UNIT 5
RADIO PROPAGATION AND MULTIPLE ACCESS SCHEME

PROF. THUSHARA WEERAWARDANE

Outcomes

- Explain Frequency Propagation Models
- Differentiate Ground wave, Sky wave and Space wave propagations
- Illustrate the Electromagnetic Spectrum and its Applications
- Recognize Duplex Modes
- Application of Multiple Access Schemes

Unit Outlines

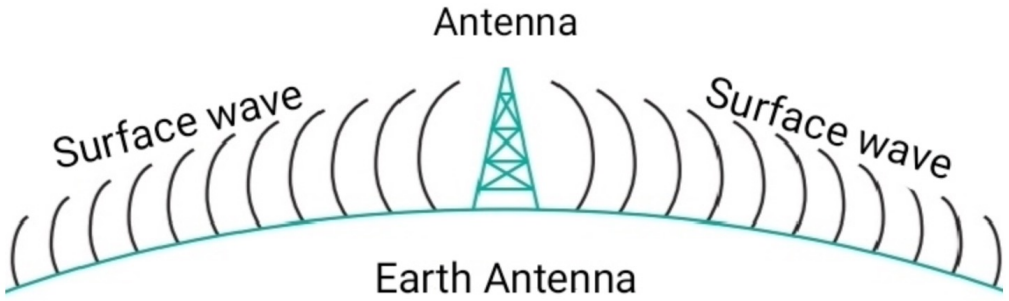
- Frequency Propagation Models
- Ground wave, Sky wave and Space wave propagations
- Electromagnetic Spectrum and its Applications
- Duplex Modes and Multiple Access Schemes

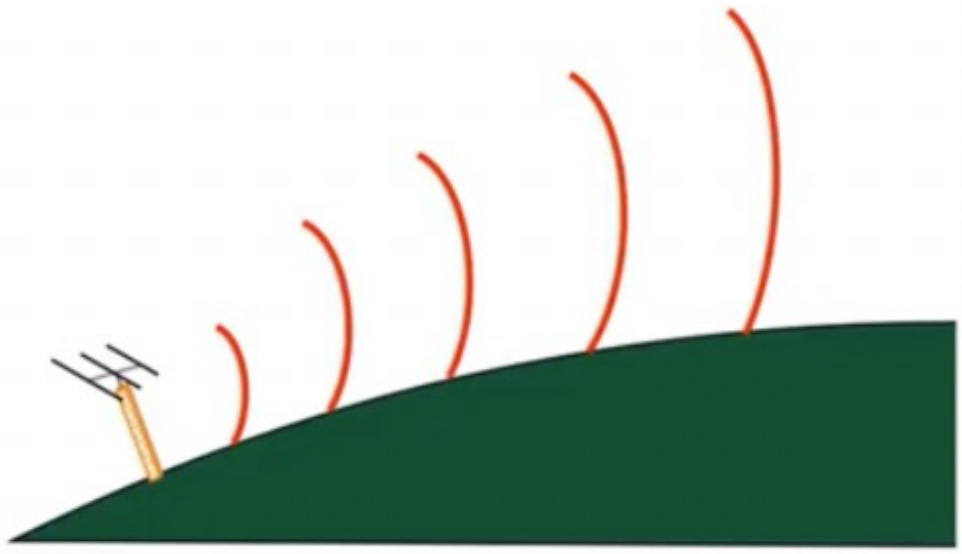
Wave Propagation Models

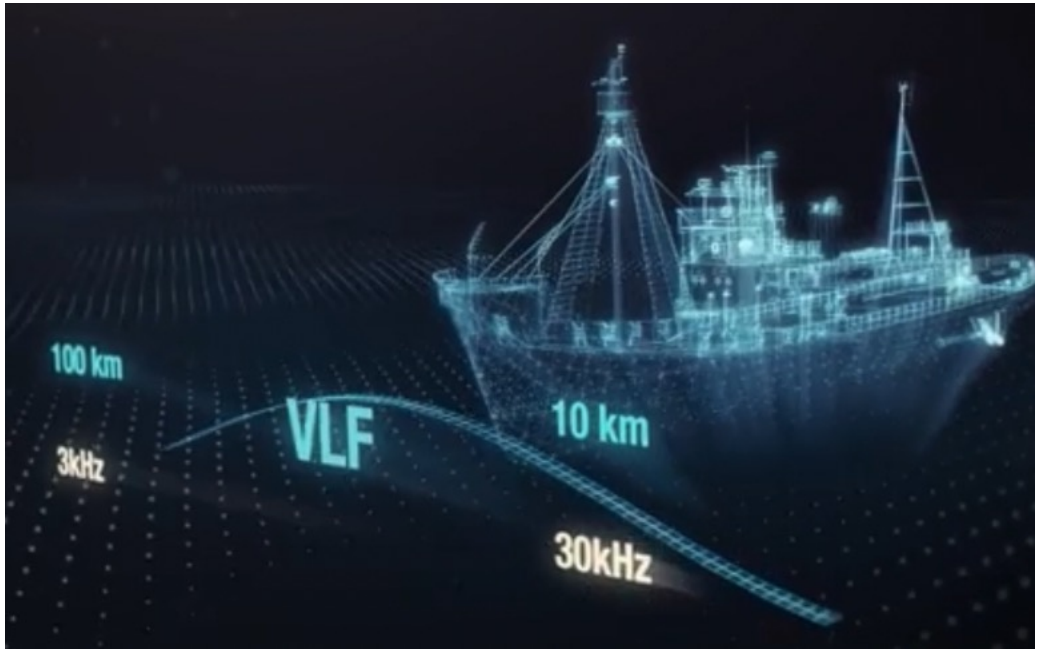
- Ground Wave Propagation
- Sky Wave
- Space wave
  - Terrestrial Communication and Satellite Communication

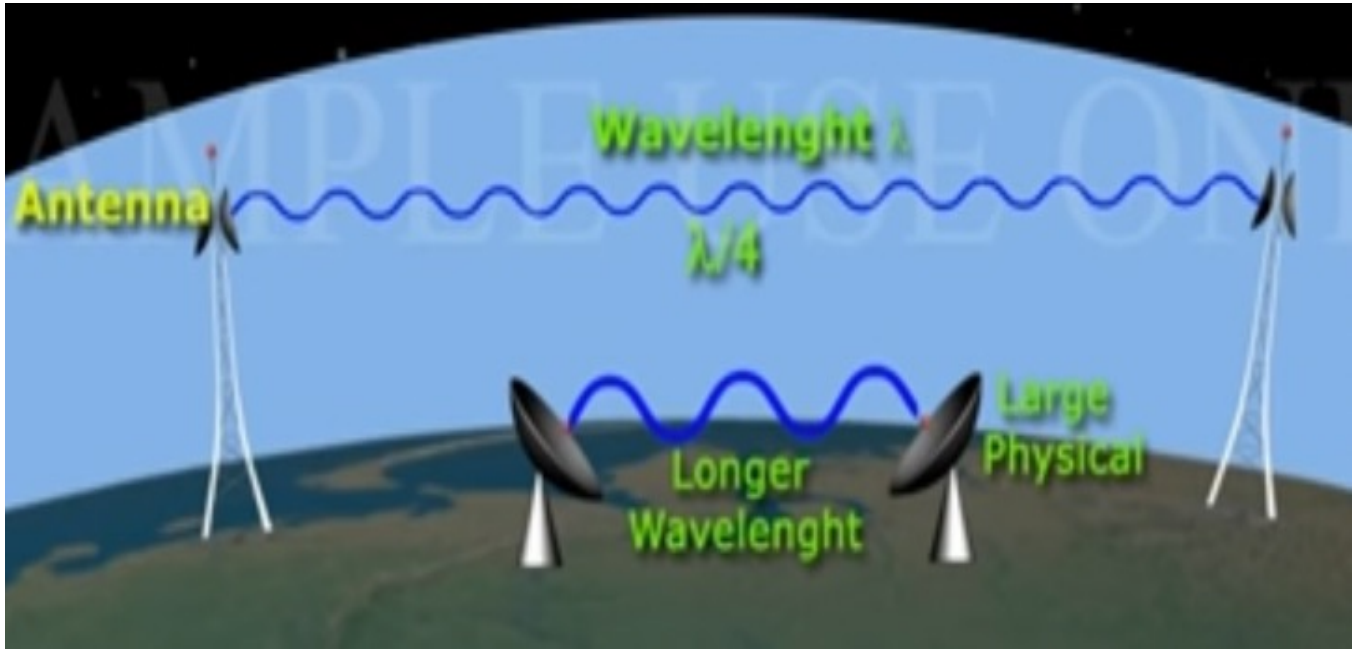
Ground wave Propagation (VLF and LF)

- Signals propagate along the Earth's surface (the wave follows the contour of earth)
- Frequency Ranges: 50 kHz – 250 kHz
  - VLF: 3kHz – 30 kHz
  - LF: 30 kHz – 300 kHz
- Propagation highly dependent on
  - Surface conductivity
  - Frequency
- Higher surface conductivity (eg. Salt water) yields better results (greater distances)
  - Good for ship-to-ship or ship-to-shore





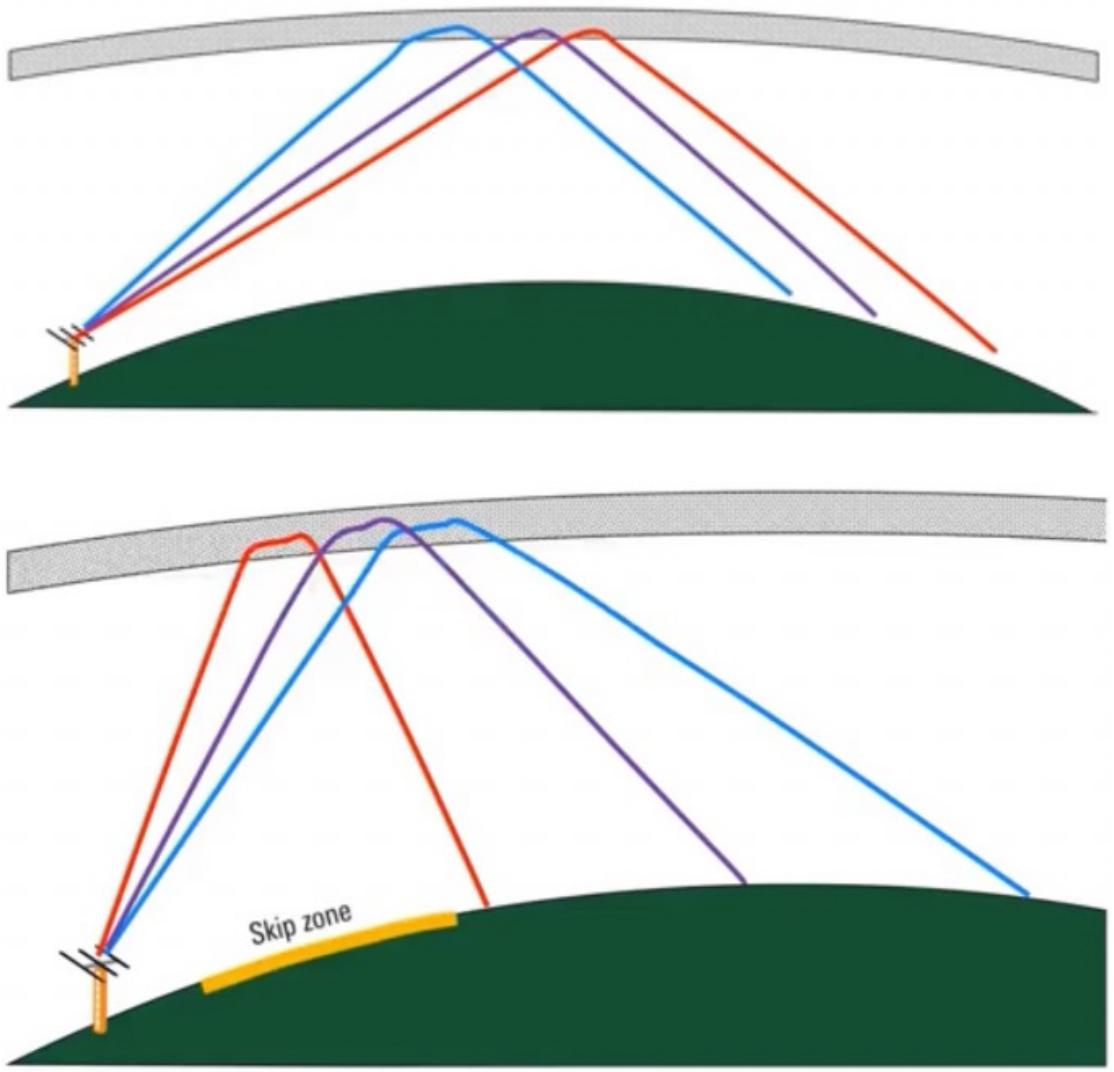


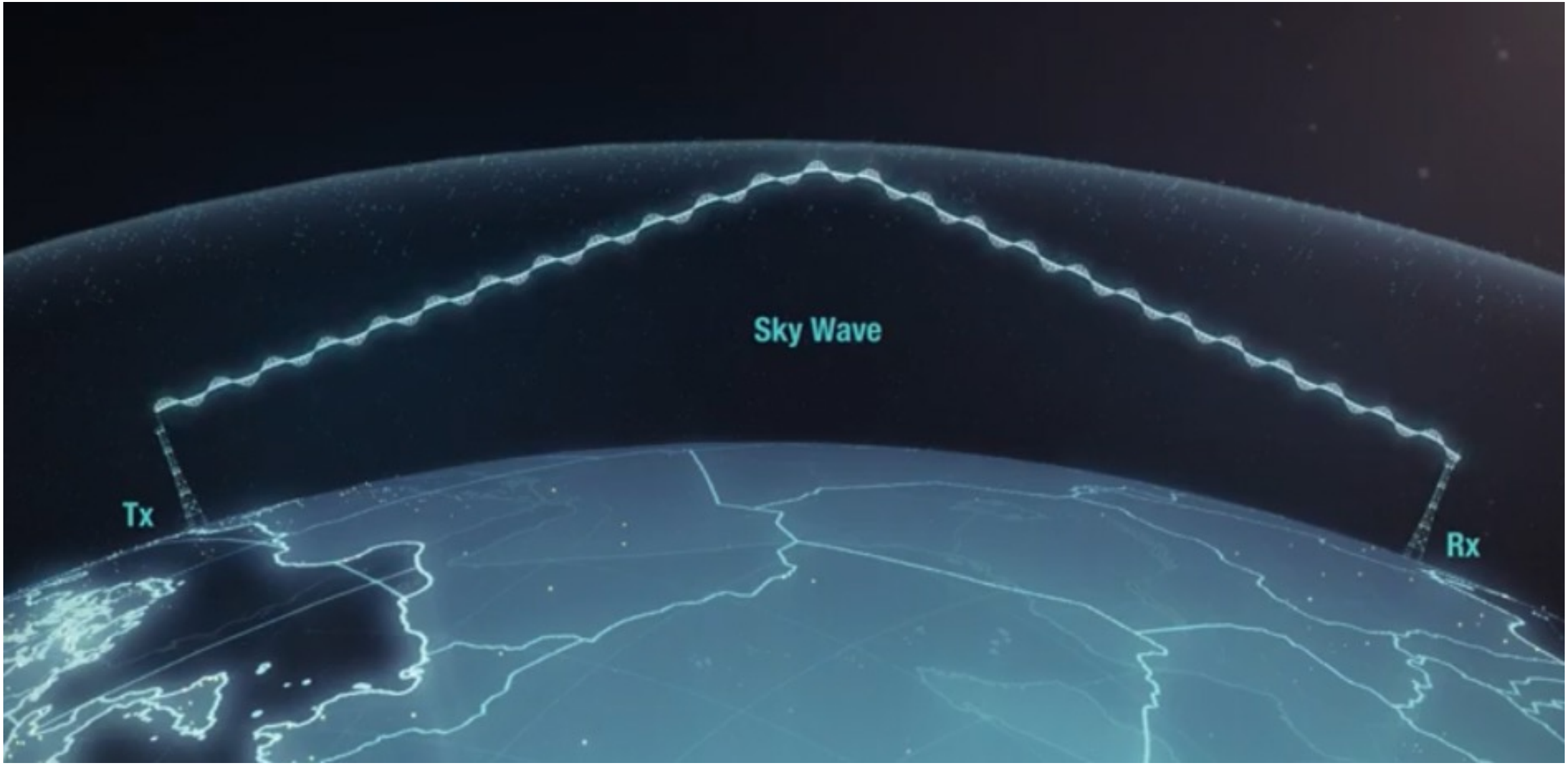


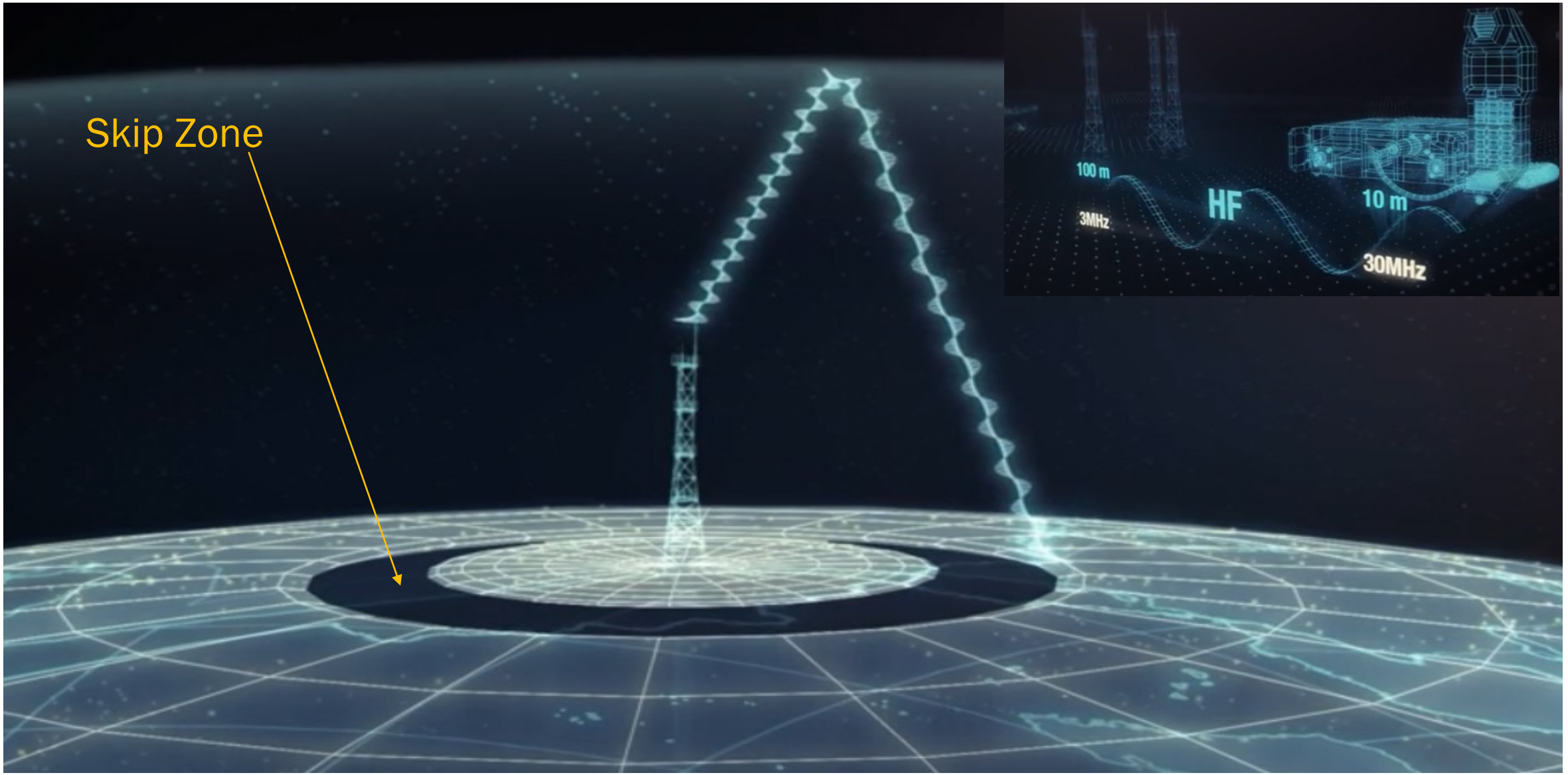
Groundwave: VLF, LF MF

Sky wave Propagation

- Enables beyond line of sight (BLOS) communications
- Frequency Range: 5MHz – 25 MHz,
  - High frequency Range: 3 MHz – 30 MHz
- Signals are refracted by layers of ionized particles in the atmosphere
- Skywave propagation is function of the state of the ionosphere
- Incident angle affects the range achievable (depends on Antenna types and installation)
  - Lower incident angles yield greater distances
  - In a “Skip Zone” signals cannot be received

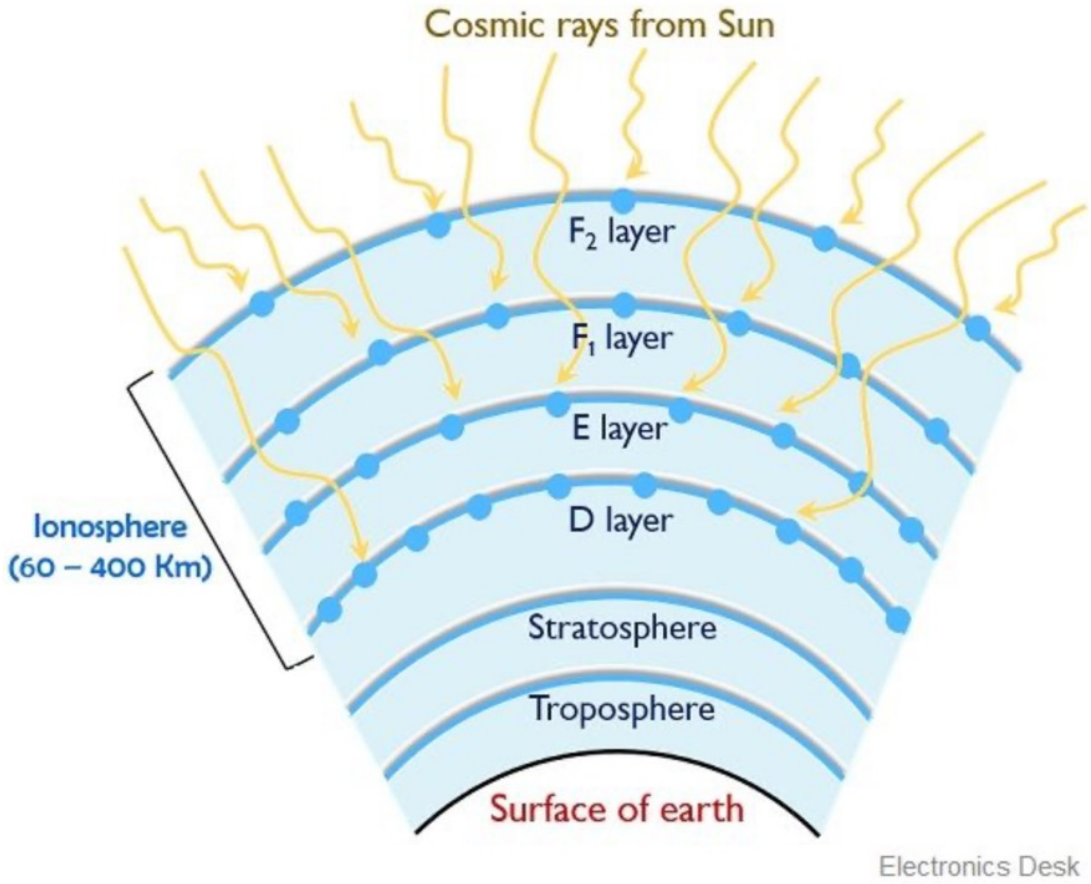



Sky Wave
Tx
Rx


Skip Zone
100 m
3MHz
HF
10 m
30MHz

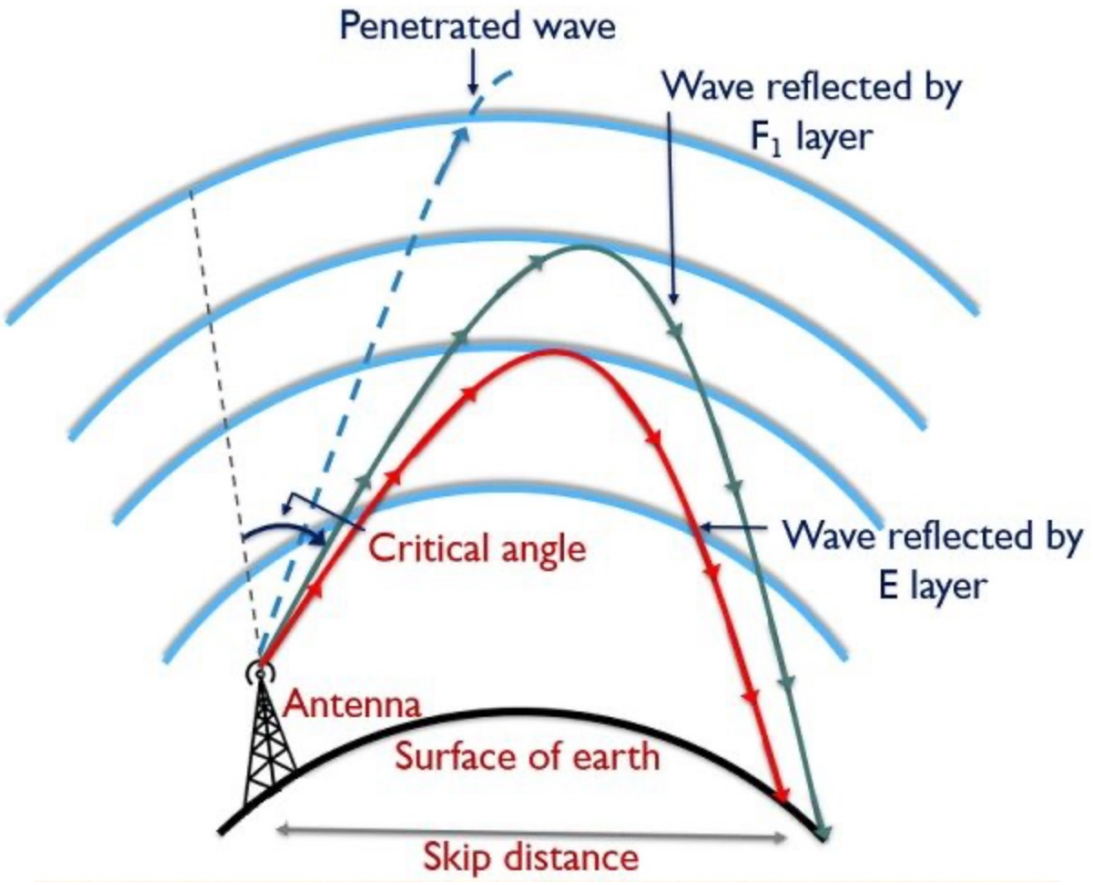
About the Ionosphere and Ionization

- The ionized region of the earth's atmosphere is called ionosphere
  - Powerful cosmic rays penetrates the inner layers of ionosphere
  - Inner layers denser than the outer layers of ionosphere (less number of atoms of the outer layer)
  - Moreover, this interaction between cosmic rays and the atoms increases tremendously in the E layer of the ionosphere, as this layer has a greater number of atoms.
  - But on penetrating to such a level inside the earth's atmosphere, the intensity of the cosmic rays reduces to a large extent.
  - Hence very few cosmic rays interact with the innermost layer of the ionosphere although this layer is denser than other layers. This is clearly shown in the figure given.



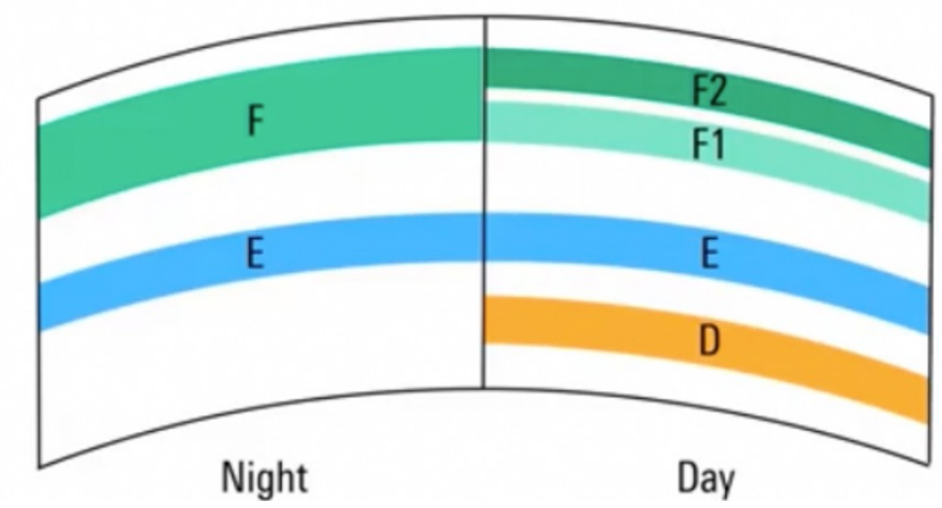
Total internal reflection at the Ionosphere

- When cosmic rays interact with the atoms present in the ionospheric layers then electrons are emitted from the valence shell of the atom. Thus, ionization takes place.
- The interaction is higher in the case of middle layers of the atmosphere hence, ionization will be higher in middle layer itself.
- EMF waves interact with charged partials and leads to Total internal reflections for lower frequencies



Ionosphere Layers and Ionizations

- The low-frequency wave is reflected by the lower layer and the high-frequency wave is reflected by the upper layer. But beyond a certain permissible frequency (generally 30 MHz) the wave despite getting reflected penetrates the atmospheric region and is lost
- Peaks in ionization levels are called layers or regions
  - D Layer (60 – 100km)
  - E Layer (100 – 125 km)
  - F Layer (200 – 350 km)
- These differently-ionized layers refract and / or absorb HF signals in different ways



Summary of wave propagation in Ionosphere

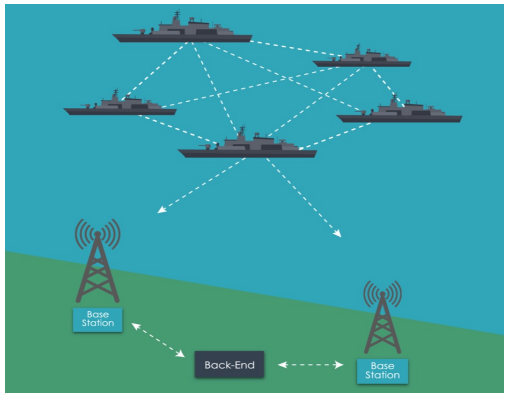
Name of the stratum (Layers)	Approximate height over earth's surface	Exist During	Frequencies most effected
Troposphere	10 km	Day and night	VHF (up to several GHz)
D Layer	65 – 85 km	Day only	Reflect LF, Absorb MF and HF to some degree
E Layer	100 – 125 km	Day only	Help Surface wave, reflect HF
F1 Layer	175 – 200 km	Day time. merge with F2 at night	Partially absorb HF waves yet allowing them to reach F2
F2 Layer	300 km at night, 250-350km Day time	Day and Night	Efficiently reflect HF waves, particular at Night

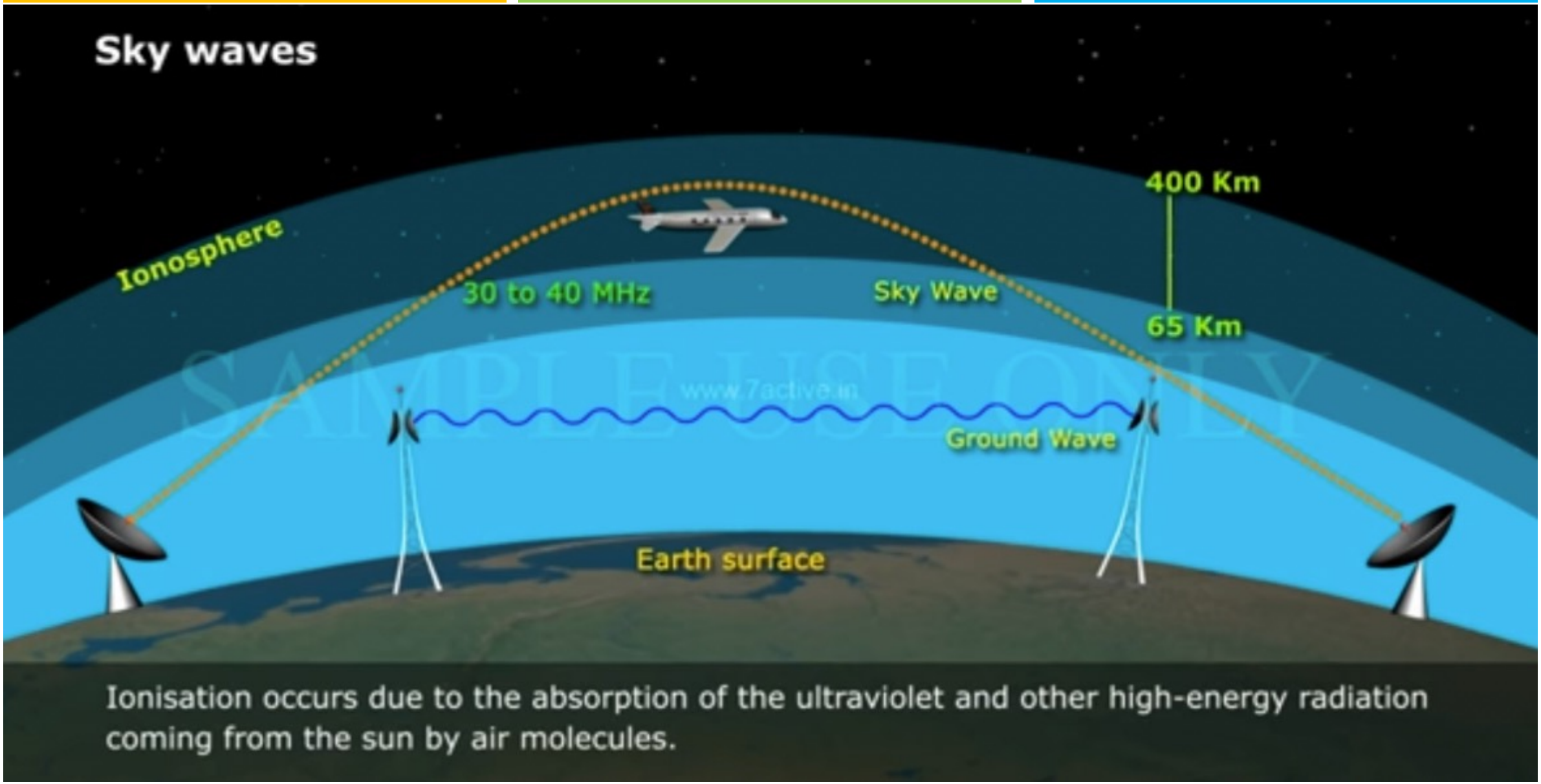
High Frequency (HF)

- High Frequency – HF
  - Frequency Range: 3 MHz to 30 MHz
  - Wavelength: 100 – 10 meters
  - Some time referred to as “SHORTWAVE”
- Primary use is Long-Range Communications
  - Broadcasters
  - Government and Military uses
  - Amateur Radio communication
- HF enables long range and global communication

HF Radio

VOICE OF AMERICA

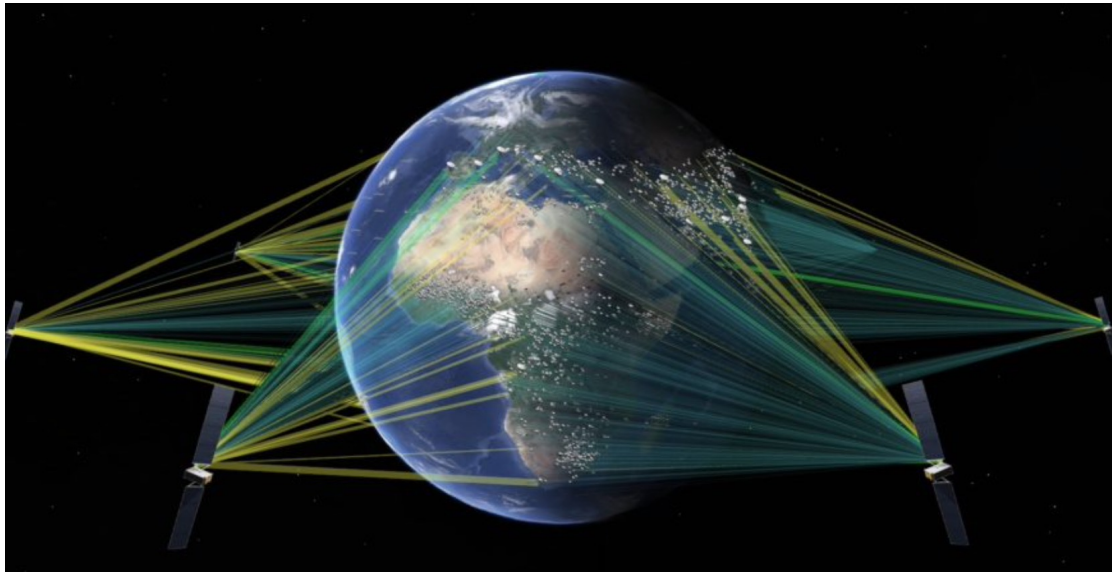


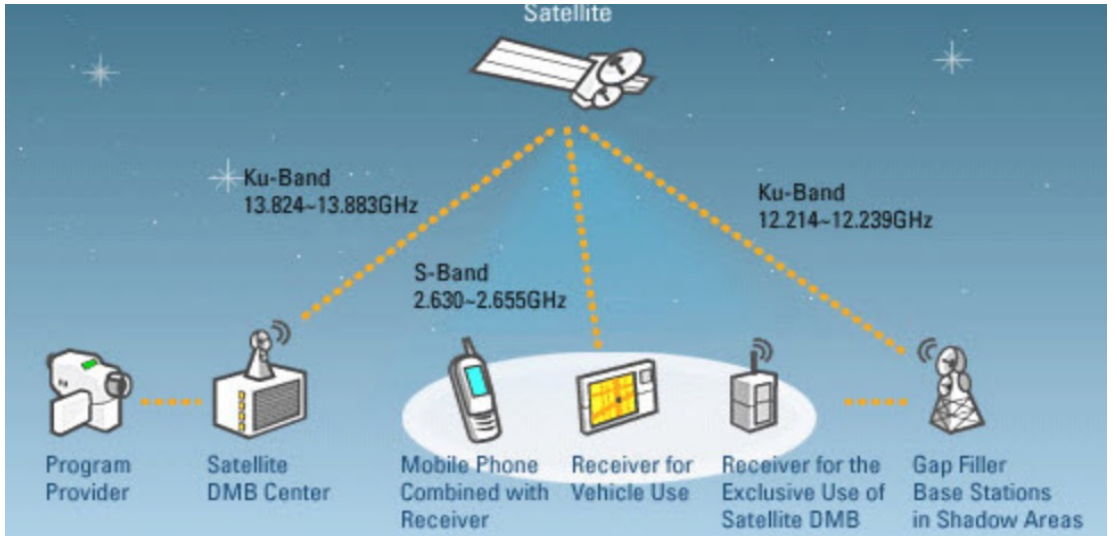

Sky waves
Ionosphere
30 to 40 MHz
Sky Wave
400 Km
65 Km
Ground Wave
Earth surface
Ionisation occurs due to the absorption of the ultraviolet and other high-energy radiation coming from the sun by air molecules.

Space communication

- The ionosphere reflects radio waves with frequencies below 30 MHz, so higher frequencies are needed for space communication. There are two types
  - Line of sight communication
  - Satellite communication

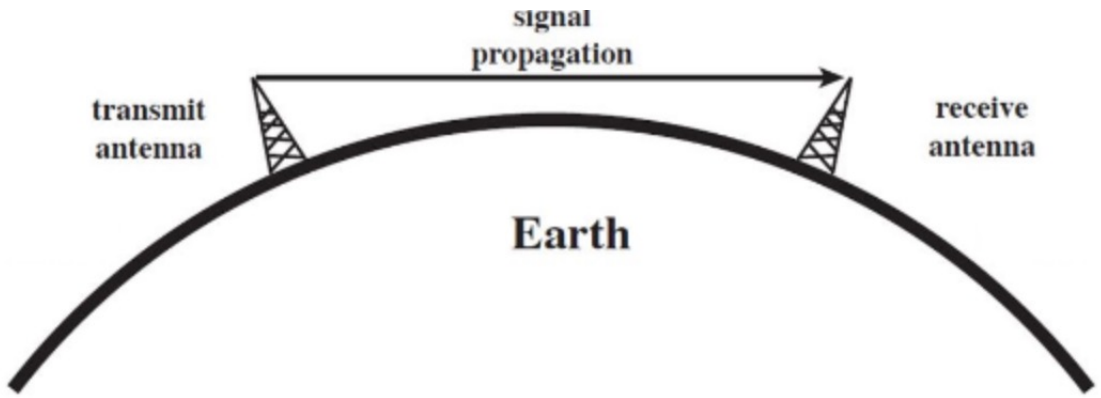
- audio waves with frequencies above 30 GHz are easily absorbed and scattered by rain, dust and other atmospheric effects reducing signal strength.

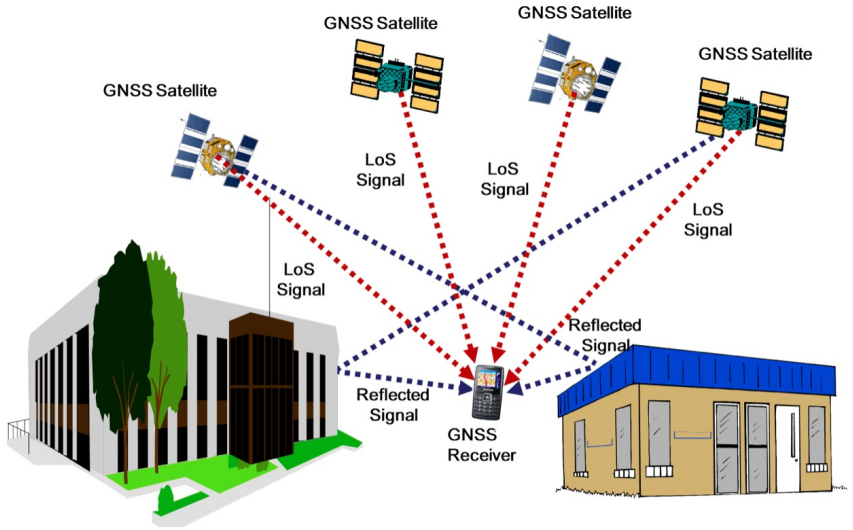


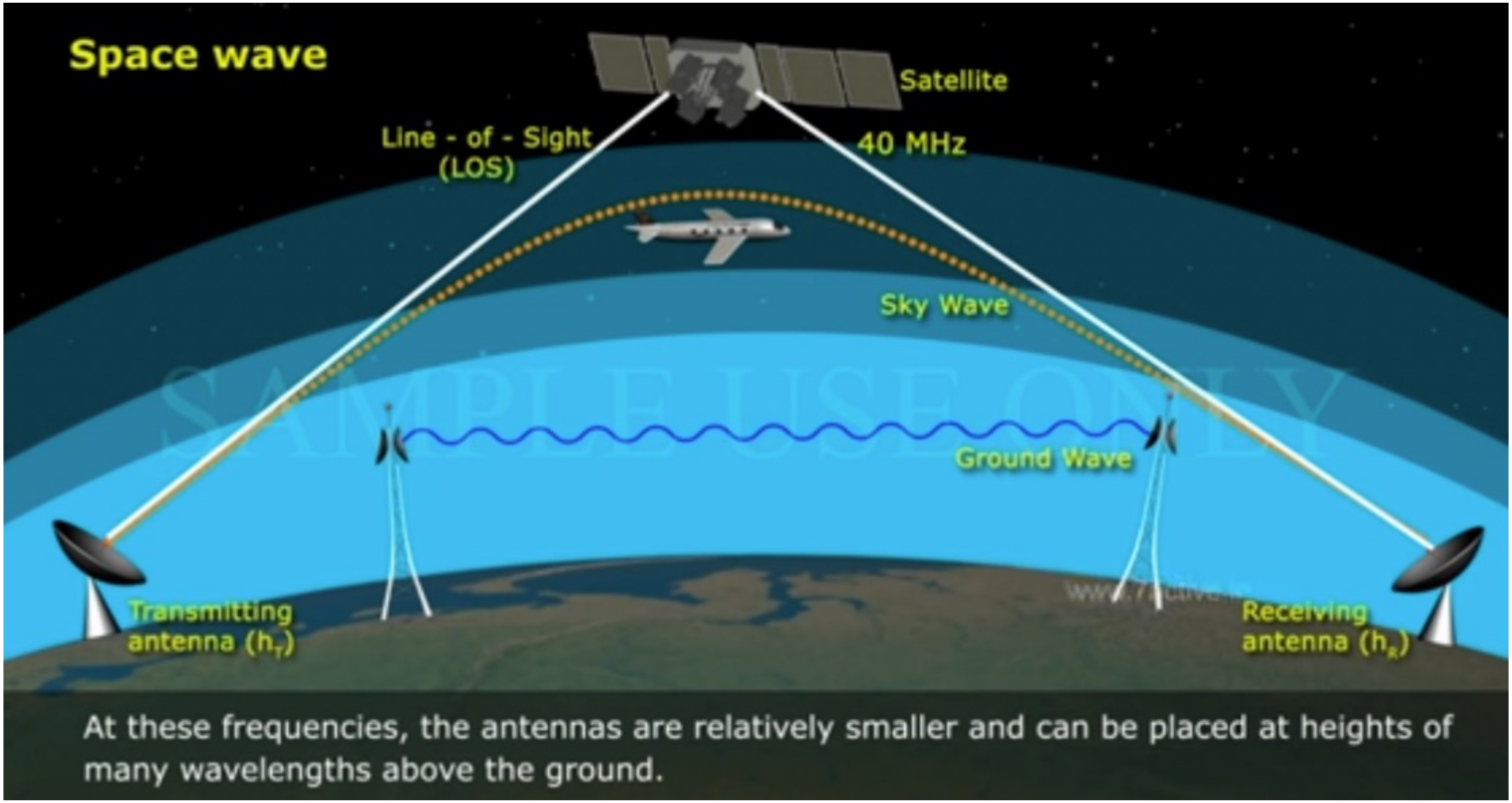


Line of sight

- Signal Propagate in a straight line between transmitter and receiver
- LOS propagation is fairly consistent
- HF is often not a good choice for line-of-sight communications
  - Large Antenna
  - Limited BW
  - Higher Noise
- As the signal can travel only to lesser distances in this mode, this transmission is used mostly for infrared or microwave transmissions.

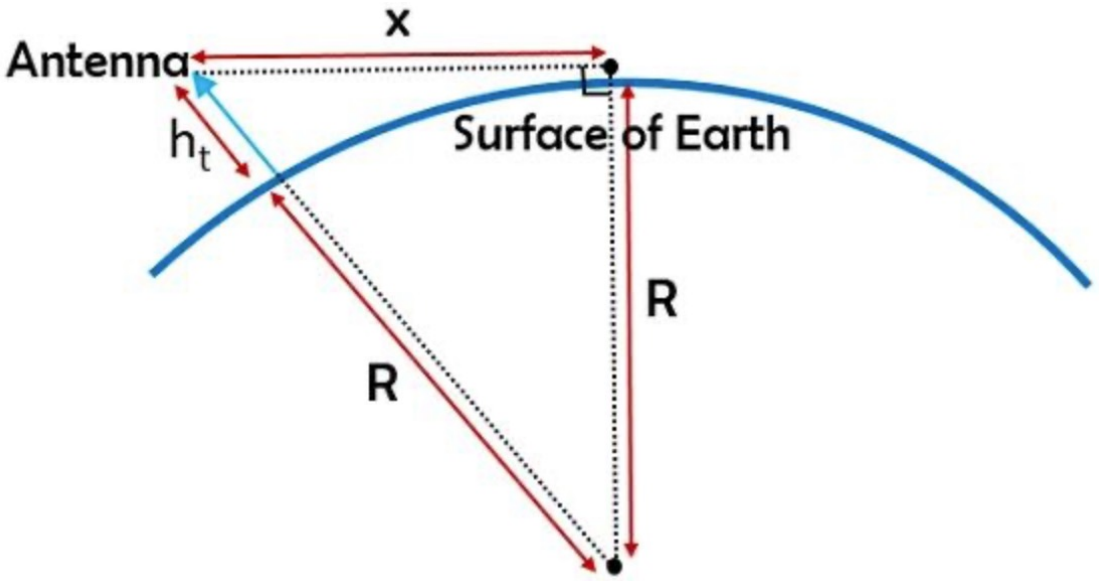


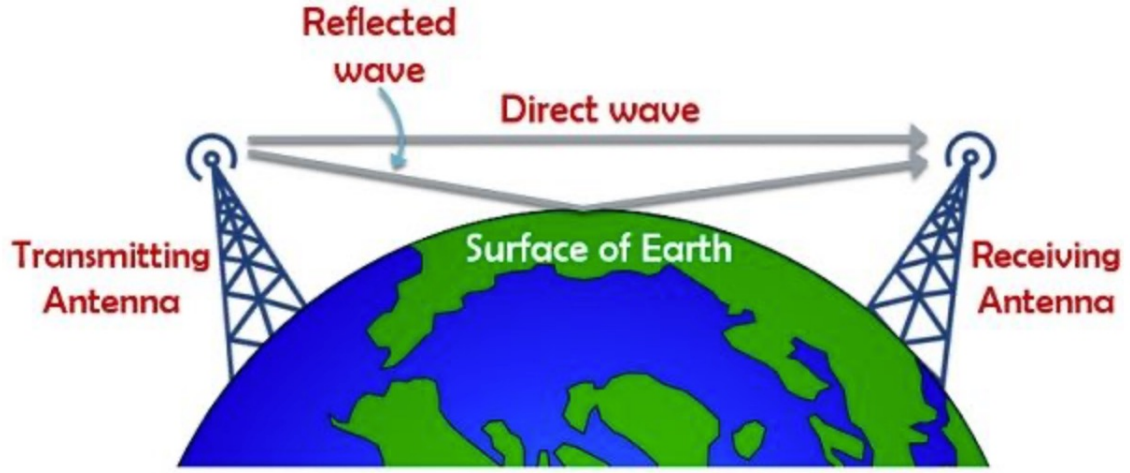



Space wave
Satellite
Line - of - Sight
(LOS)
40 MHz
Sky Wave
Ground Wave
Transmitting
antenna (h_T)
Receiving
antenna (h_R)
At these frequencies, the antennas are relatively smaller and can be placed at heights of
many wavelengths above the ground.

LINE OF SIGHT (LOS) COMMUNICATION: RANGE DETECTION

- The basic relationship between f and λ is given as: $f = \frac{C}{\lambda}$
- Let us first consider a single transmitting antenna having height h_t, propagating the signal up to a certain range on the ground.
- Suppose x specifies the range between the transmitting antennas and the center of the earth at the curvature where the signal is getting received and R is the radius of curvature of the earth.





Range Detection

- Consider the Triangle

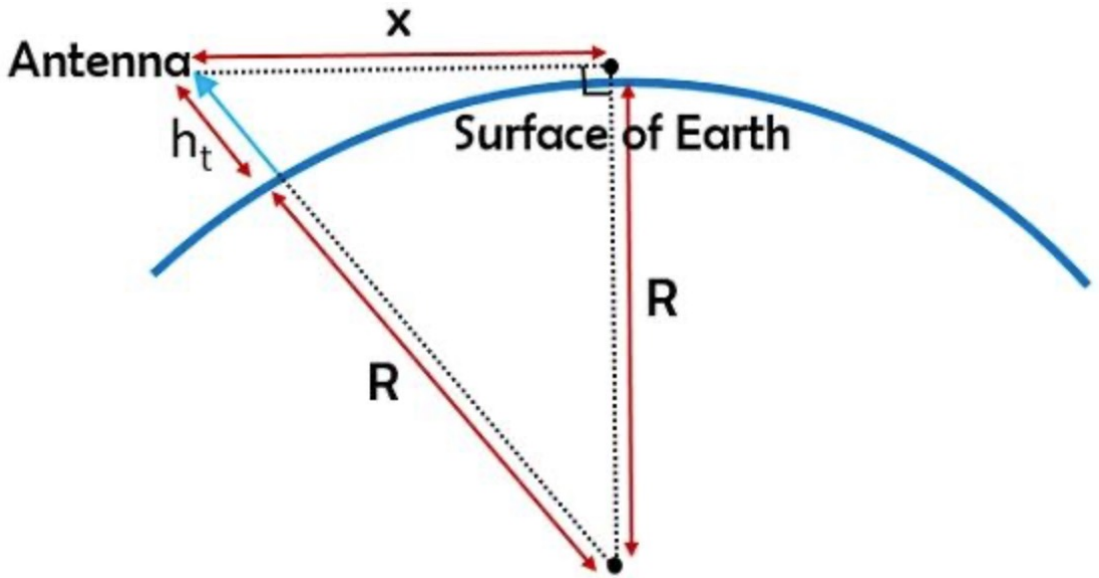
$$(R + h_t)^2 = R^2 + x^2$$

$$R^2 + 2Rh_t + h_t^2 = R^2 + x^2$$

h_t^2 can be neglected

$$x = \sqrt{2h_tR}$$

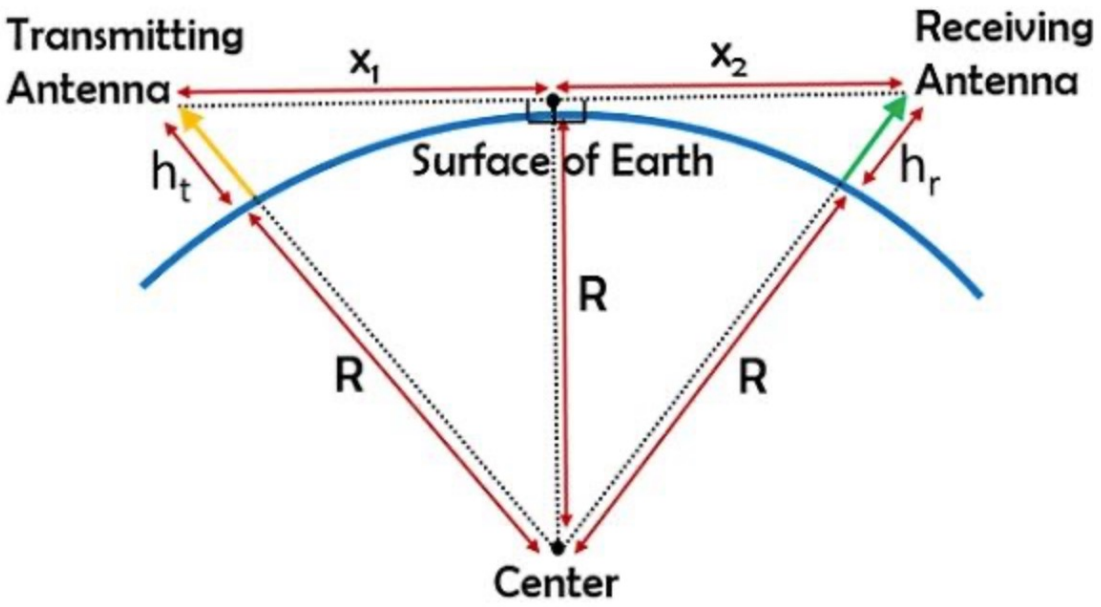
$$h_t = \frac{x^2}{2R}$$



the range of signal transmission shows dependency on the height of the antenna which is transmitting the signal.

Range and Area Detection

- Suppose the transmitted signal must be received by another antenna on the ground. So, the question arises what must be the height of the receiving antenna in order to have LOS communication
- Here two antennas are placed on the surface of the earth. Let the height of transmitting and receiving antennas be h_t and h_r respectively. Also, the range from a common point on the curvature to transmitting and receiving antenna is x_t and x_r. Then individually we will have:



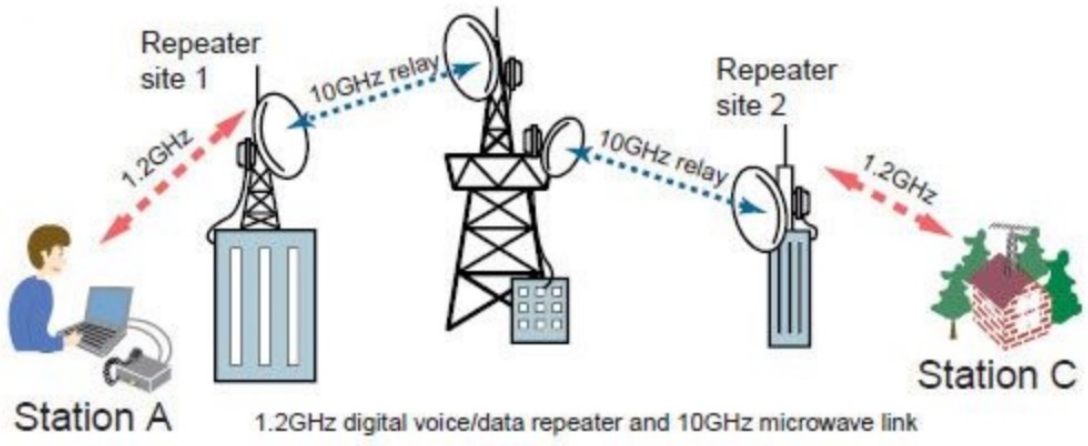
$$x_1 + x_2 = \sqrt{2h_tR} + \sqrt{2h_rR}$$

$$Area = \pi r^2 = \pi\, 2h_t\mathrm{R}$$

As we can see that the area and height of the antenna are directly proportional to each other. Thus higher the height of the antenna, the greater will be the area covered by it.

Terrestrial Microwaves

- Used to broadcast wireless signal across a short distance
- Transmitter is parabolic dish mounted on height to get best line of sight connection
- Frequency range: The frequency range of terrestrial microwave is from 4-6 GHz to 21-23 GHz.
- Microwaves cannot bend or pass through building or hills
- Repeater is used at the distance of 25-30 km between transmitter station and receiver station
- Used in both Audio and Television transmissions



- Bandwidth: It supports the bandwidth from 1 to 10 Mbps.
- Short distance: It is inexpensive for short distance.
- Long distance: It is expensive as it requires a higher tower for a longer distance.
- Attenuation: Attenuation means loss of signal. It is affected by environmental conditions and antenna size.

Advantages and disadvantages

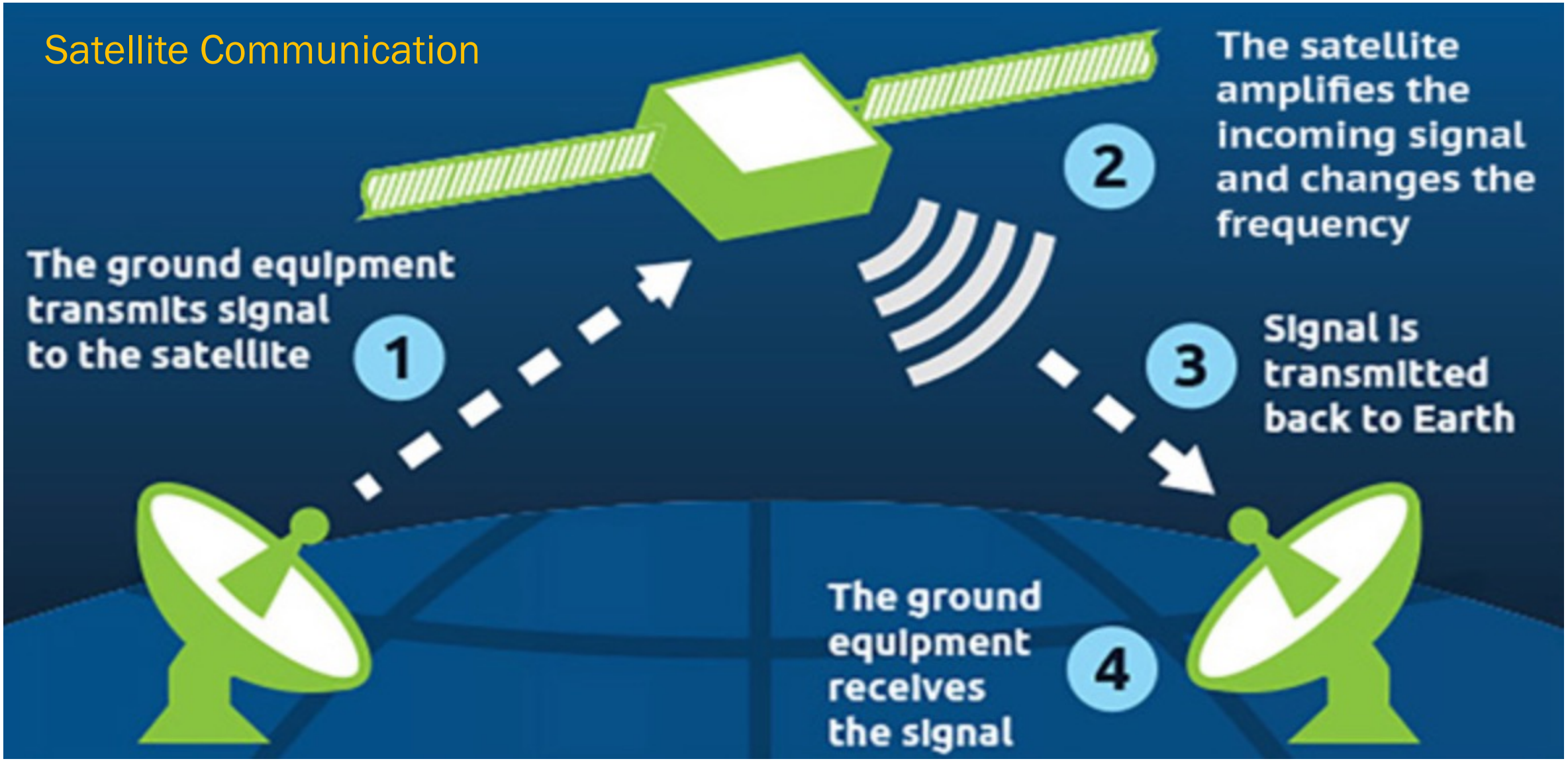
Advantages Of Microwave:

- Microwave transmission is cheaper than using cables.
- It is free from land acquisition as it does not require any land for the installation of cables.
- Microwave transmission provides an easy communication in terrains as the installation of cable in terrain is quite a difficult task.
- Communication over oceans can be achieved by using microwave transmission.

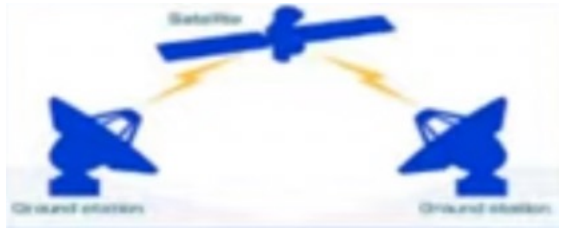
Disadvantages of Microwave transmission:

- Eavesdropping: An eavesdropping creates insecure communication. Any malicious user can catch the signal in the air by using its own antenna.
- Out of phase signal: A signal can be moved out of phase by using microwave transmission.
- Susceptible to weather condition: A microwave transmission is susceptible to weather condition. This means that any environmental change such as rain, wind can distort the signal.
- Bandwidth limited: Allocation of bandwidth is limited in the case of microwave transmission.

Satellite Communication



Satellite Microwaves



- Transponders that are set in orbit directly over the equator
- Microwave relays station placed in space
- We can communicate with any point on the globe by using satellite communication
- Satellite dishes are used to send the signal to the satellite where it is send back down to the receiver satellite. Satellite amplifies the signal
- Uplink: Data from earth to satellite, whereas downlink data sent satellite to ground station
- Satellite is the technological revolution of data communication for television broadcasting, long distance telephone communication and private commercial networks

Satellite Microwaves

Advantages

- The coverage area of a satellite microwave is more than the terrestrial microwave.
- The transmission cost of the satellite is independent of the distance from the centre of the coverage area.
- Satellite communication is used in mobile and wireless communication applications.
- It is easy to install.
- It is used in a wide variety of applications such as weather forecasting, radio/TV signal broadcasting, mobile communication, etc.

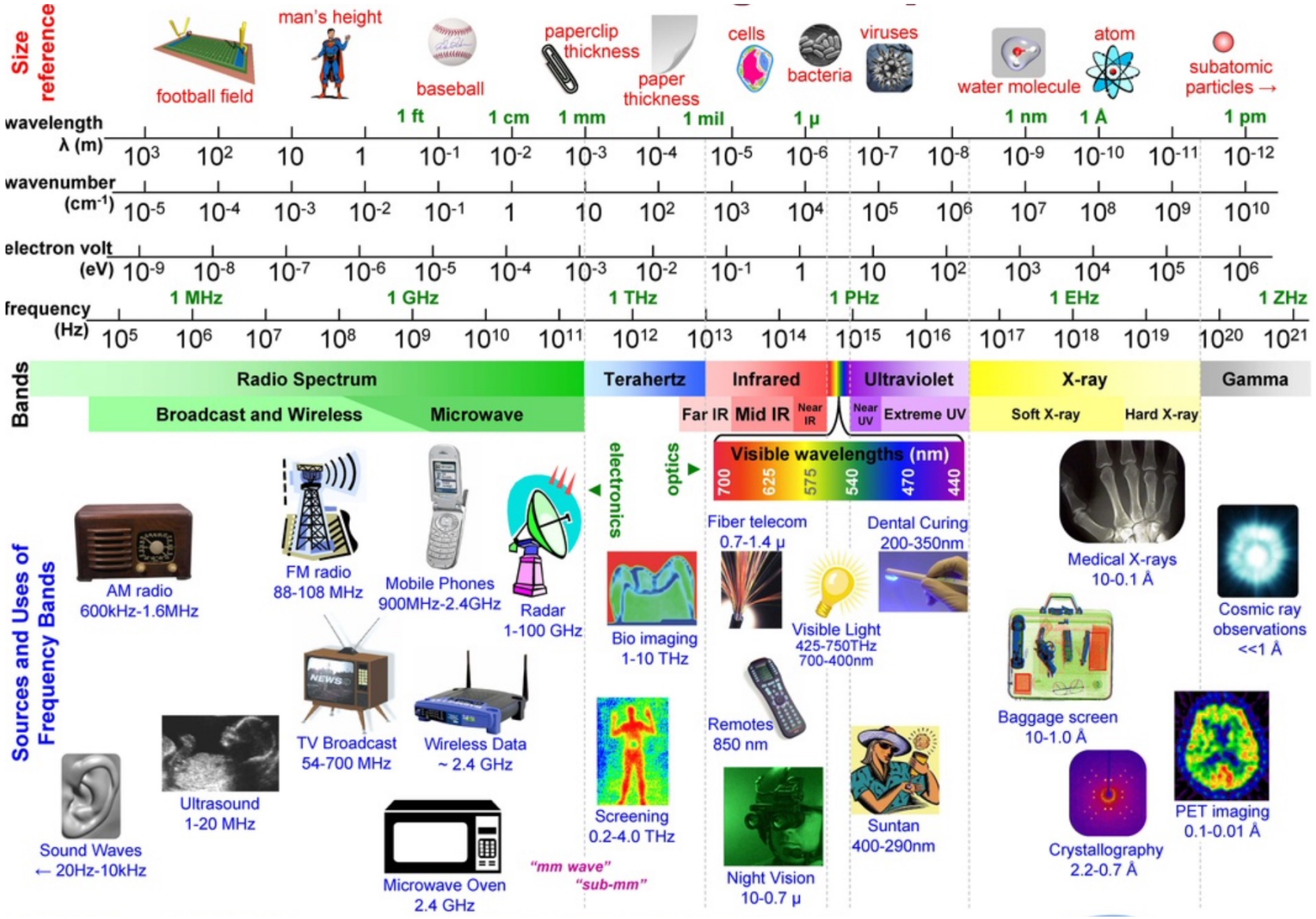
Disadvantages

- Satellite designing and development requires more time and higher cost.
- The Satellite needs to be monitored and controlled on regular periods so that it remains in orbit.
- The life of the satellite is about 12-15 years. Due to this reason, another launch of the satellite has to be planned before it becomes non-functional.

Radio Communication Frequencies and their applications

Band name	Abbreviation	Frequency	Uses
Tremendously-low frequency	TLF	<3Hz	Natural and artificial electromagnetic noise
Extremely-low frequency	ELF	3Hz to 30Hz	Communication with submarines
Super-low frequency	SLF	30Hz to 300Hz	Communication with submarines
Ultra-low frequency	ULF	300Hz to 3000Hz	Communication with submarines and within mines
Very-low frequency	VLF	3kHz to 30kHz	Navigation, time signals, submarine communication, wireless heart rate monitors, geophysics
Low frequency	LF	30kHz to 300kHz	Navigation, clock time signals, AM long-wave broadcasting (Europe and parts of Asia), RFID, amateur radio
Medium frequency	MF	300kHz to 3000kHz	AM (medium-wave) broadcasts, amateur radio, avalanche beacons
High frequency	HF	3MHz to 30MHz	Shortwave broadcasts, citizens' band radio, amateur radio and over-the-horizon aviation communications, RFID, over-the-horizon radar, automatic link establishment (ALE)/near-vertical incidence sky-wave (NVIS) radio communications, marine and mobile radio telephony
Very-high frequency	VHF	30MHz to 300MHz	FM, television broadcasts and line-of-sight ground-to-aircraft and aircraft-to-aircraft communications, land mobile and maritime mobile communications, amateur radio, weather radio
Ultra-high frequency	UHF	300MHz to 3000MHz	Television broadcasts, microwave oven, microwave devices/communications, radio astronomy, mobile phones, wireless LAN, Bluetooth, ZigBee, GPS and two-way radios such as land mobile, FRS and GMRS radios, amateur radio
Super-high frequency	SHF	3GHz to 30GHz	Radio astronomy, microwave devices/communications, wireless LAN, most modern radars, communications satellites, satellite television broadcasting, DBS, amateur radio
Extremely-high frequency	EHF	30GHz to 300GHz	Radio astronomy, high-frequency microwave radio relay, microwave remote sensing, amateur radio, directed-energy weapon, millimeter wave scanner
Terahertz or tremendously-high frequency	THz or THF	300GHz to 3,000GHz	Terahertz imaging, a potential replacement for X-rays in some medical applications, ultra-fast molecular dynamics, condensed-matter physics, terahertz time-domain spectroscopy, terahertz computing/communications, sub-mm remote sensing, amateur radio

Electromagnetic spectrum and applications



Microwave Frequency Bands

Band	Frequency range	Applications
L	1 to 2 GHz	Satellite, navigation (GPS, etc.), cellular phones
S	2 to 4 GHz	Satellite, SiriusXM radio, unlicensed (Wi-Fi, Bluetooth, etc.), cellular phones
C	4 to 8 GHz	Satellite, microwave relay
X	8 to 12 GHz	Radar
K_u	12 to 18 GHz	Satellite TV, police radar
K	18 to 26.5 GHz	Microwave backhaul
K_a	26.5 to 40 GHz	Microwave backhaul
Q	30 to 50 GHz	Microwave backhaul
U	40 to 60 GHz	Experimental, radar
V	50 to 75 GHz	New WLAN, 802.11ad/WiGig
E	60 to 90 GHz	Microwave backhaul
W	75 to 110 GHz	Automotive radar
F	90 to 140 GHz	Experimental, radar
D	110 to 170 GHz	Experimental, radar

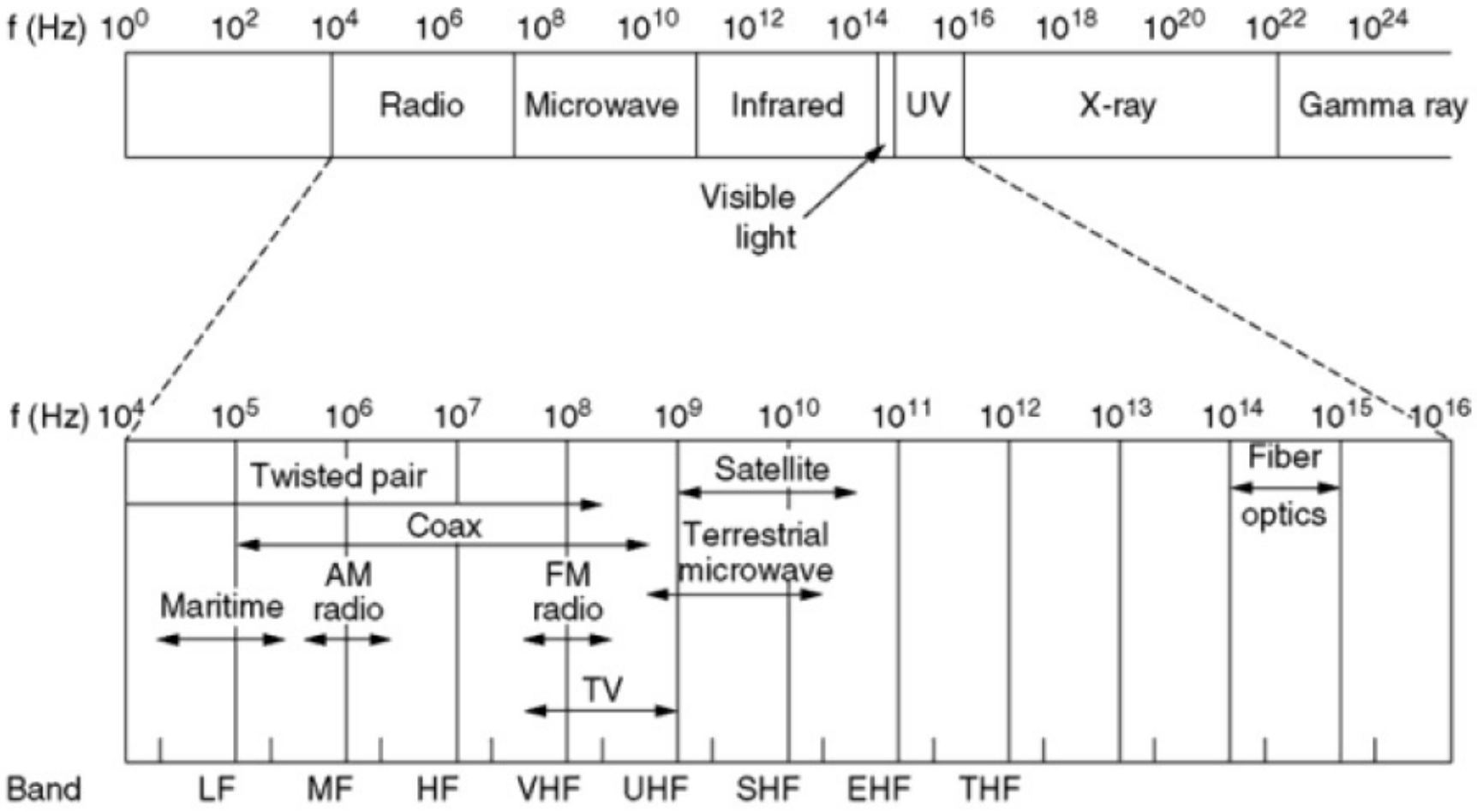
Advantages of Microwave Technology

- It does not require any cable connection.
- They can carry high quantities of information due to their high operating frequencies.
- Large BW and we can able to access more numbers channels.
- Low-cost land purchase: each tower occupies a small area.
- High frequency/short wavelength signals require a small antenna.

Disadvantages

- Attenuation by solid objects: birds, rain, snow, and fog.
- It's much expensive to build many towers.
- Reflected from flat surfaces like water and metal.
- Diffracted (split) around solid objects.
- Refracted by the atmosphere, thus causing the beam to be projected away from the receiver.

Wireless..

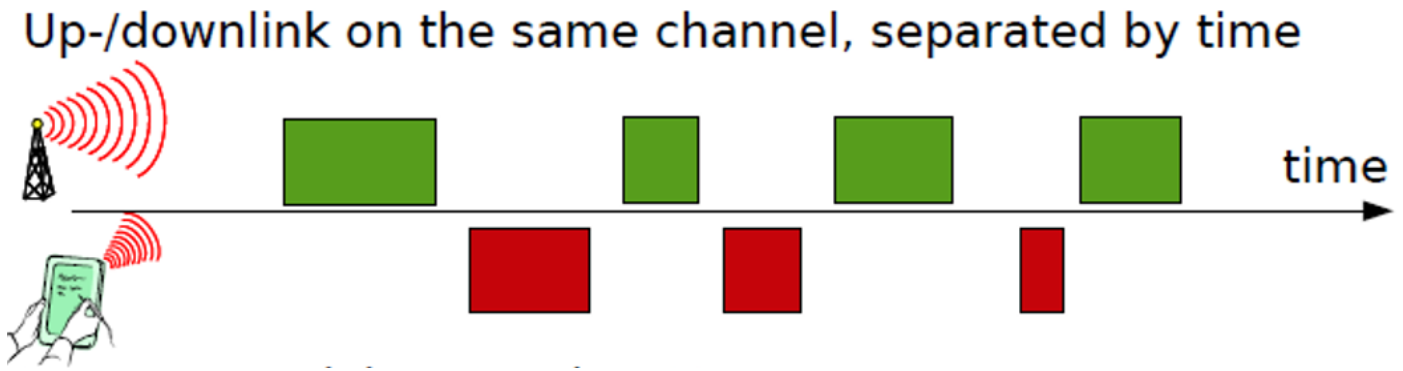


The electromagnetic spectrum and its use for communication

Duplex Modes and Basic Multiple Access Schemes

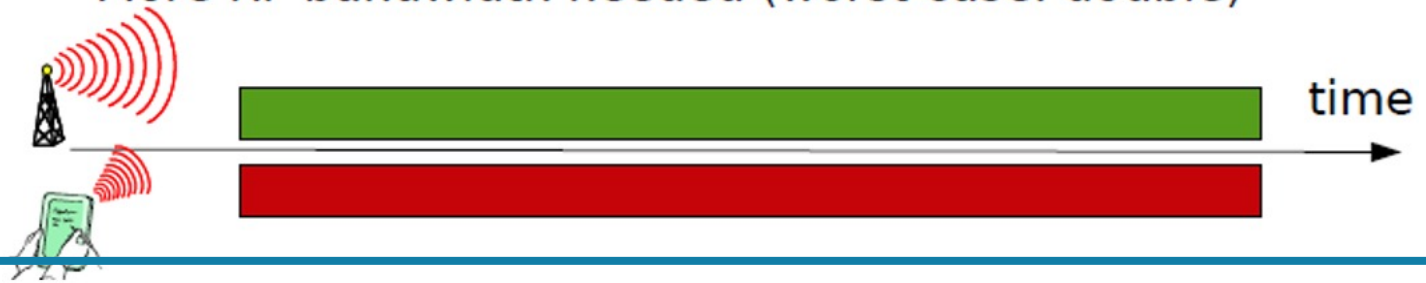
Wireless Communication: Duplex Modes

TDD: Time Division Duplex



FDD: Frequency Division Duplex

- up/downlink separated by frequency, permanent transmission possible
- More RF bandwidth needed (worst case: double)



Basic Multiplex Schemes

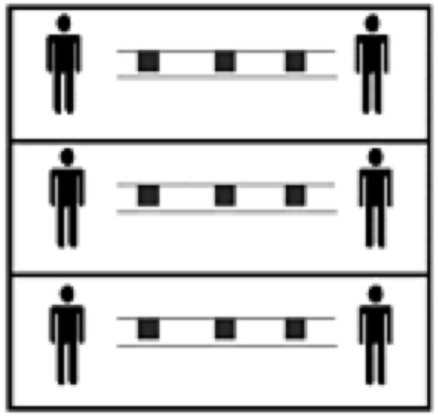
Divide the spectrum into portions in order to implement different channels

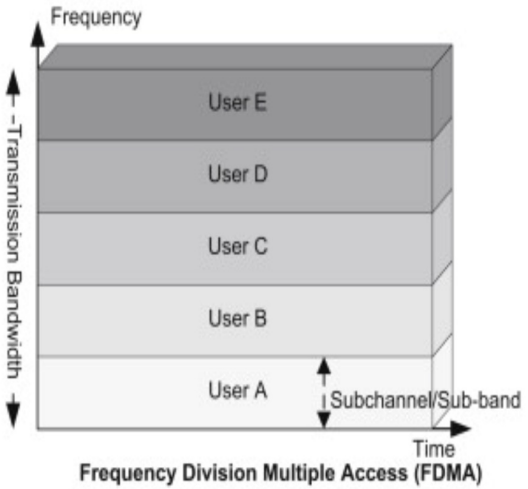
In case of assigning these channels to different users, also called multiple access schemes

- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)
- Space Division Multiple Access (SDMA)

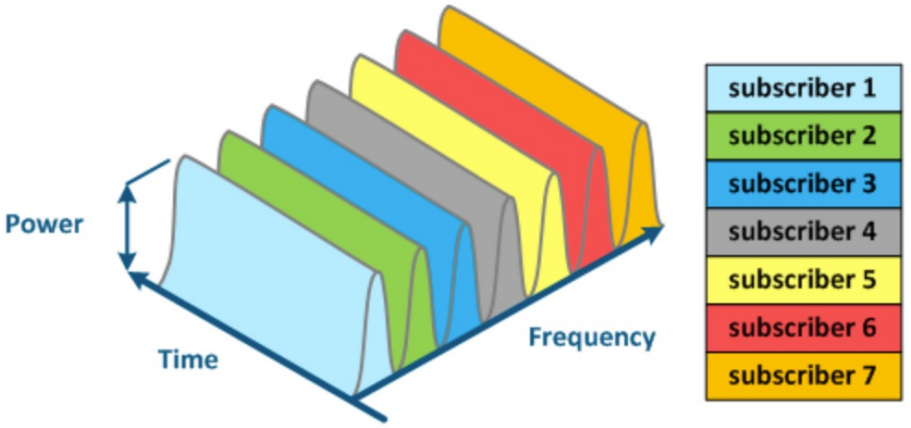
Frequency Division Multiple Access (FDMA)

- Separation of the whole spectrum into smaller frequency bands
- A channel gets a certain band of the spectrum for the whole time
- Advantages:
  - no dynamic coordination needed
  - applicable to analog signals
- Disadvantages:
  - waste of bandwidth if the traffic is distributed unevenly
  - inflexible
  - guard space



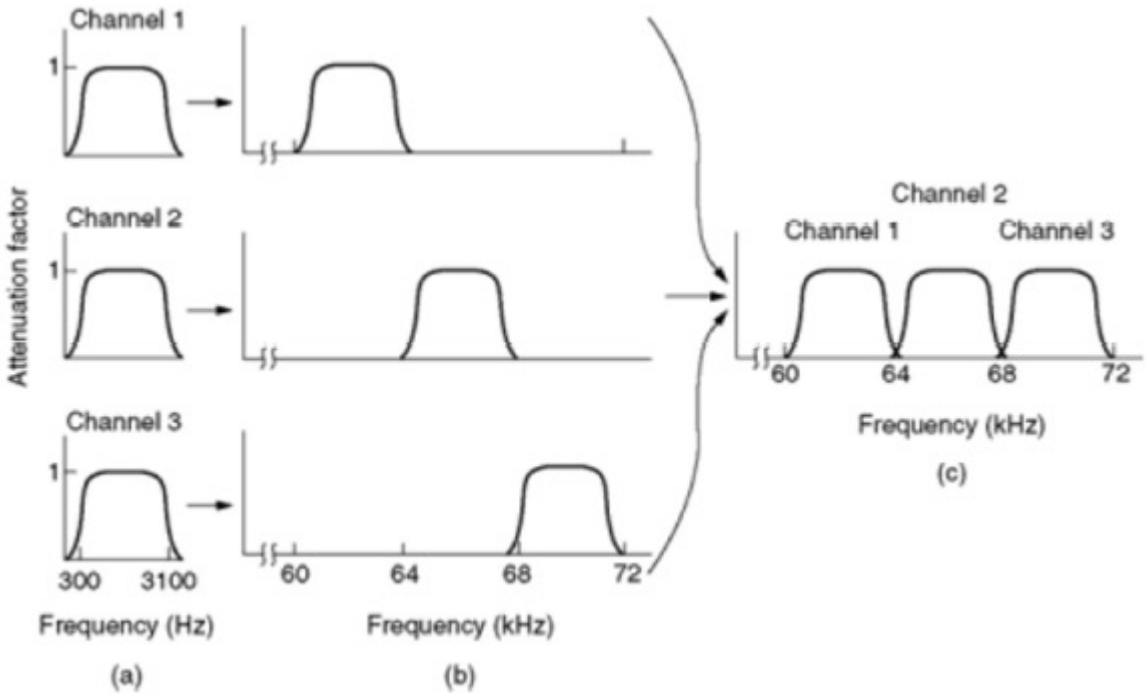


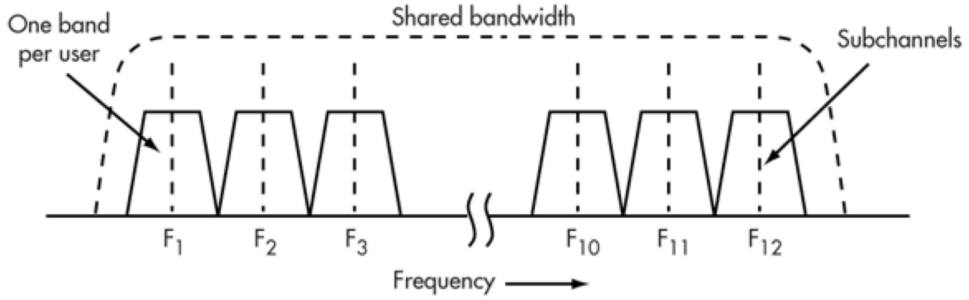
Frequency Division Multiple Access (FDMA)



FDMA cont.

- In FDM, the frequency spectrum is divided into several frequency bands, each of which is assigned exclusively to a user. Figure shows how telephone channels are multiplexed using FDM

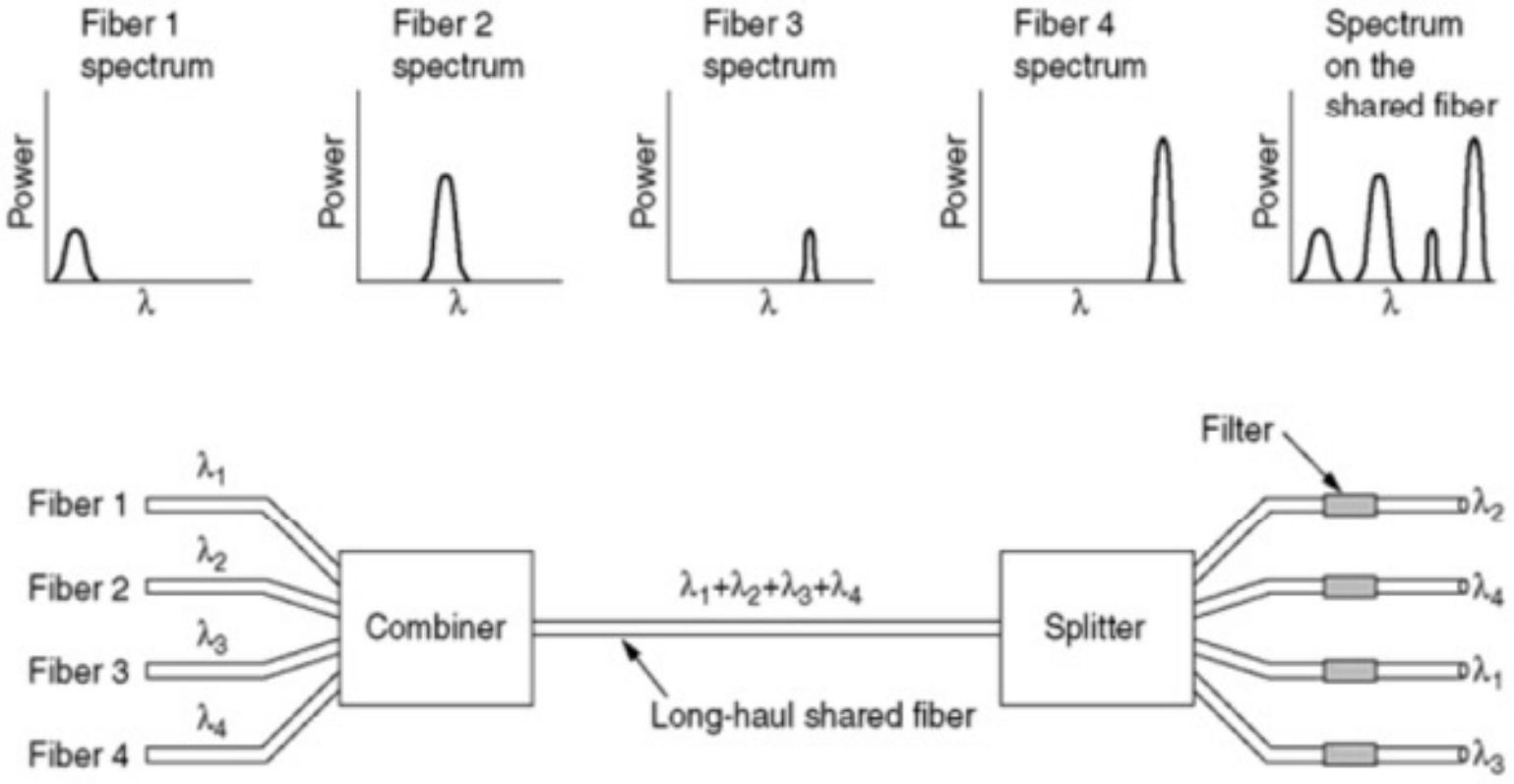




Even though there is a gap between two adjacent channels to keep them separated, there is still some overlap between them, because the band pass filter doesn't have a sharp edge.

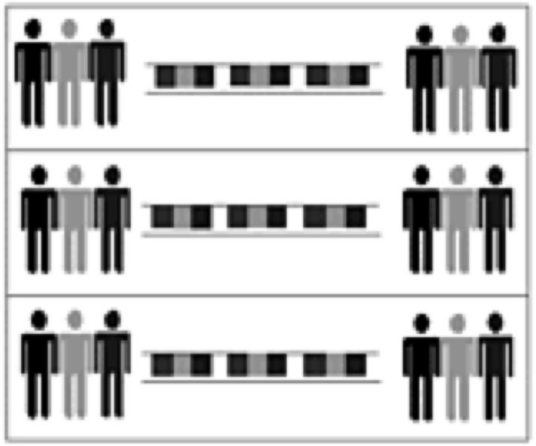
Wavelength Division Multiplexing (WDM)

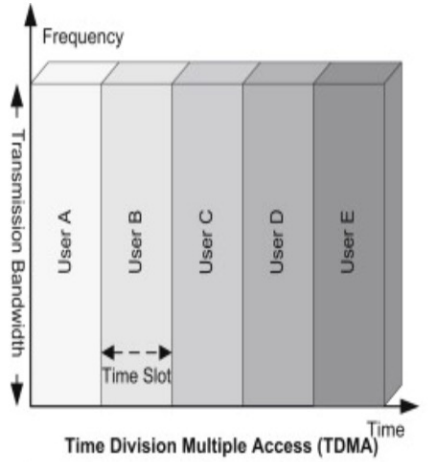
- WDM is a variation of FDM, which is used in optical fibers. WDM can be seen as frequency division multiplexing at very high frequencies.



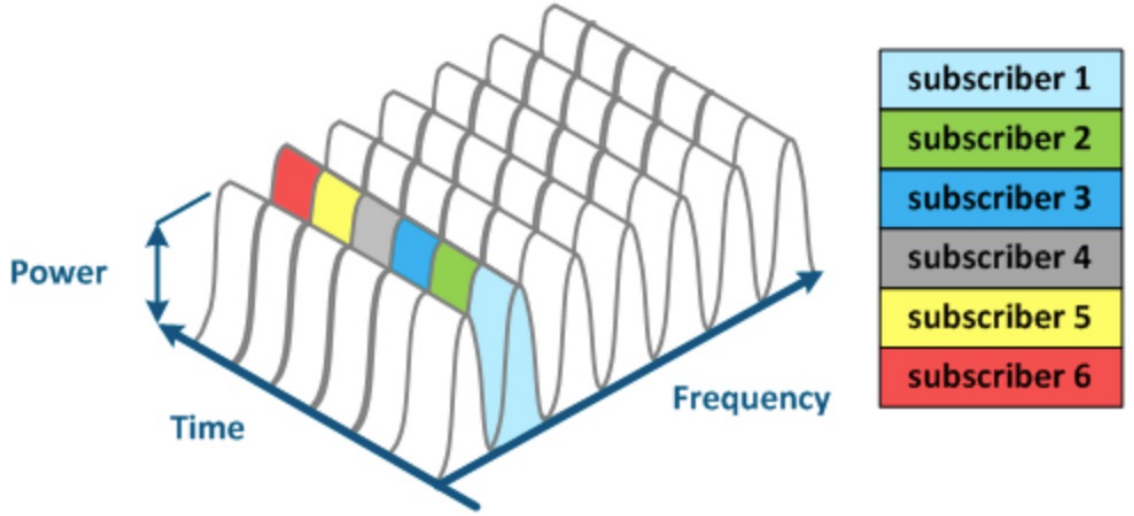
Time Division Multiple Access (TDMA)

A channel gets the whole spectrum for a certain amount of time



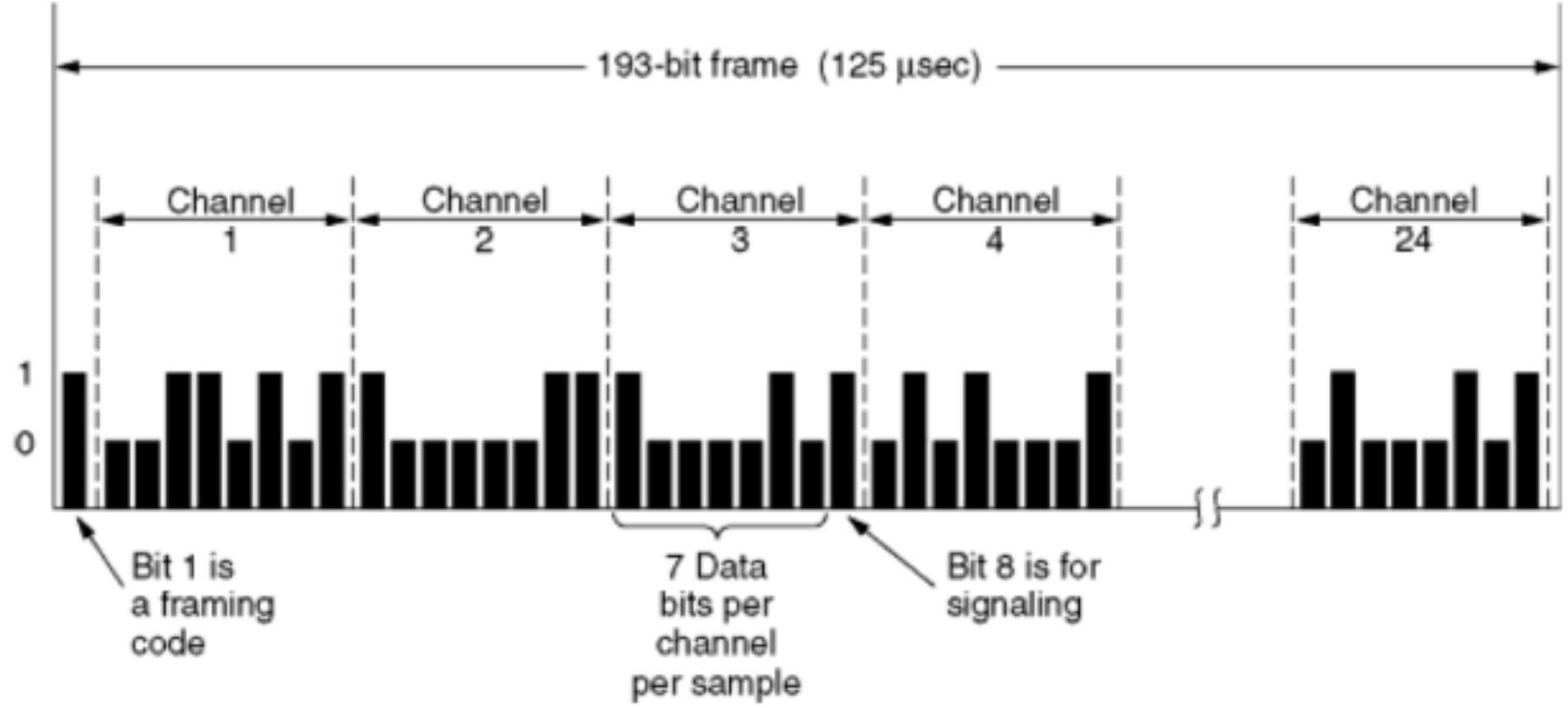


- Advantages:
  - Only one carrier in the medium at any time
  - Throughput high even for many users
- Disadvantages:
  - Precise synchronization needed



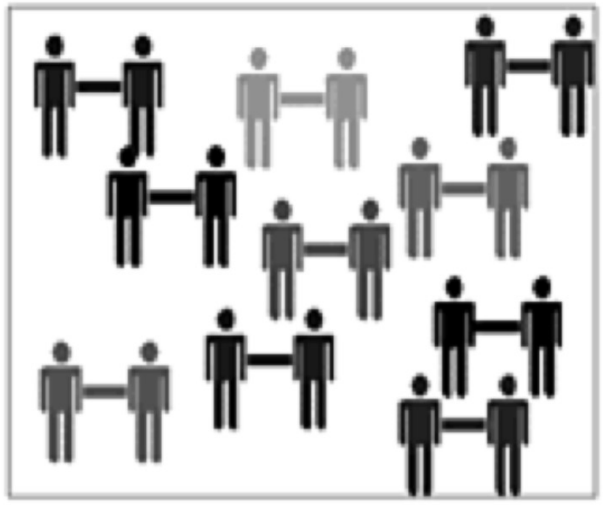
TDMA cont.

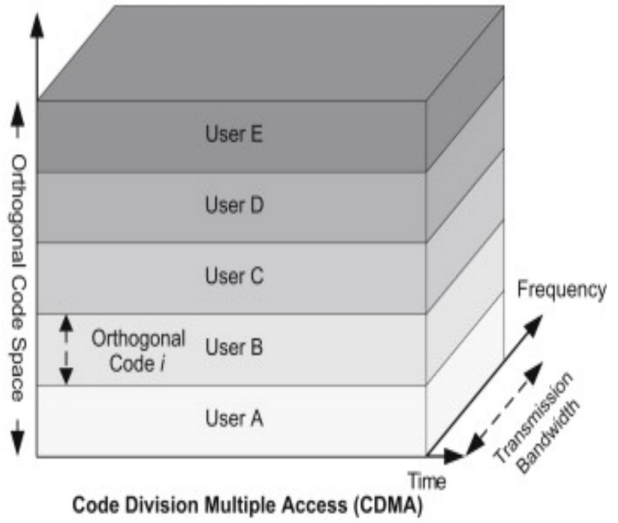
- In TDM, the channels are divided into time slots, each of which is assigned to a specific user. Users get the entire bandwidth during their time slot. Different from FDM, which requires analog data, TDM can be used only for digital data.

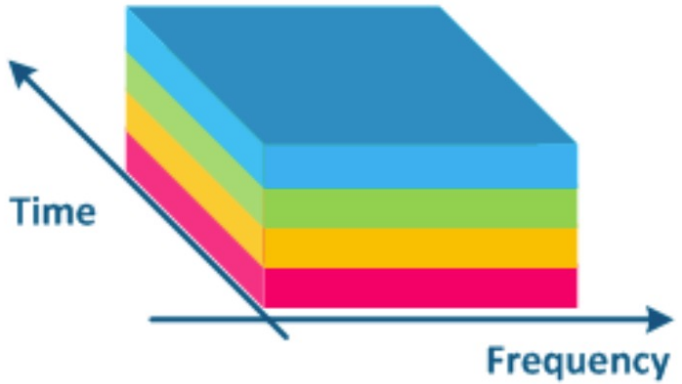


Code division multiple access

- Each channel has a unique code UMTS
- All channels use the same spectrum at the same
- Advantages:
  - Bandwidth efficient
  - No coordination and synchronization necessary
  - Good protection against interference and tapping
- Disadvantages:
  - More complex receivers
  - Intra cell interference

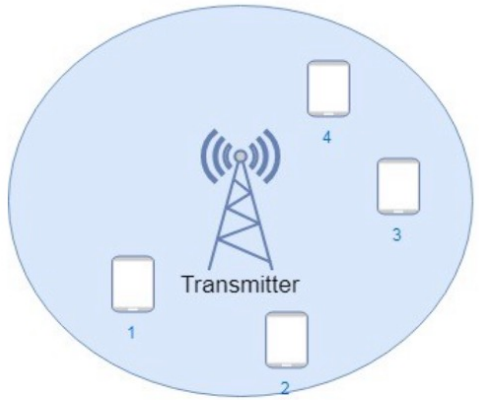




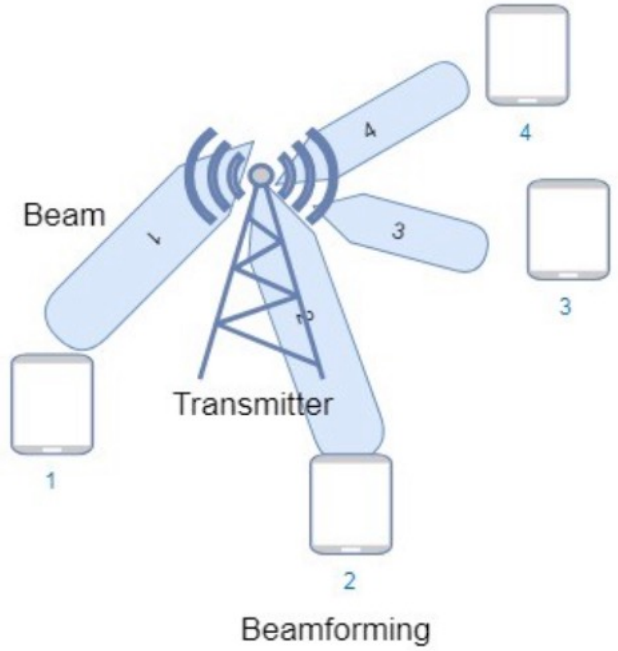


Space Division Multiple Access

- Each user can be separated from other users by means of directional antennas
- All users use the same spectrum at the same time
- Advantages:
  - bandwidth efficient
  - no coordination and synchronization necessary
- Disadvantages:
  - Mutual interference cannot be fully avoided
  - lower user data rates
  - more complex signal regeneration
- Example: Beamforming

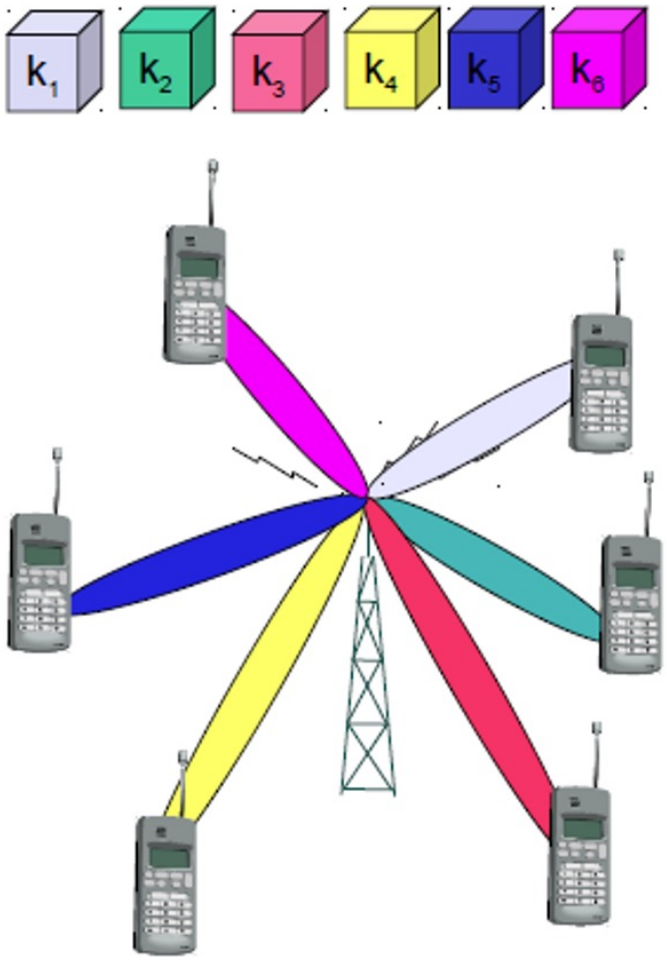


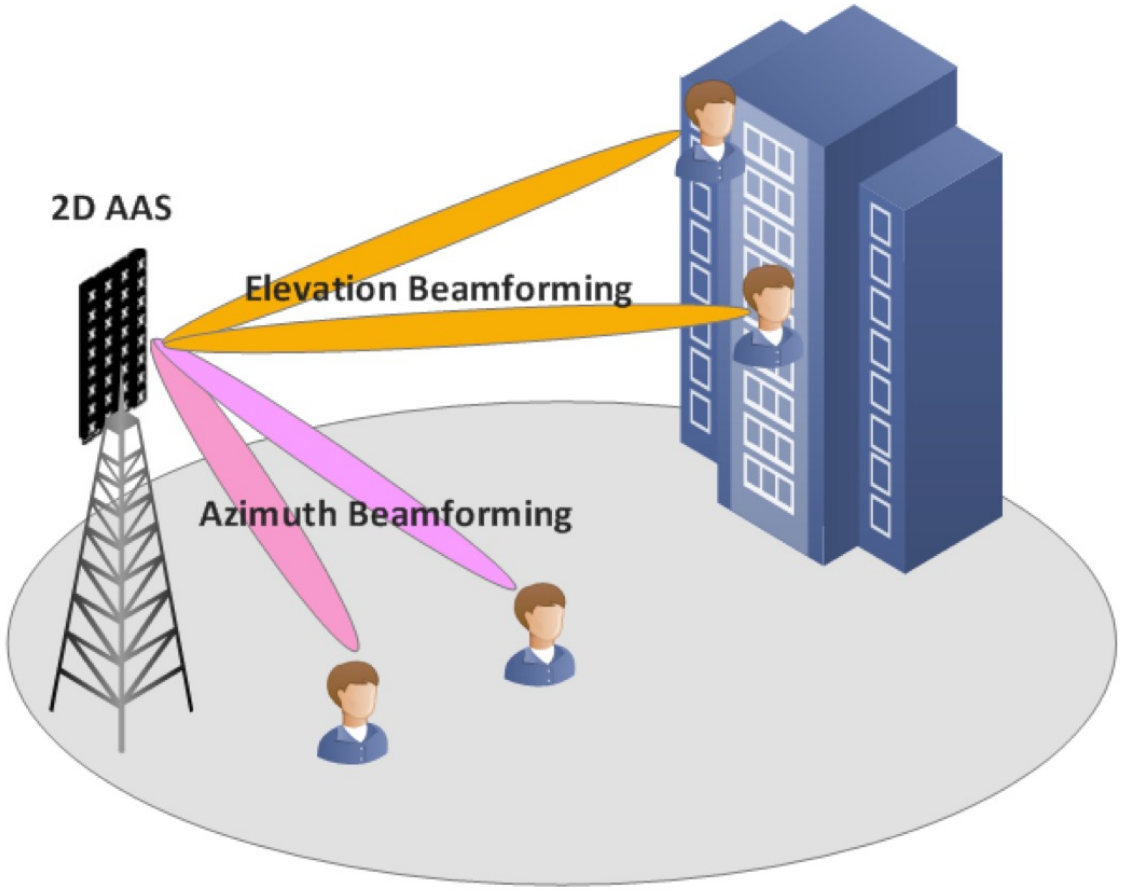
Equal Energy Transmission in all Direction



Beamforming

SDMA


k1
k2
k3
k4
k5
k6


2D AAS
Elevation Beamforming
Azimuth Beamforming

ANY QUESTION??

THANK YOU!!

Sapce communication

- The ionosphere reflects radio waves with frequencies below 30 MHz, so higher frequencies are needed for space communication. There are two types
  - Line of sight communication
  - Satellite communication
- Communications satellite is an artificial satellite that relays and amplifies radio telecommunication signals via a transponder
- It creates a communication channel between a source transmitter and a receiver at different locations on Earth.
- There are three types of communication services that satellites provide: telecommunications, broadcasting, and data communications.
- audio waves with frequencies above 30 GHz are easily absorbed and scattered by rain, dust and other atmospheric effects reducing signal strength.