Introduction to Wireless Technology

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- Increasing number of mobile radio communication systems used in everyday life. Garage door openers, remote controllers for home entertainment equipment, cordless telephones, hand-held walkie-talkies, pagers, and cellular telephones are all examples of mobile radio communication systems.
- However, the cost, complexity, performance, and types of services offered by each of these mobile systems are decreasing.

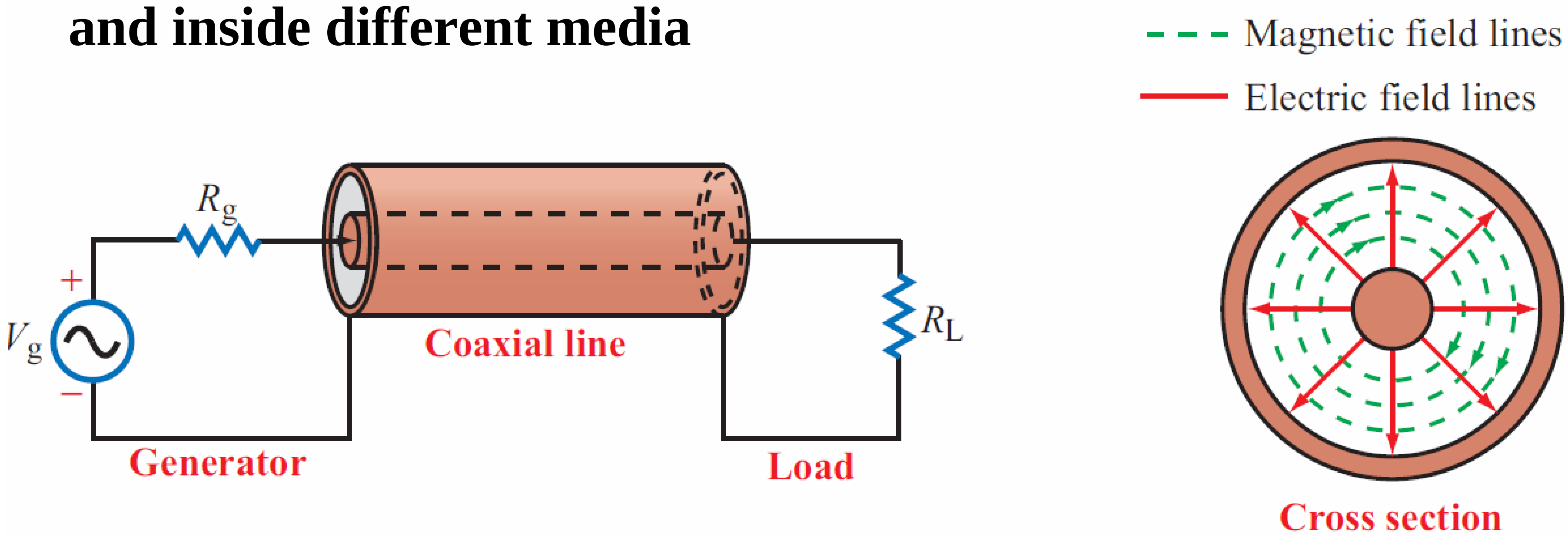
Introduction to wireless Technology

- The term *wireless communication* refers to the transfer of information using electromagnetic (EM) or acoustic waves over the atmosphere rather than using any propagation medium that employs wires. Not requiring an explicit network of wires and permitting communication while on the move
- Fortunately, EM waves travel with the speed of light in free space and inside medium (cables) – with a

delay-time =length of cable/C

This allows very fast communication.

EM waves can propagate in free space and inside different media



- Inside coaxial cables, the electric field is the radial direction between the inner and outer conductors, and the magnetic field forms circles around the inner conductors, both perpendicuar to the direction of propagation (cable)

Thus, in order to be able to design good wireless systems, it becomes imperative, to have a good understanding of electromagnetic waves and the propagation media used in conjunction to achieve communication.

This chapter will try to cover the following topics

1 **An introduction to the wireless systems and different technologies,**

2 Characterization of the various frequency bands,

3 Basic radio propagation theory

Currently:

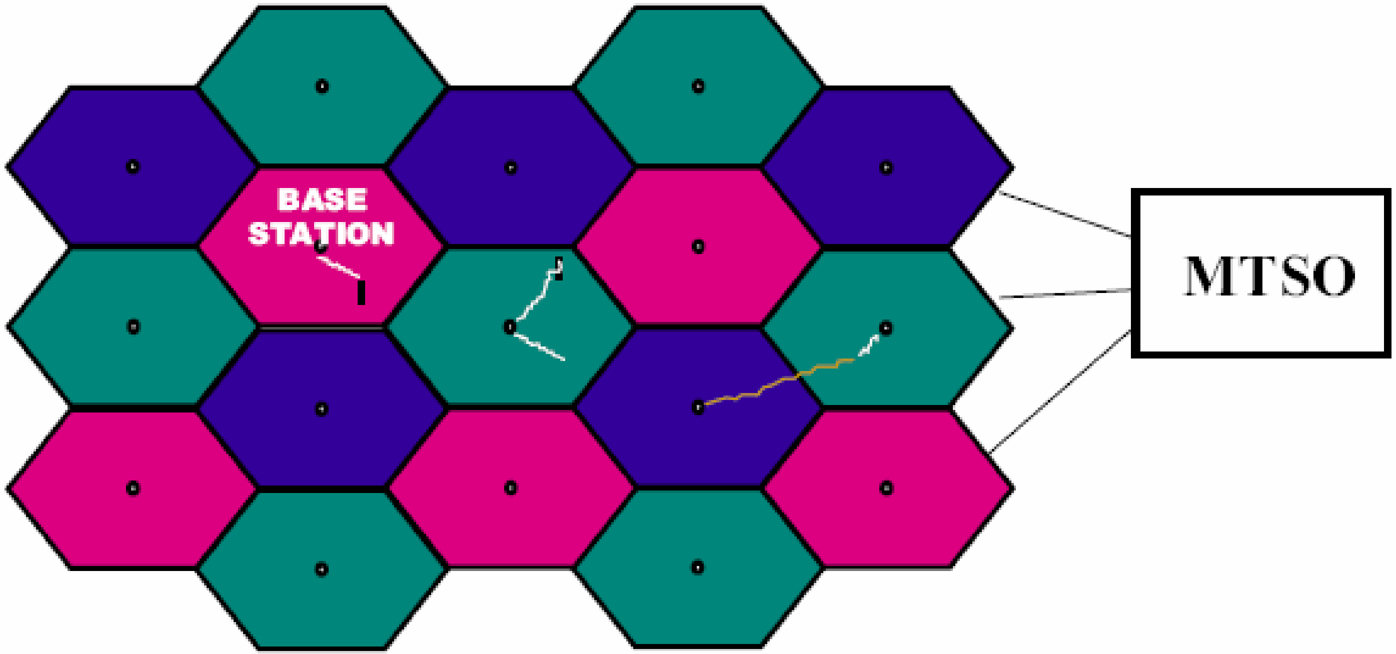
- Wireless technology is a fast growing one with lots of exciting actions
- WLAN rapidly growing
  - 802.11b, 802.11a, g,..
- Wide area wireless data also growing
- Support for voice and data in 2.5G and 3G wireless
- Wireless broadband
- Location-based services, WAP

Current Wireless Systems

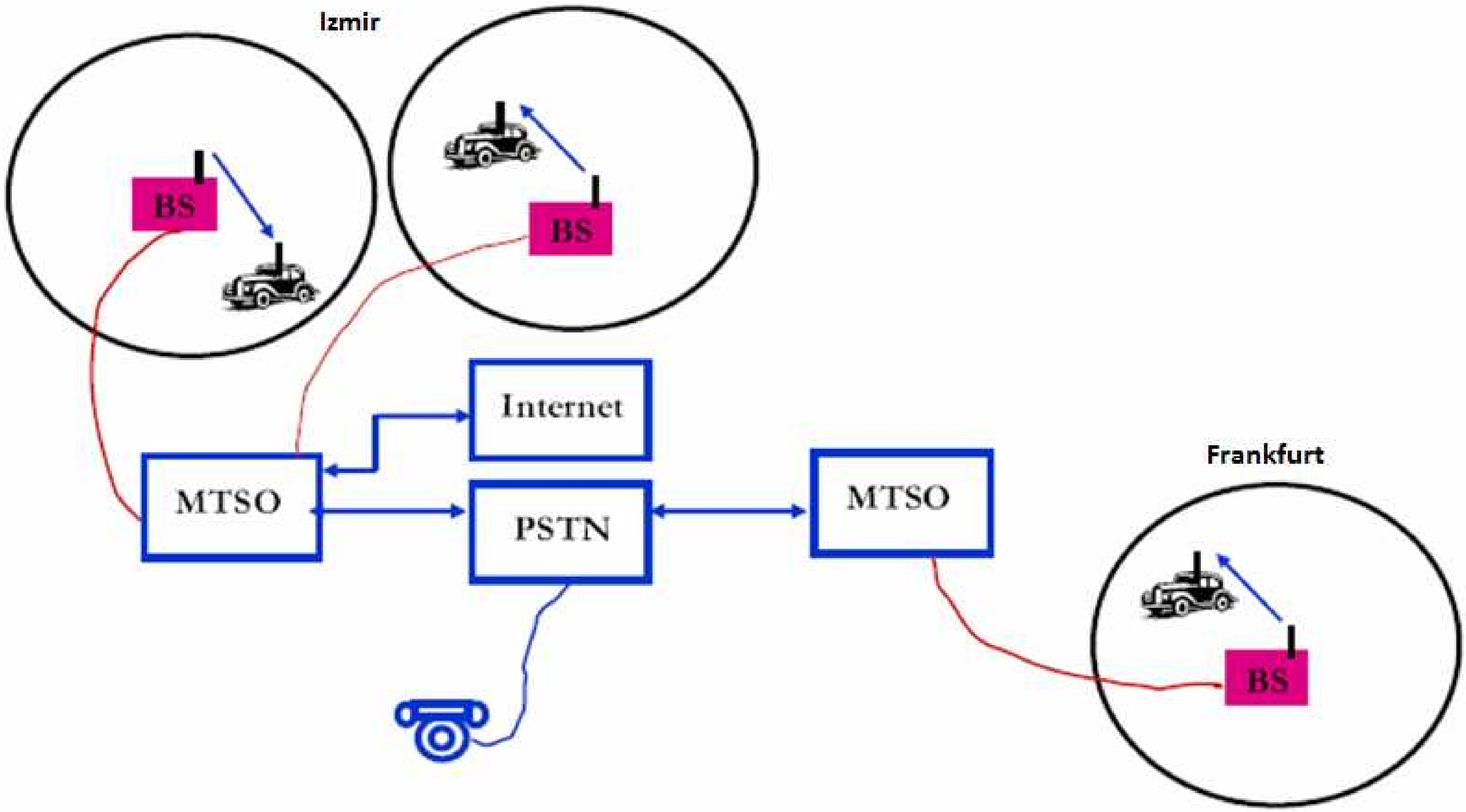
- Cellular Systems
- Wireless LANs
- WIMAX
- Satellite Systems
- Paging Systems
- Bluetooth
- Ultrawideband Radios
- Zigbee Radios

Cellular Systems:
Reuse channels to maximize capacity

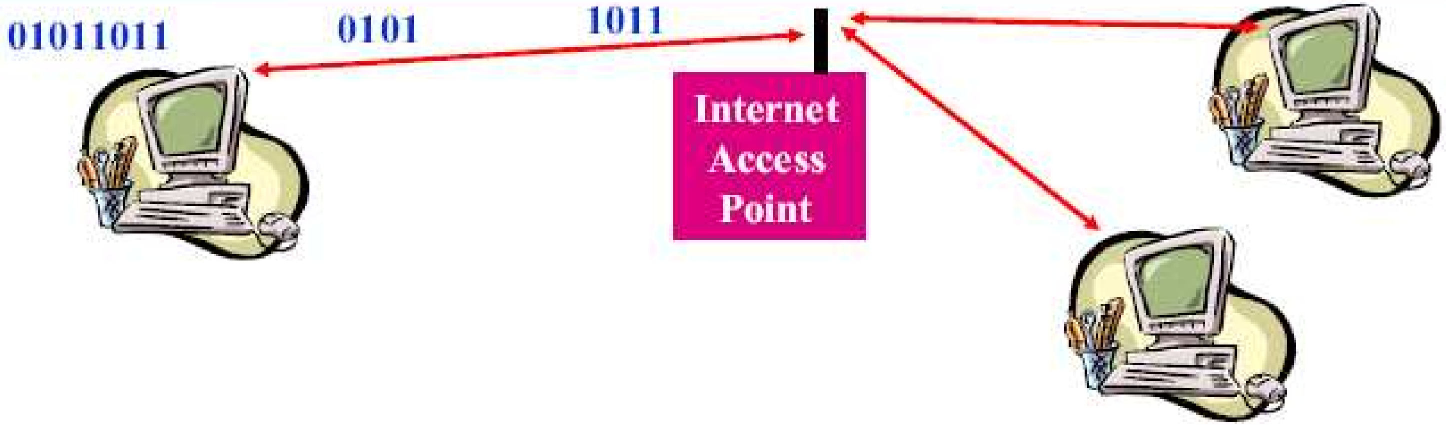
- Geographic region divided into cells
- Frequency/timeslots/codes/ reused at spatially-separated locations.
- Co-channel interference between same color cells.
- Base stations/MTSOs coordinate handoff and control functions
- Shrinking cell size increases capacity, as well as networking burden



Cellular Phone Networks



Wireless Local Area Networks (WLANs)

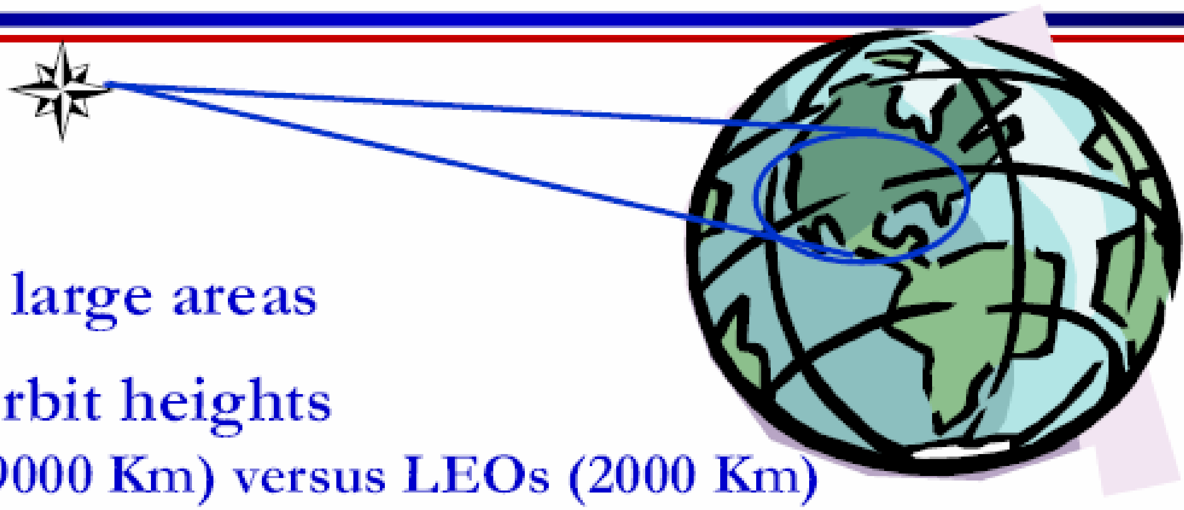


- WLANs connect "local" computers (100m range)
- Breaks data into packets
- Channel access is shared (random access)
- Backbone Internet provides best-effort service
  - Poor performance in some apps (e.g. video)

Wimax (802.16)

- Wide area wireless network standard
  - System architecture similar to cellular
  - Hopes to compete with cellular
- OFDM/MIMO is core link technology
- Operates in 2.5 and 3.5 MHz bands
  - Different for different countries, 5.8 also used.
  - Bandwidth is 3.5-10 MHz
- Fixed (802.16d) vs. Mobile (802.16e) Wimax
  - Fixed: 75 Mbps max, up to 50 mile cell radius
  - Mobile: 15 Mbps max, up to 1-2 mile cell radius

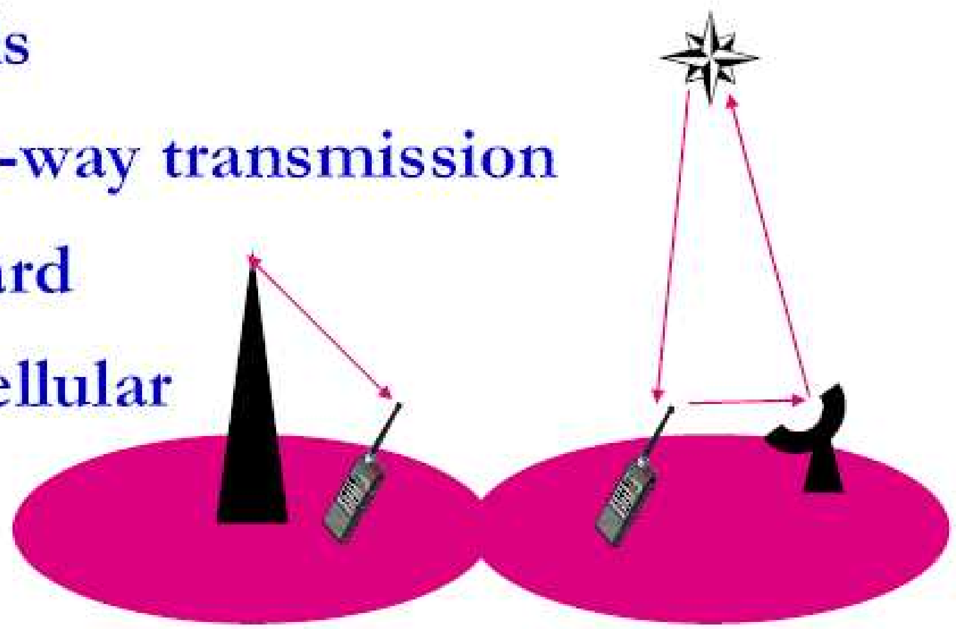
Satellite Systems



- Cover very large areas
- Different orbit heights
  - GEOs (39000 Km) versus LEOs (2000 Km)
- Optimized for one-way transmission
  - Radio (XM, Sirius) and movie (SatTV, DVB/S) broadcasts
  - Most two-way systems struggling or bankrupt
- Global Positioning System (GPS) use growing
  - Satellite signals used to pinpoint location
  - Popular in cell phones, PDAs, and navigation devices

Paging Systems

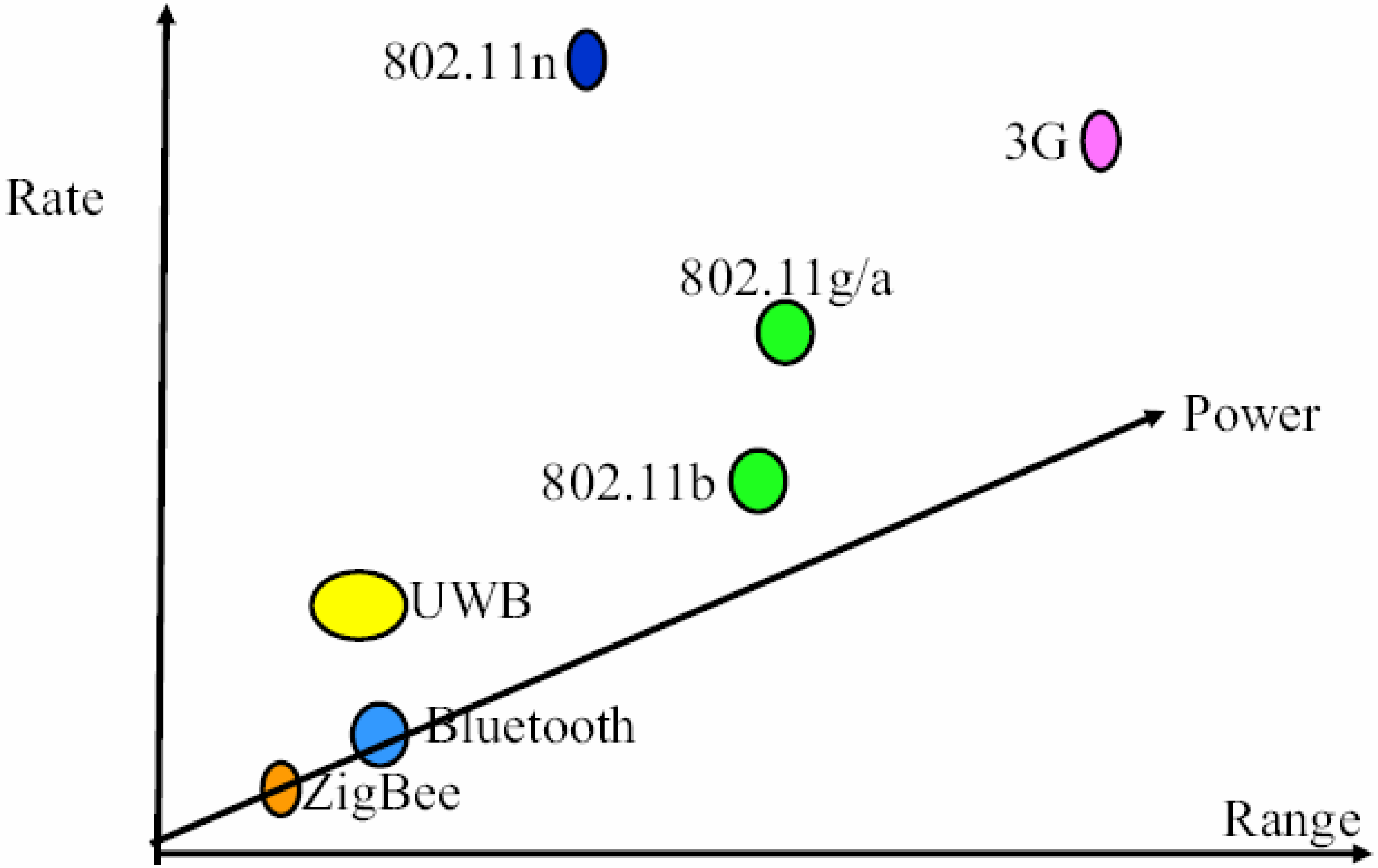
- Broad coverage for short messaging
- Message broadcast from all base stations
- Simple terminals
- Optimized for 1-way transmission
- Answer-back hard
- Overtaken by cellular



Bluetooth

- Cable replacement RF technology (low cost)
- Short range (10m, extendable to 100m)
- 2.4 GHz band (crowded)
- 1 Data (700 Kbps) and 3 voice channels
- Widely supported by telecommunications, PC, and consumer electronics companies
- Few applications beyond cable replacement

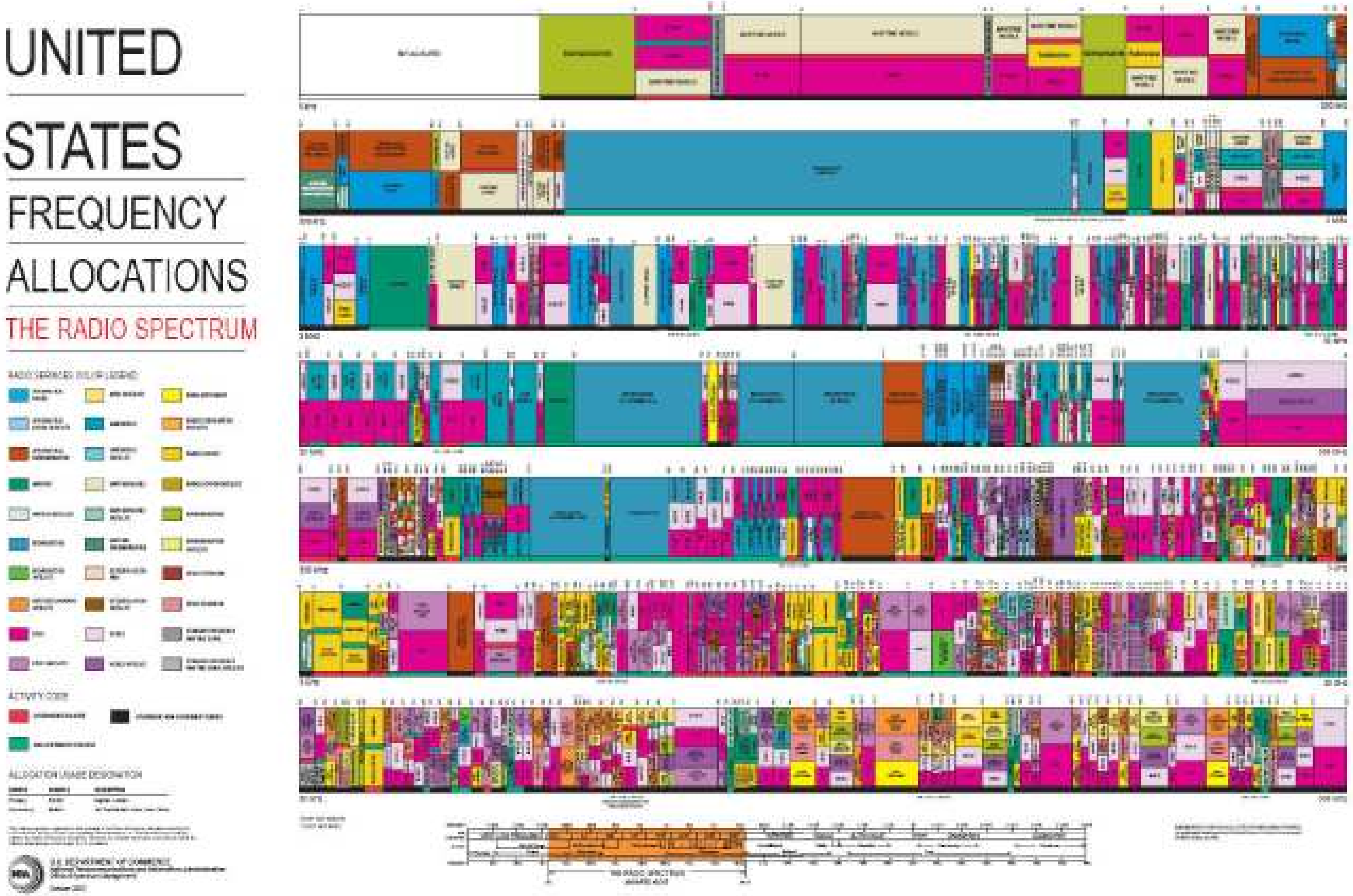
Tradeoffs



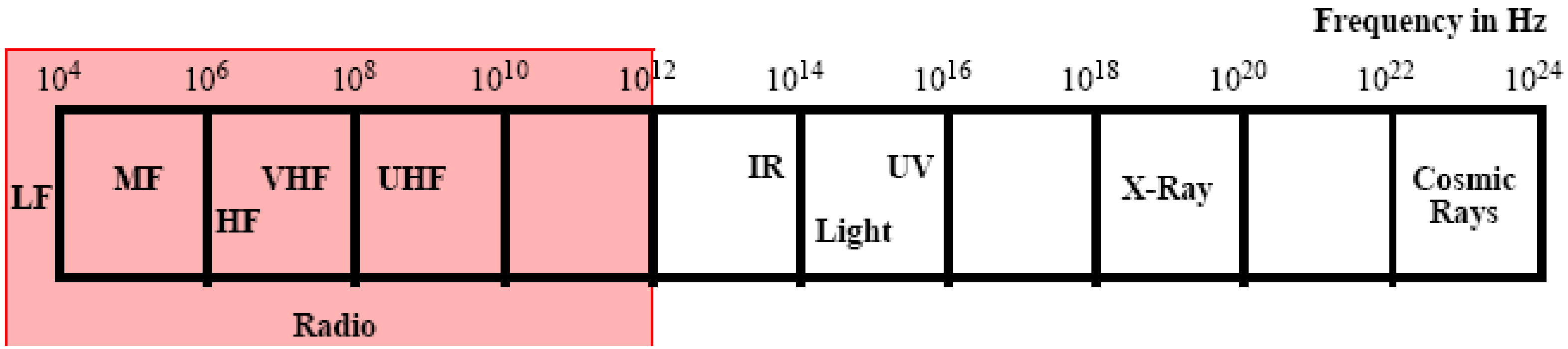
802.11n
3G
Rate
802.11g/a
Power
802.11b
UWB
Bluetooth
ZigBee
Range

Radio Spectrum Allocation and Classification

US Spectrum allocation today



Radio Spectrum Classification



Frequency Band	Frequency Range (Wavelength)	Propagation Modes
ELF (Extremely Low Frequency)	Less than 3 KHz ($\lambda > 100$ km)	Ground wave
VLF (Very Low Frequency)	3-30 KHz (10 km $\leq \lambda <$ 100 km)	Earth-Ionosphere guided
LF (Low Frequency)	30-300 KHz (1 km $\leq \lambda <$ 10 km)	Ground wave
MF (Medium Frequency)	300 KHz-3 MHz (100 m $\leq \lambda <$ 1 km)	Ground/sky wave for short/long distances.
HF (High Frequency)	3-30 MHz (10 m $\leq \lambda <$ 100 m)	Sky wave, but limited, short-distance ground wave also.
VHF (Very High Frequency)	30-300 MHz (1 m $\leq \lambda <$ 10 m) 30-60 MHz (5 m $< \lambda <$ 10 m)	Space wave Space wave
UHF (Ultra High Frequency)	300 MHz-3 GHz (10 cm $\leq \lambda <$ 1 m)	Space wave
SHF (Super High Frequency)	3 GHz-30 GHz (1 cm $\leq \lambda <$ 10 cm)	Space wave
EHF (Extremely High Frequency)	30 GHz-300 GHz (1 mm $\leq \lambda <$ 10 mm)	Space wave

Table 1: Radio Frequency Allocations.

- The radio spectrum is divided into sub-bands based on each frequency range's suitability for a given set of applications. Suitability is determined as a function of the atmospheric propagation characteristics of the given frequencies as well as system aspects, such as required antenna size and power limitations.
- Based on these considerations, the radio spectrum has been divided into the following sub bands:

1) Extremely Low Frequency (ELF)

300 - 3000 Hz (λ=1000 - 100 km)

2) Very Low Frequency (VLF)

3 - 30 kHz (λ=100 - 10 km)

Propagation Characteristics: Propagates between the surface of the Earth and the Ionosphere. Can penetrate deep underground and underwater. As the required antenna size is proportional to the wavelength, the large wavelength in this case mandates the use of large antennas.

Applications**:** underwater communication (submarines), SONAR

3) Low Frequency (LF)

30 - 300 kHz (λ=10 - 1 km)

Propagation Characteristics: The sky wave can be separated from the ground wave for frequencies above 100 kHz. This enables communication over large distances by reflecting the sky wave off the atmosphere.

Applications: broadcasting, radio navigation

4) Medium Frequency (MF)

300 - 3000 kHz (λ=1000 - 100 m)

***Propagation Characteristics*:** The sky wave separates from the ground wave in this range. Ground wave gives usable signal strength up to 100 km from transmitter.

***Applications*:** AM radio broadcasting (550 - 1600 kHz)

5) High Frequency (HF) → 3 - 30 MHz (λ=100 - 10 m)

Propagation Characteristics: The sky wave is the main propagation mode. The ground wave is used for communication over shorter distances than the sky wave. As propagation loss increases with frequency increase, the use of repeaters is required.

Applications: Broadcasting over large areas, amateur radio, citizens band (CB) radio

6) Very High Frequency (VHF) →30 - 300 MHz (λ=10 - 1 m)

***Propagation Characteristics*:** Diffraction (bending of waves due to obstruction) and reflection give rise to communication beyond the horizon. Propagation distances are thousands of kilometers. The diffraction and reflection enables reception within buildings.

***Applications*:** broadcast TV, FM radio (88 - 108 MHz), radio beacons for air traffic control

7) Ultra High Frequency (UHF) → 300 - 3000 MHz (λ=1 m - 10 cm)

Propagation Characteristics: Reflections from atmospheric layers are possible. Effects of rain and moisture are negligible.

Applications: broadcasting, satellite (TV) broadcasting, all (1G to 3G) land mobile phones, cordless phones, some air traffic control

8) Super High Frequency (SHF) → 3 - 30 GHz (λ=10 - 1 cm)

Propagation Characteristics: Range becomes limited by obstacles as frequency increases. Propagation is limited by absorption by rain and clouds.

Applications: Satellite service for telephony and TV, mobile services in the future

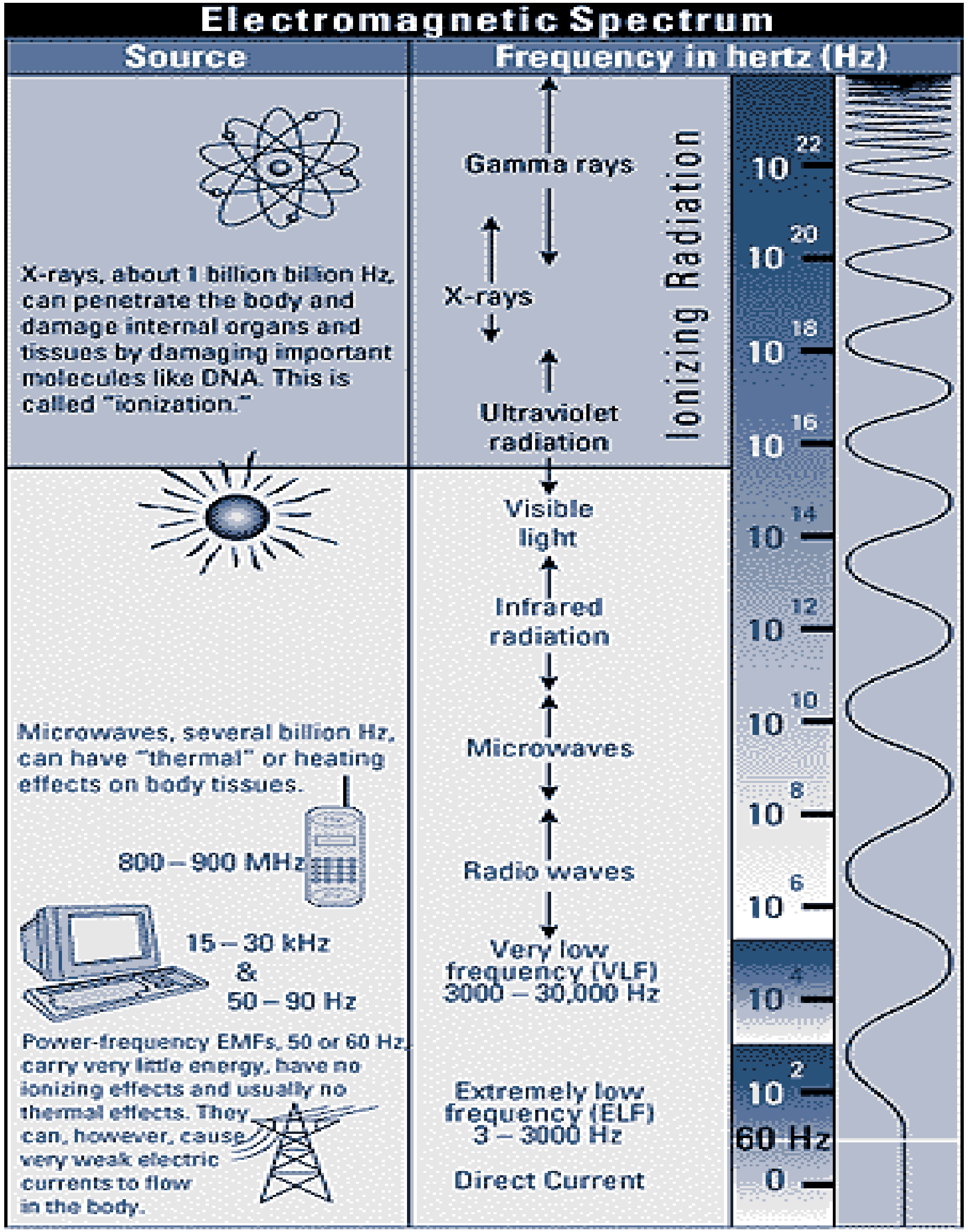
9) Extremely High Frequency (EHF) →

30 - 300 GHz (λ=10 - 1 mm)

***Propagation Characteristics*:** Very high losses due to water, oxygen, vapor.

***Applications*:** communications at short distances (within line of sight), broadcast satellite for HDTV (for communication between satellites in space, not space to earth)

Summary: EM Spectrum

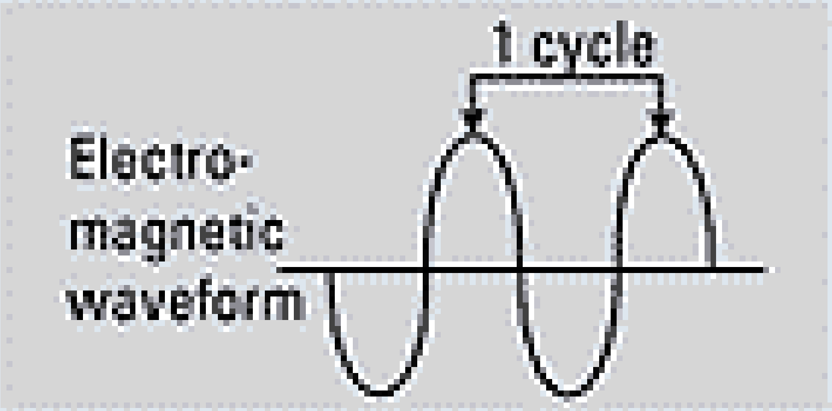


Frequency and Wavelength

Frequency is shown in **Hertz (Hz)**. 1 Hz = 1 cycle per second.

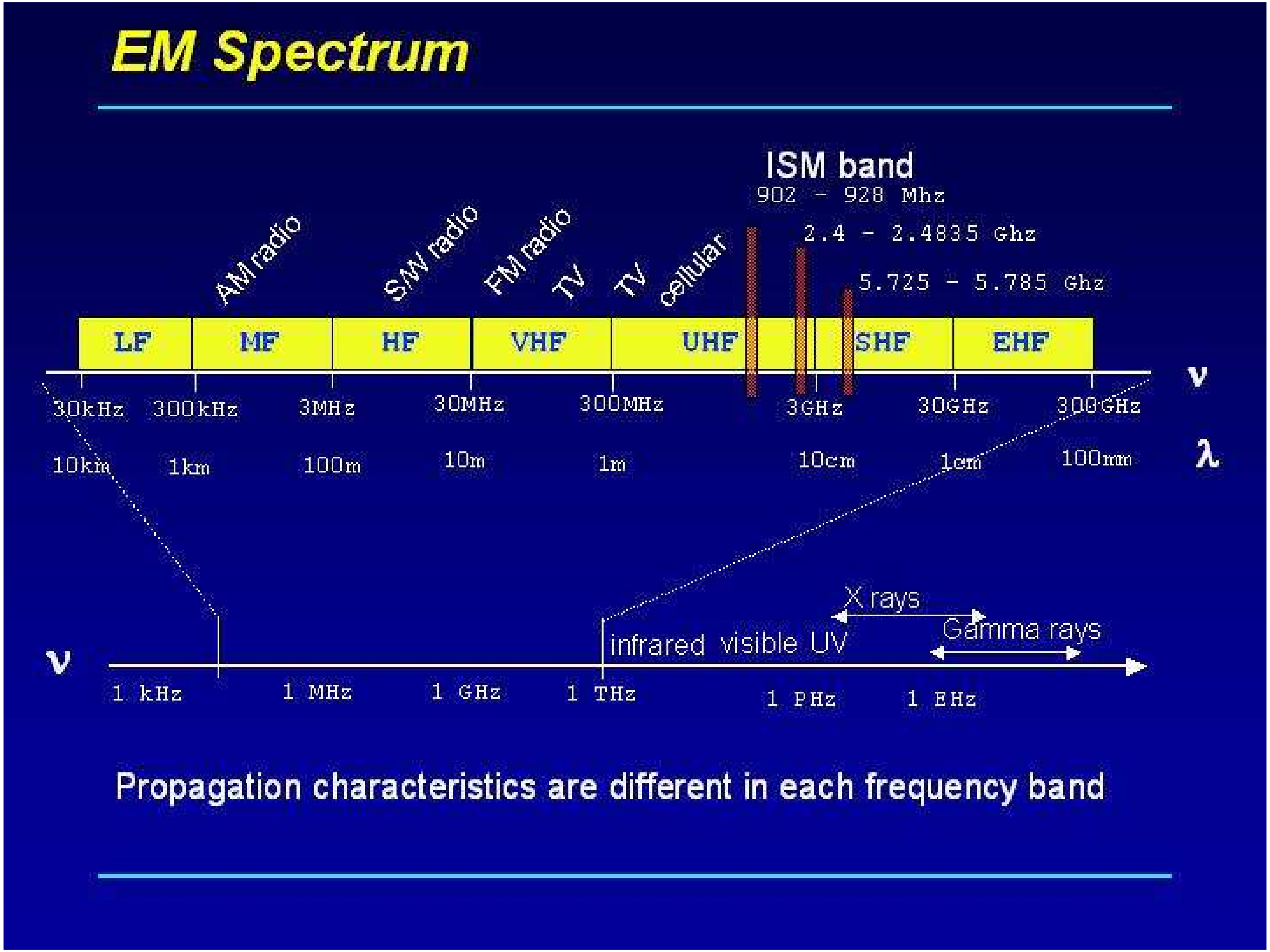
kHz = kilohertz = 1000 Hz

MHz = megahertz = 1,000,000 Hz



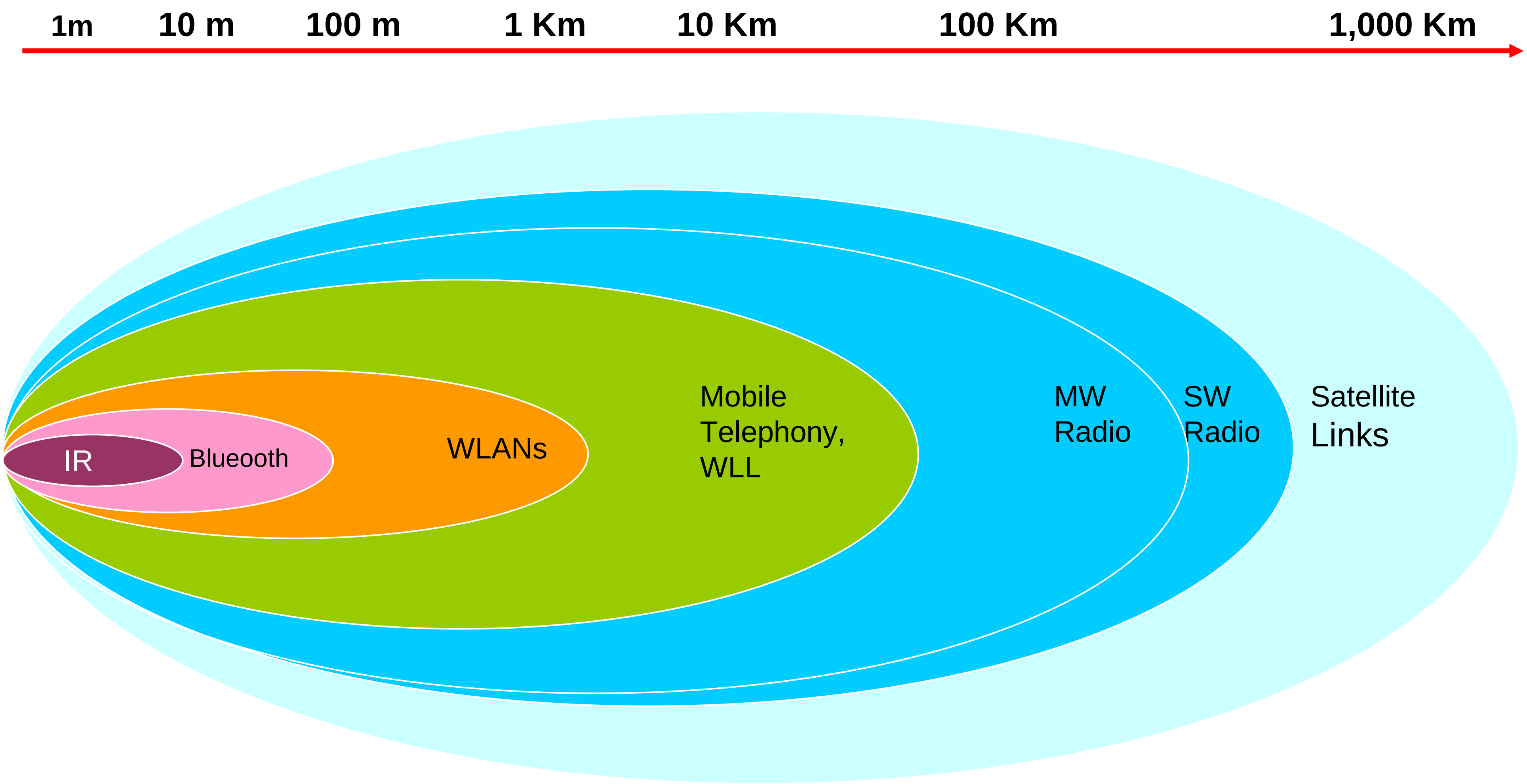
Examples:

Source	**Frequency**	**Wavelength**
Power line	60 Hz	3100 miles (5000 km)
Microwave oven (inside)	2450 MHz	4.8 inches (12.2 cm)



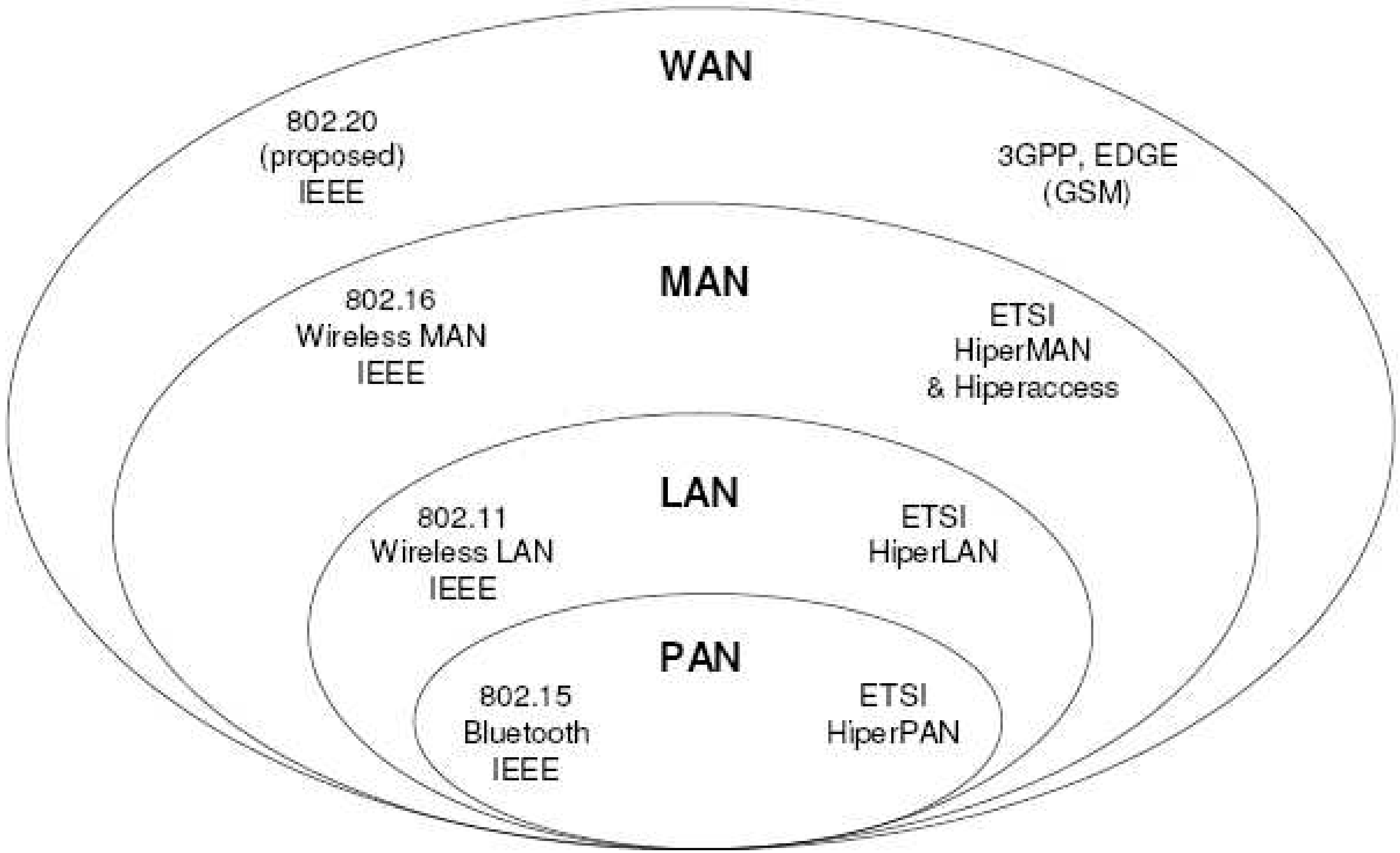
EM Spectrum
ISM band
902 - 928 Mhz
2.4 - 2.4835 Ghz
5.725 - 5.785 Ghz
AM radio
S/W radio
FM radio
TV
TV
cellular
LF
MF
HF
VHF
UHF
SHF
EHF
ν
30kHz
300kHz
3MHz
30MHz
300MHz
3GHz
30GHz
300GHz
λ
10km
1km
100m
10m
1m
10cm
1cm
100mm
X rays
Gamma rays
infrared visible UV
ν
1 kHz
1 MHz
1 GHz
1 THz
1 PHz
1 EHz
Propagation characteristics are different in each frequency band

Wireless Systems: Range Comparison:



The Different Wireless systems:

Standards:



Wired vs. wireless communication:

Wired	Wireless
Each cable is a different channel	One media (cable) shared by all
Signal attenuation is low	High signal attenuation
No interference	High interference

Why go wireless? --- Wirelss is mobilizing all services

Users want applications independent of access, device and location

Advantages:

- Sometimes it is difficult to lay cables
- User mobility
- Cost

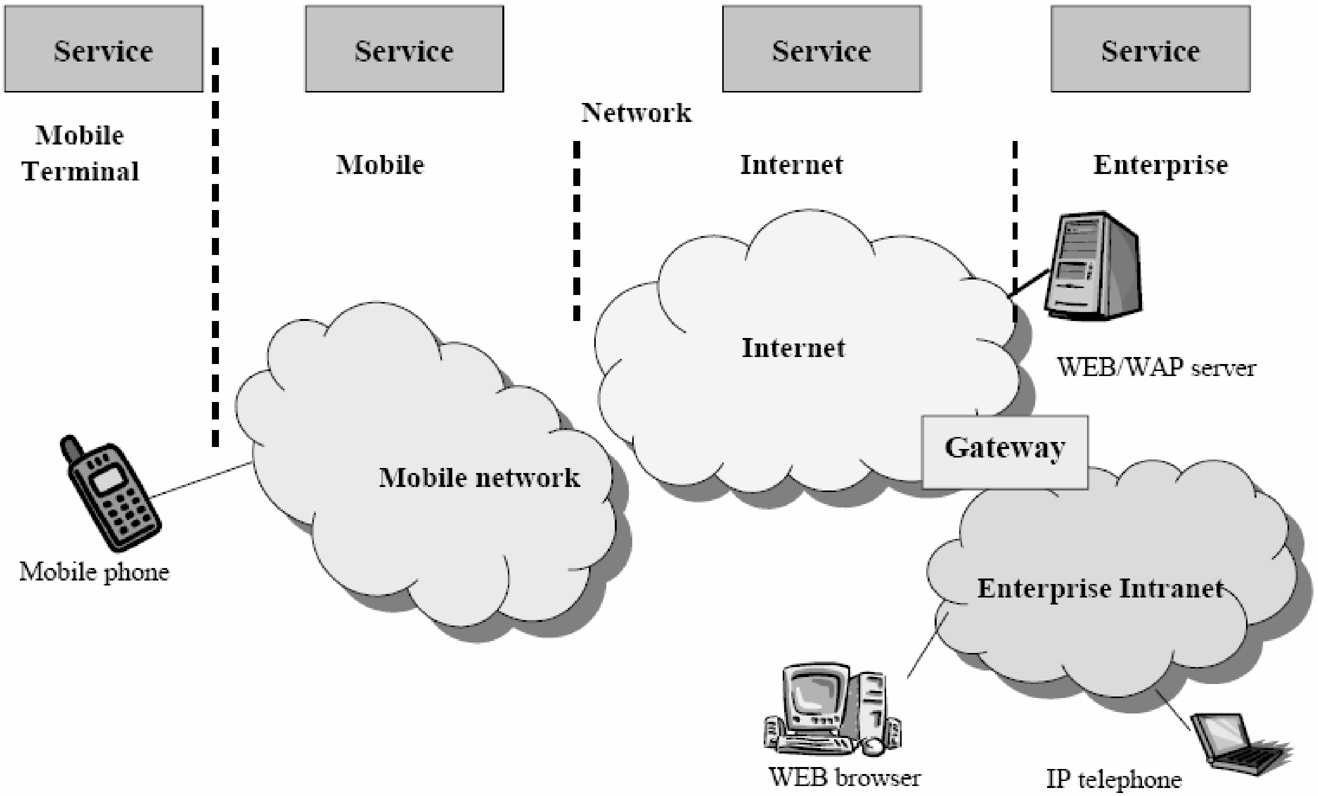
Limitations:

- Bandwidth
- Power
- (In)security

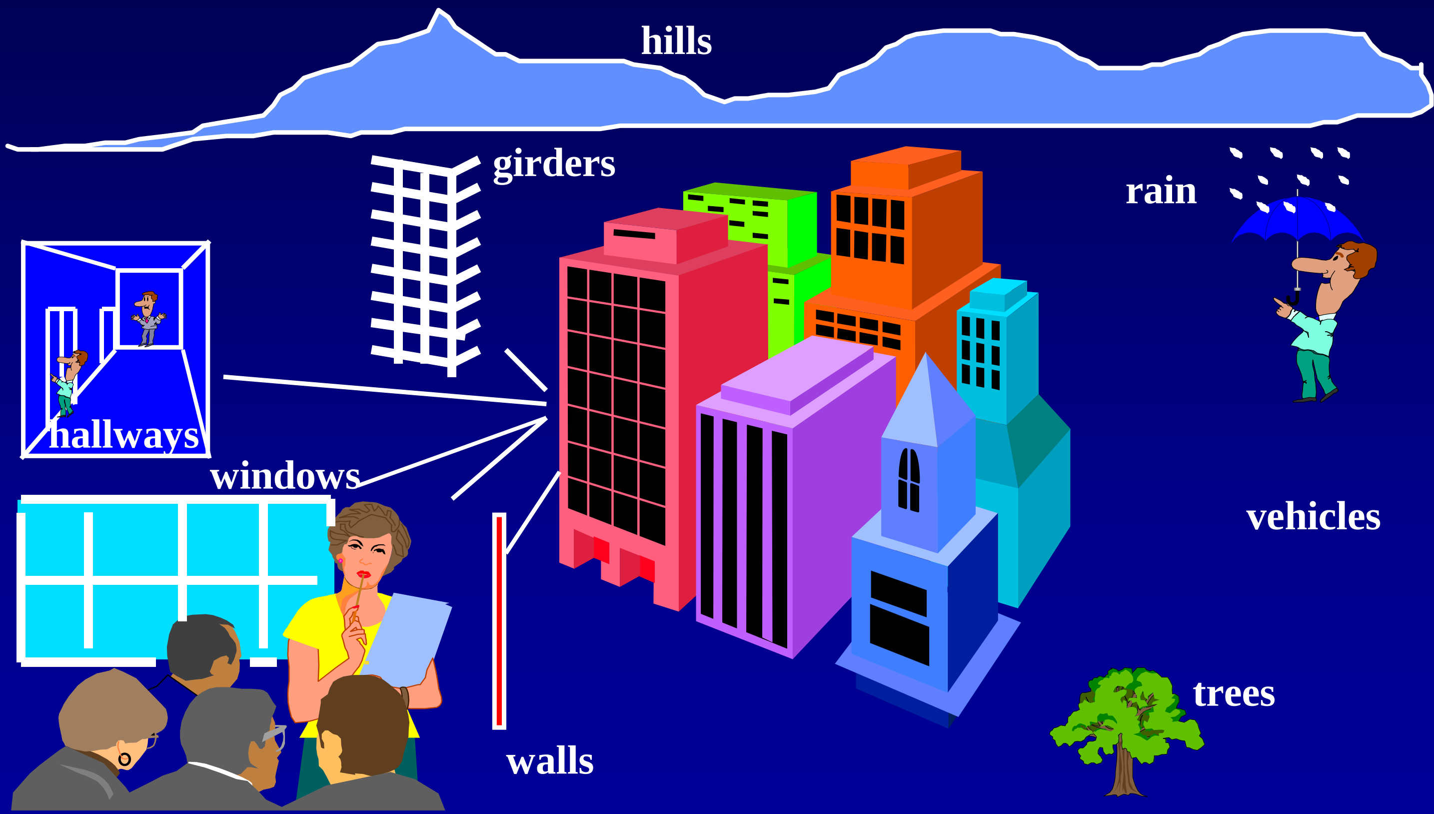
AIM:

Is to have an open mobile plateform for many multimedia services.

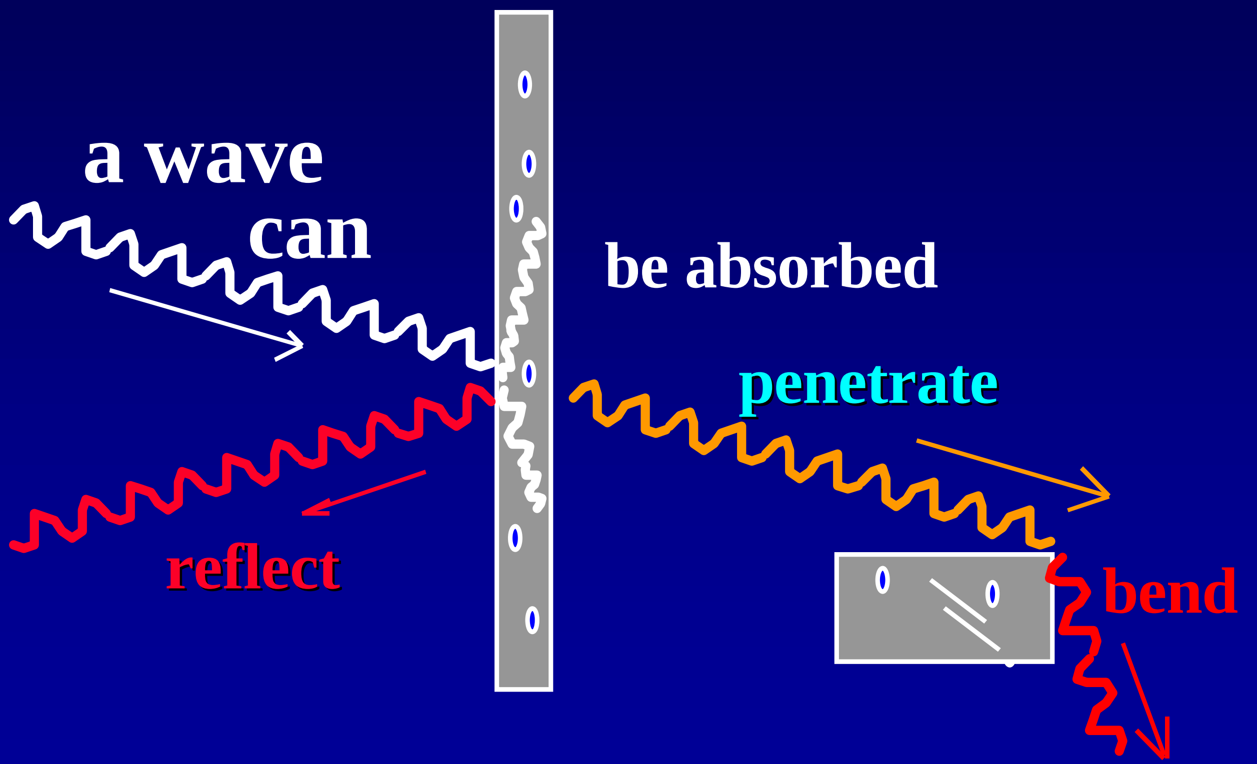
Towards Open Mobile Services



The Cluttered World of Radio Waves

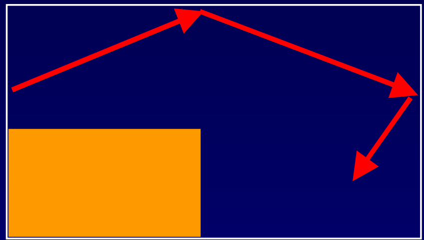


Propagation in the "Real World"



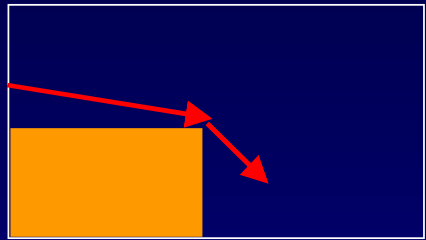
Radio Propagation

Three basic propagation mechanisms



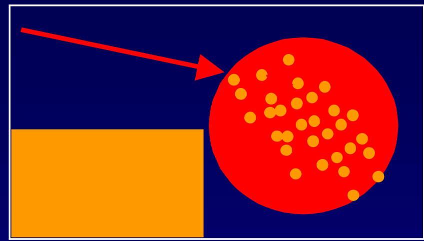
Reflection

$\lambda \ll D$



Diffraction

$\lambda \approx D$



Scattering

$\lambda \gg D$

- Propagation effects depend on not only on the specific portion of spectrum used for transmission, but also on the bandwidth (or spectral occupancy) of the signal being transmitted

- Spatial separation of Tx-Rx

- **Propagation Mechanisms:**

Propagation in free space is the ideal. When propagation takes place close to obstacles, the following propagation mechanisms occur:

a) Reflection – Occurs when a radio wave strikes an object with dimensions that are large relative to its wavelength, i.e. buildings.

b) Diffraction – Occurs when a radio wave is obstructed by surfaces with irregularities.Secondary waves arise from the obstructing surface and give rise to the bending of waves around and behind obstacles.

c) Scattering – Occurs when a radio wave travels through a medium containing lots of small (compared to wavelength) objects.

Wave Propagation Problems:

- Path loss and attenuation on obstacles
- Reflection, diffraction, scattering
- Interference (adjacent or co-channel)
- Thermal or man-made noise
- Imperfections of transmit / receive circuitry

ATMOSPHERIC EFFECTS ON WIRELESS CHANNELS

The wireless medium introduces difficulties for communication by its very inherent nature. The atmosphere reflects, absorbs or scatters radio waves. The layers most relevant to terrestrial radio propagation are shown in fig 1 below.

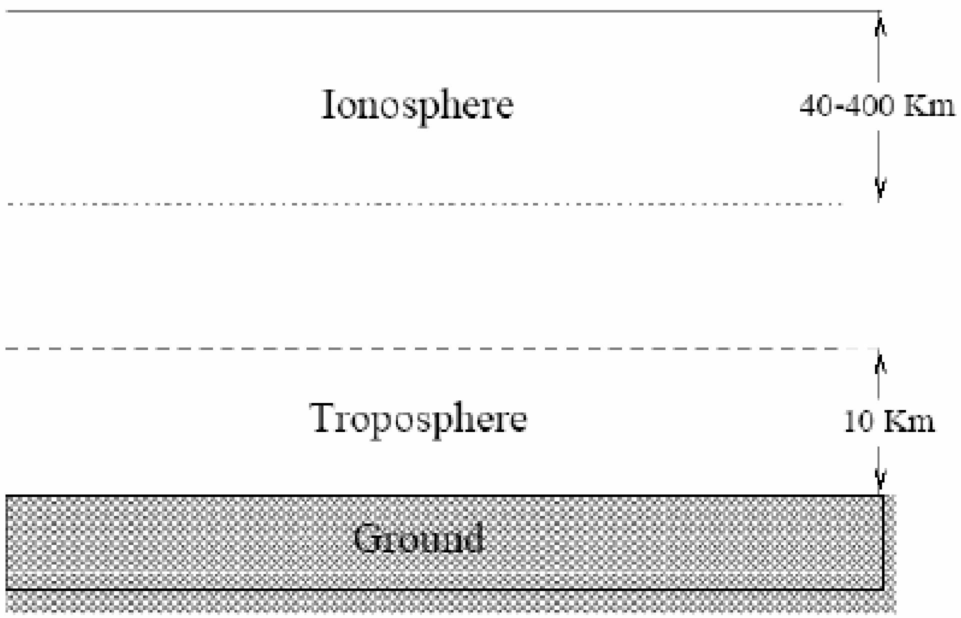


Fig 1: Atmospheric Layers relevant to terrestrial radio propagation.

Evaluating Frequencies

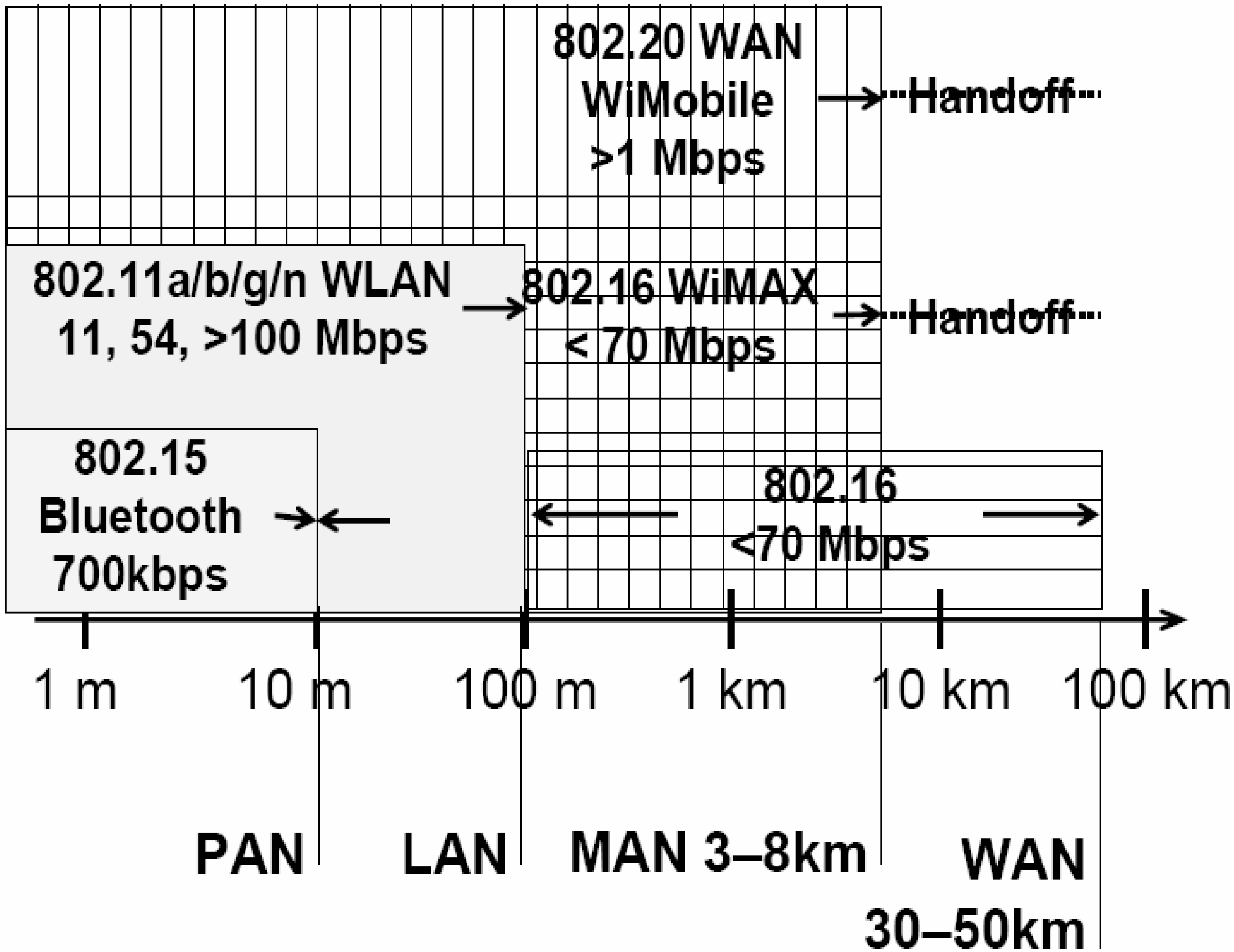
- 50 MHz- Good for range outdoors (antenna size, bending and penetrating), no foliage problems. “Sees” metallic building structures, doesn’t pass through windows or down corridors, needs large antenna (2 meter). TV?
- 450 MHz to 2 GHz - Good compromise for cellular-type systems. Antenna small, but big enough for outdoor range. Minor foliage effects. OK for windows walls and corridors. (450 might be best, but ...) (Range issue for 2 GHz systems- more bases)
- 5-20 GHz- Antenna too small for range. Foliage and rain effects. Indoor microcells? Point-to-point? Satellites to ground stations?

Foliage losses are due to trees and forests.

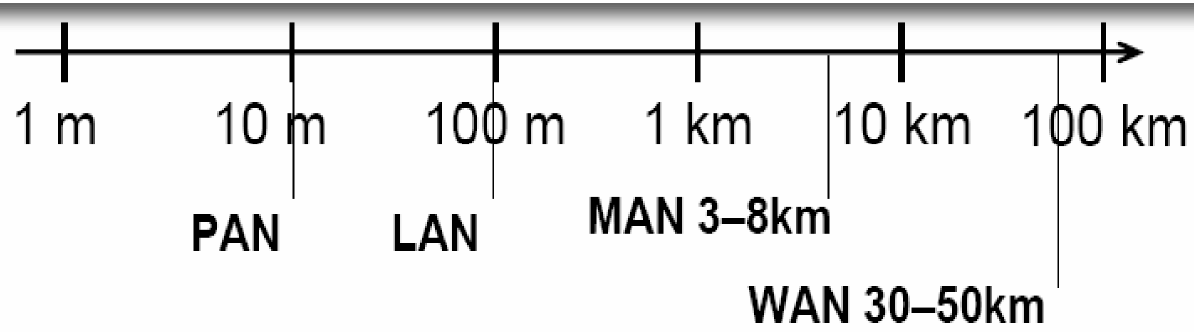
The Wireless Link: Channel Models

- Environmental conditions effect the qualities of a wireless link depending on:
  - frequency and bandwidth
  - terrain or urban "clutter"
    - shadowing
    - fading (multipath interference)
    - ambient noise
  - distance and transmit power
  - relative speed of transmitter and receiver
  - antenna type and properties
    - gain
    - diversity and array
    - directionality

IEEE 802 family Wireless Networks



Cellular / IEEE 802 family Convergence



PAN	LAN	MAN	WAN
802.15 Bluetooth	802.11 WLAN	802.16a,d WiMAX	2.5G/3G 802.16e
		2.5G/3G 802.16e 802.20 >1Mbps	

IEEE 802.11 Family:

802.11 is a family of specifications for wireless local area networks (WLANs) developed by a working group of the Institute of Electrical and Electronics Engineers (IEEE).**There are currently four specifications in the family. 802.11e and 802.11i are scheduled for approval.**

802.11
802.11a
802.11b
802.11g

All four use the Ethernet protocol and CSMA/CA (carrier sense multiple access with collision avoidance) for path sharing.

IEEE 802.11 - applies to wireless LANs and provides 1 or 2 Mbps transmission in the 2.4 GHz band using either frequency hopping spread spectrum (FHSS) or direct sequence spread spectrum (DSSS).

IEEE 802.11a - an extension to 802.11 that applies to wireless LANs and provides up to 54 Mbps in the 5GHz band; but most commonly, communications takes place at 6 Mbps, 12 Mbps, or 24 Mbps. 802.11a uses an orthogonal frequency division multiplexing encoding scheme rather than FHSS or DSSS. The specification applies to wireless ATM systems and is used in access hubs.

IEEE 802.11b - often called Wi-Fi - is backward compatible with 802.11. The modulation used in 802.11 has historically been phase-shift keying (PSK). The modulation method selected for 802.11b is known as complementary code keying (CCK), which allows higher data speeds and is less susceptible to multipath-propagation interference.

IEEE 802.11e - first wireless standard that spans home and business environments. It adds quality-of-service (QoS) features and multimedia support to the existing IEEE 802.11b and IEEE 802.11a wireless standards, while maintaining full backward compatibility with these standards. QoS and multimedia support are critical to wireless home networks where voice, video and audio will be delivered.

IEEE 802.11g - applies to wireless LANs and provides 20+ Mbps in the 2.4 GHz band.
This is the most recently approved standard and offers wireless transmission over relatively short distances at up to 54 megabits per second (Mbps) compared with the 11 megabits per second of the 802.11b standard. Like 802.11b, 802.11g operates in the 2.4 GHz range and is thus compatible with it.

IEEE 802.11i - adds the Advanced Encryption Standard (AES) security protocol to the 802.11 standard for wireless LANs. Security has been a primary concern for IT managers reluctant to deploy wireless networks, but AES is a stronger level of security than found in the current Wi-Fi Protected Access security standard.

IEEE 802.15

is a communications specification that was approved in early 2002 by the Institute of Electrical and Electronics Engineers Standards Association (IEEE-SA) for wireless personal area networks (WPANs). The initial version, 802.15.1, was adapted from the Bluetooth specification and is fully compatible with Bluetooth 1.1.

IEEE 802.16

802.16 is a group of broadband wireless communications standards for metropolitan area networks (MANs) developed by a working group of the Institute of Electrical and Electronics Engineers (IEEE). The original 802.16 standard, published in December 2001, specified fixed point-to-multipoint broadband wireless systems operating in the 10-66 GHz licensed spectrum. An amendment, 802.16a, approved in January 2003, specified non-line-of-sight extensions in the 2-11 GHz spectrum, delivering up to 70 Mbps at distances up to 31 miles. Officially called the WirelessMAN™ specification, 802.16 standards are expected to enable multimedia applications with wireless connection and, with a range of up to 30 miles, provide a viable last mile technology.

Wireless Communications System Definitions	
Base Station	A fixed station in a mobile radio system used for radio communication with mobile stations. Base stations are located at the center or on the edge of a coverage region and consist of radio channels and transmitter and receiver antennas mounted on a tower.
Control	Radio channel used for transmission of call setup, call request, call initiation,
Forward Channel	Radio channel used for transmission of information from the base station to the mobile.
Full Duplex Systems	Communication systems which allow simultaneous two-way communication. Transmission and reception is typically on two different channels (FDD) although new cordless/PCS systems are using TDD.
Half Duplex Systems	Communication systems which allow two-way communication by using the same radio channel for both transmission and reception. At any given time, the user can only either transmit or receive information.
Handoff	The process of transferring a mobile station from one channel or base station to another.
Mobile Station	A station in the cellular radio service intended for use while in motion at unspecified locations. Mobile stations may be hand-held personal units (portables) or installed in vehicles (mobiles).

Mobile Switching Center	Switching center which coordinates the routing of calls in a large service area. In a cellular radio system, the MSC connects the cellular base stations and the mobiles to the PSTN. An MSC is also called a mobile telephone switching office (MTSO).
Page	A brief message which is broadcast over the entire service area, usually in a simulcast fashion by many base stations at the same time.
Reverse Channel	Radio channel used for transmission of information from the mobile to base station.
Roamer	A mobile station which operates in a service area (market) other than that from which service has been subscribed.
Simplex Systems	Communication systems which provide only one-way communication.
Subscriber	A user who pays subscription charges for using a mobile communications system.
Transceiver	A device capable of simultaneously transmitting and receiving radio signals.

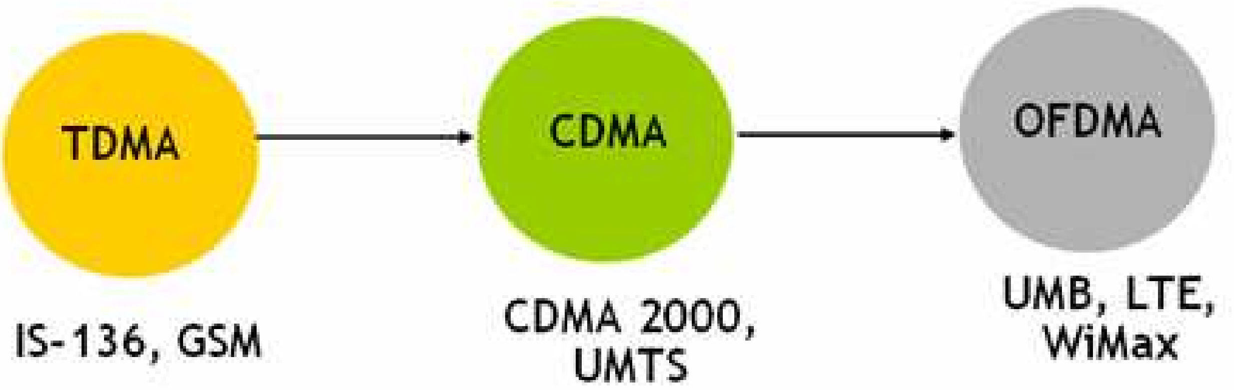
- Mobile radio transmission systems may be classified as simplex, half-duplex or full-duplex.
- In simplex systems, communication is possible in only one direction. Paging systems, in which messages are received but not acknowledged, are simplex systems.
- Half-duplex radio systems allow two-way communication, but use the same radio channel for both transmission and reception. This means that at any given time, a user can only transmit or receive information. Constraints like "push-to-talk" and "release-to-listen" are fundamental features of half-duplex systems.

- Full duplex systems, allow simultaneous radio transmission and reception between a subscriber and a base station, by providing two simultaneous but separate channels (frequency division duplex, or FDD) or adjacent time slots on a single radio channel (time division duplex, or TDD) for communication to and from the user.
- FDD is used exclusively in analog mobile radio systems

- Frequency division duplexing (FDD) provides simultaneous radio transmission channels for the subscriber and the base station, so that they both may constantly transmit while simultaneously receiving signals from one another.
- At the base station, separate transmit and receive antennas are used to accommodate the two separate channels. At the subscriber unit, however, a single antenna is used for both transmission to and reception from the base station, and a device called a duplexer is used inside the subscriber unit to enable the same antenna to be used for simultaneous transmission and reception.
- To facilitate FDD, it is necessary to separate the transmit and receive frequencies by about 5% of the nominal RF frequency, so that the duplexer can provide sufficient isolation while being inexpensively manufactured.

- Time division duplexing (TDD) uses the fact that it is possible to share a single radio channel in time, so that a portion of the time is used to transmit from the base station to the mobile, and the remaining time is used to transmit from the mobile to the base station.
- TDD is only possible with digital transmission formats and digital modulation, and is very sensitive to timing.

Cellular Technology Evolution



Next-Generation Devices

Everything Wireless in One Device

Multiradio Integration Challenges

- RF Interference
- Where to put antennas
- Size
- Power Consumption