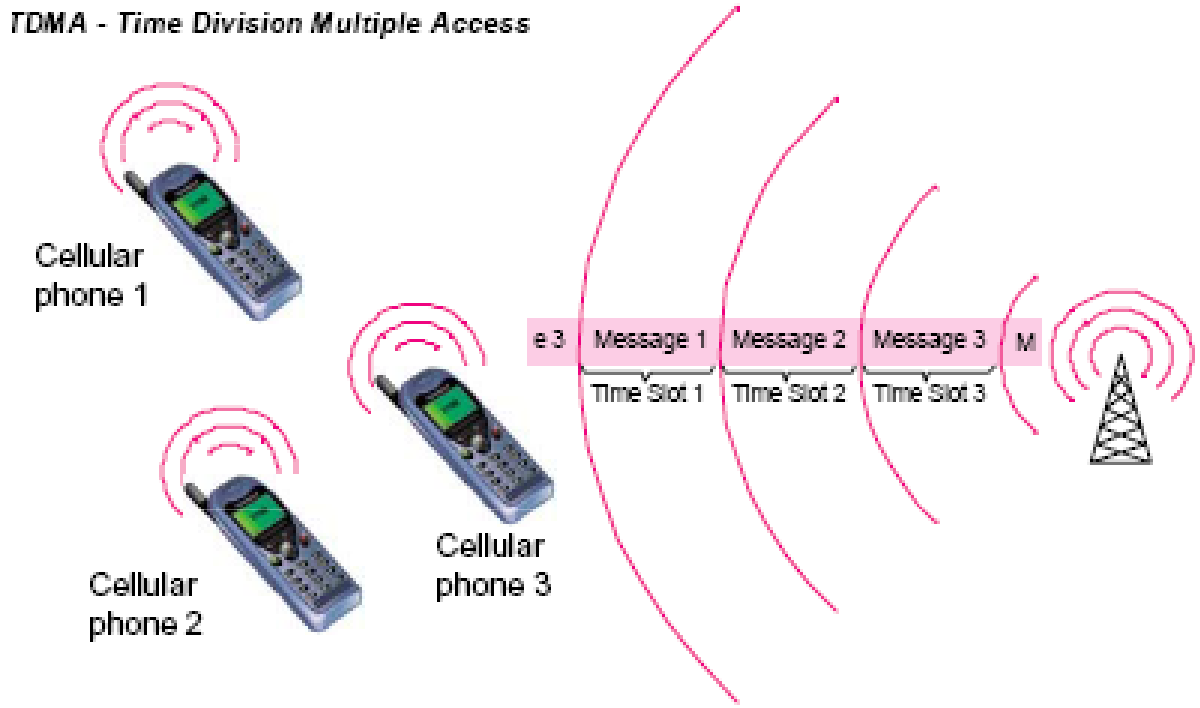




# Multiple Access Technologies

- ***FDMA: Frequency Division Multiple Access***
  - **Each call occupies a different frequency and has an exclusive use of that frequency during the call**
- ***TDMA: Time Division Multiple Access***
  - ***Several* calls can share the same frequency by alternating in time**
- ***CDMA: Code Division Multiple Access***
  - **Multiple calls mixed together; each call spread over the entire available spectrum; calls can be reconstructed by using call-specific keys.**

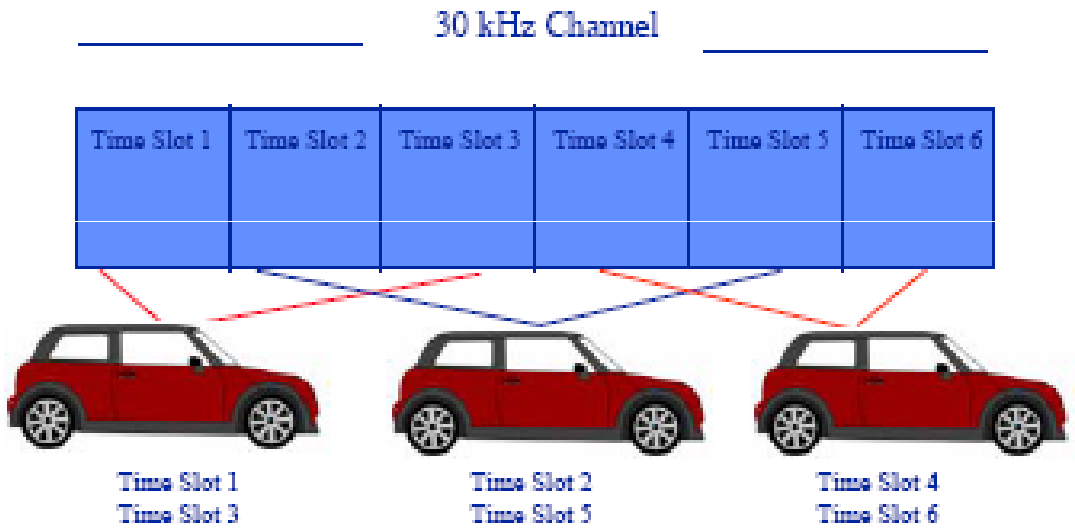
# TDMA: Time Division Multiple Access





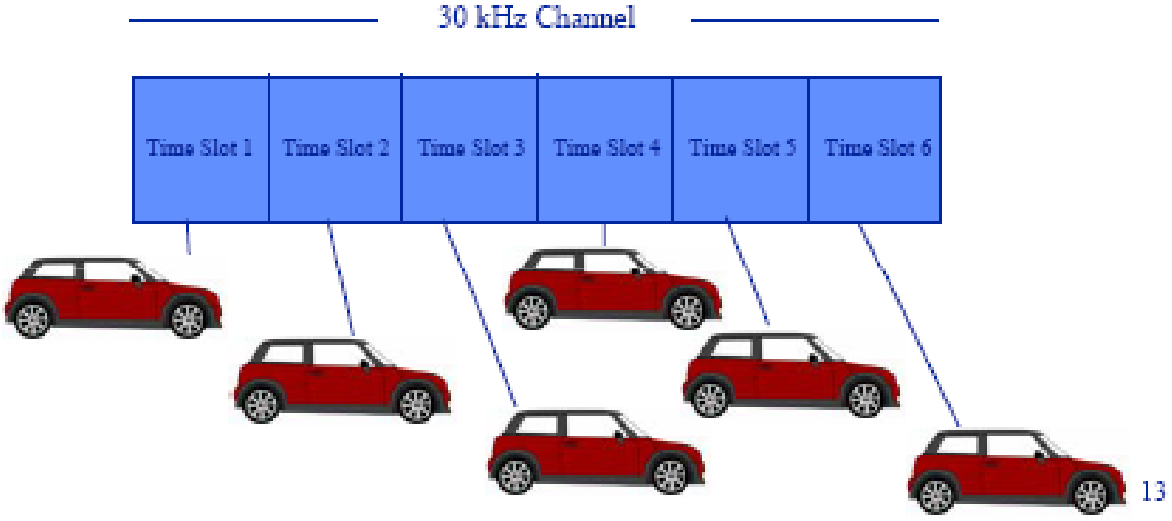

# TDMA

- *Dual-Mode Capability*
- *3x the capacity of analog networks*
- *30 kHz Channel Spacing*
- *832 Channels*
- *8 kbps (Full Rate Mobiles)*
- *6 time slots per channel*
- *2 time slots per mobile*
- *uplink Tx*
- *downlink Rx*
- *3 calls per channel*



# TDMA

- *4 Kbps (Half Rate Mobiles)*
- *6 time slots per channel*
- *1 time slots per mobile*
  - *handles both uplink Tx/ downlink Rx*
- *6 calls per channel*

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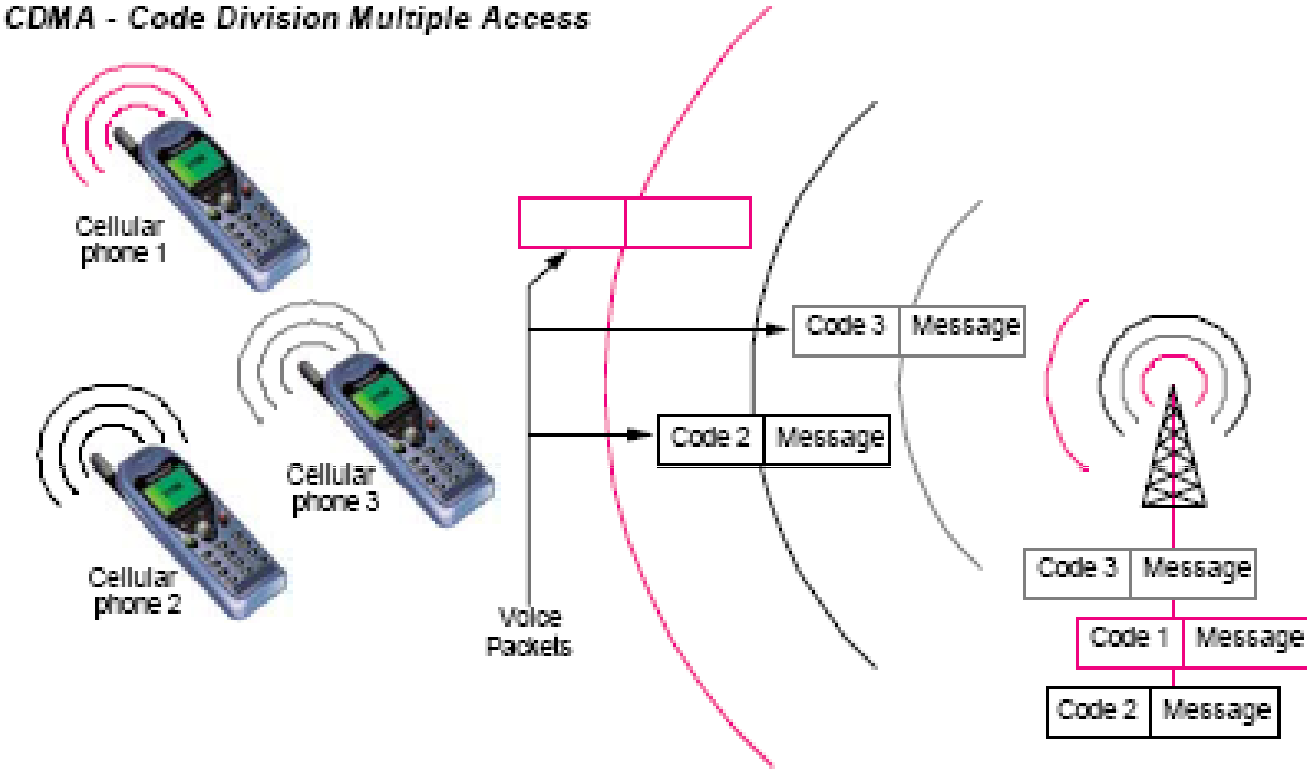
# CDMA



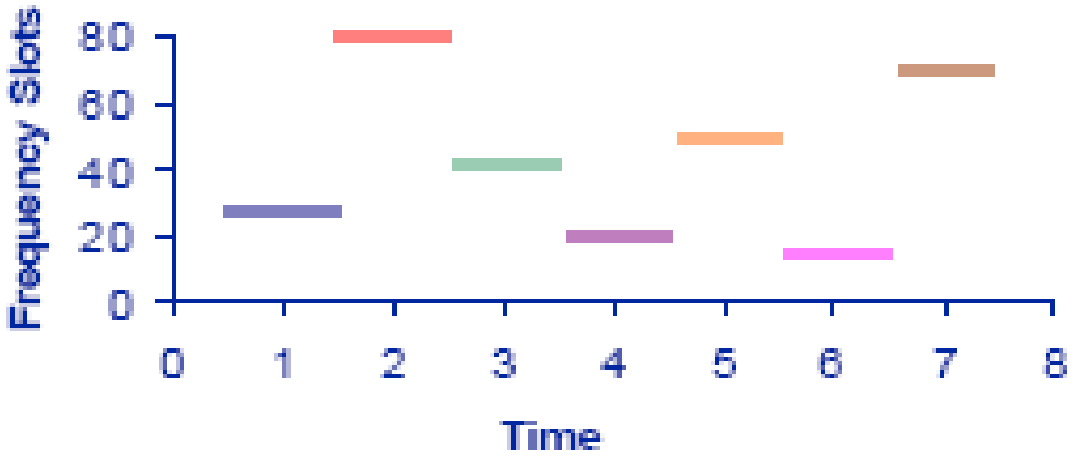
# Varian CDMA

- W-CDMA
- TD-CDMA
- TD-SCDMA
- DS-CDMA
- FH-CDMA
- MC-CDMA



# Frequency Hopping Spread Spectrum

- **Short duration hops between radio frequencies**
- **Sender and receiver know sequence**



# Random number generators

- **Simplest approach is to use the following recurrence sequence:**

  $x_0$ = given,

  $x_{n+1} = P_1 x_n + P_2 \pmod N \quad n = 0,1,2,\ldots$

- **For example:**

  $P_1 = 16807$, $P_2 = 0$, and $N = 2^{31} - 1 = 2147483647$

- **Basic property:**
  - If P1, P2 known, then different choices of the initial seed x0 result in completely distinct sequences
  - Therefore, the seed x0 can act as the code, to be exchanged between sender and receiver



# History of CDMA

- **Co-invented by actress Hedy Lamarr during World War II as a technique against interference of submarine communications**
- **She was inspired by the musical notes encoded on the scrolls of a player piano**

# Advantages of CDMA

- Spread Spectrum Analysis
- 1.23 MHz channel vs. 30 kHz
- Each call is distinguished by a unique digital code different from others users transmitting at the same frequency band
- >= 10 times the capacity of analog networks
- Lower Power Terminals/Longer Battery Life



# Generation of mobile phone technologies

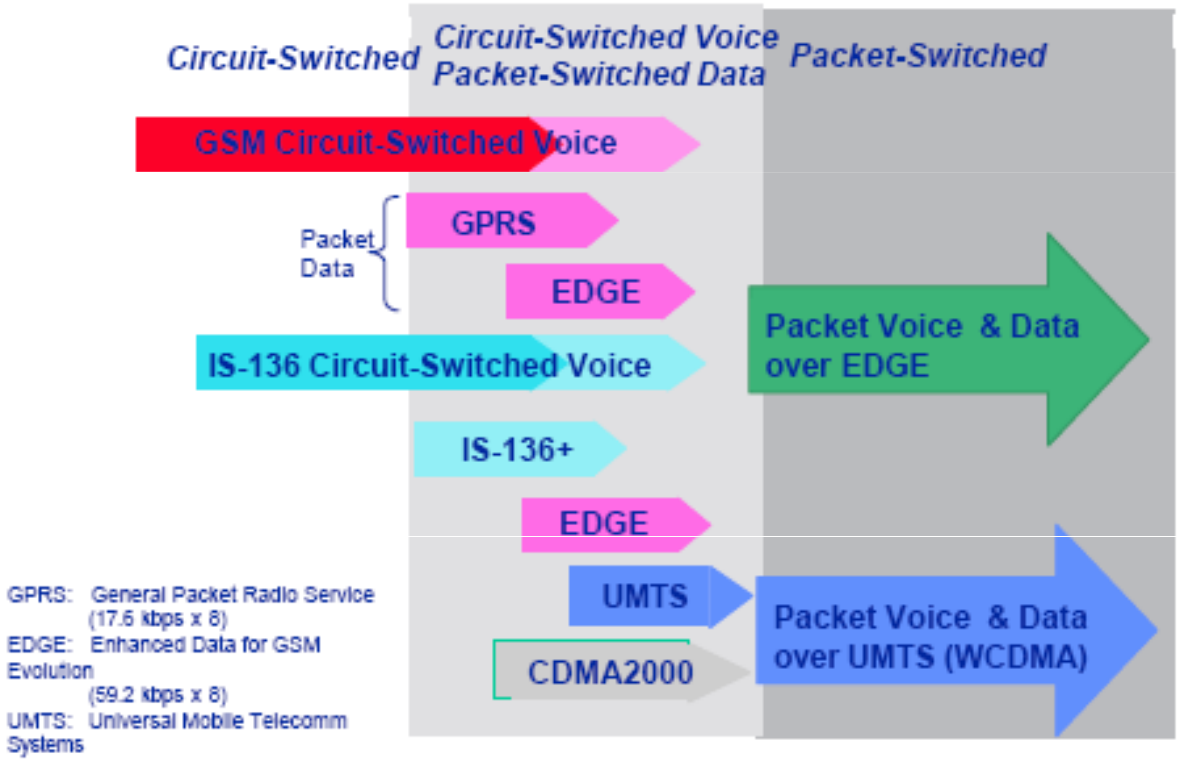
- 1G
- 2G
- 2.5G
- 3G

# History

- First Generation: Analog
  - AMPS (USA)
  - NMT (Europe)
- Second Generation: Digital
  - GSM (1st Europe, then world-wide)
  - Digital AMPS (IS-54)
- 2.5: PCS
  - DCS-1800 (world-wide except USA)
  - DCS-1900 (USA)
  - CDMA (IS-95, USA)
- Third Generation: Personal Communication Systems
  - UMTS



# Migration of Digital Cellular Systems



# General Packet Radio Service (GPRS)

- Extension to GSM to support packet transmission
- Transmission rates: 57.6 and 115.2Kbps initial rates will be lower: 20-30 Kbps
- Good integration with the TCP/IP protocol