Unit-3 – Propagation Effects and their Impact on Satellite-Earth Links

Propagation:

Propagation is the way radio signals are transmitted from one point to another inside the earth's atmosphere or free space. Since these are electromagnetic waves, they exhibit properties such as reflection, refraction, diffraction, absorption, polarization and scattering. Like light waves, radio waves can be reflected, refracted, diffracted, absorbed and polarized and scattered.

Propagation Impairments and Space Link

A signal traveling between an earth station and a satellite must pass through the earth's atmosphere, including the ionosphere.

Atmospheric Losses:

Losses occur in the earth's atmosphere as a result of energy absorption by the atmospheric gases. These losses are treated quite separately from those which result from adverse weather conditions, which of course are also atmospheric losses. To distinguish between these, the weather-related losses are referred to as atmospheric attenuation and the absorption losses simply as atmospheric absorption.

Ionospheric Effects:

Radio waves traveling between satellites and earth stations must pass through the ionosphere. The ionosphere has been ionized, mainly by solar radiation. The free electrons in the ionosphere are not uniformly distributed but form in layers. Clouds of electrons may travel through the ionosphere and give rise to fluctuations in the signal. The effects include scintillation, absorption, variation in the direction of arrival, propagation delay, dispersion, frequency change, and polarization rotation.

Propagation Effects & their Impact:

Many phenomena causes lead signal loss on through the earths atmosphere:

- Atmospheric Absorption (gaseous effects)
- Cloud Attenuation (aerosolic and ice particles)
- Tropospheric Scintillation (refractive effects)
- Faraday Rotation (an ionospheric effect)
- Ionospheric Scintillation (a second ionospheric effect)
- Rain attenuation
- Rain and Ice Crystal Depolarization

The rain attenuation is the most important for frequencies above 10 GHz

- Rain models are used to estimate the amount of degradation (or fading) of the signal when passing through rain.
- Rain attenuation models: Crane 1982 & 1985; CCIR 1983; ITU-R p,618-5(7&8)

Based on the Institute of Electrical and Electronics Engineers (IEEE) Standard Definitions of Terms for Radio Wave Propagation, general definitions of the some of the mechanisms are mentioned below:

- **Refraction:** A change in the direction of propagation of a radio wave due to the variation of refractive index of the medium.
- **Absorption:** A decrease in the amplitude of a radio wave caused by an irreversible conversion of energy from the radio wave to matter in the propagation path.
- **Scattering:** A process in which the energy of a radio wave is dispersed due to interaction with elements in the medium.
- **Diffraction:** A change in the direction of propagation of a radio wave resulting from the presence of an obstacle, a restricted aperture, or other object in the medium.
- **Multipath:** This occurs when a transmitted radio wave reaching the receiving antenna by two or more propagation paths. Multipath can result from refractive index irregularities in the troposphere or ionosphere; or from structural and terrain scattering on the earth's surface.
- **Scintillation:** Rapid fluctuations of the amplitude and the phase of a radio wave caused by small scale irregularities in the transmission path (or paths) with time.
- **Fading:** The variation of the amplitude (field strength) of a radio wave caused by changes in the transmission path (or paths) with time. The terms fading and scintillation are often used interchangeably; however, fading is usually used to describe slower time variations whereas scintillation refers to more rapid variations.

Refraction:

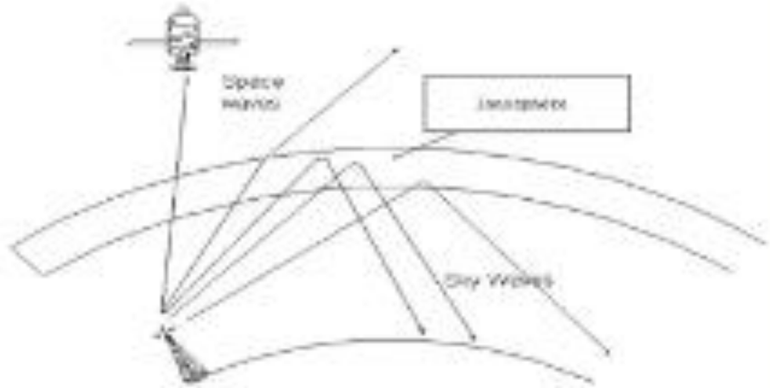
- ✓ A change in the direction of propagation of a radio wave due to the variation of refractive index of the medium.
- ✓ Occurs when a RF signal is being bent. This typically can happen as the RF signal passes through a medium with a different density, thus causing the direction of the wave to change.
- ✓ A change in refraction can typically appear when dealing with long-distance outdoor bridge links.

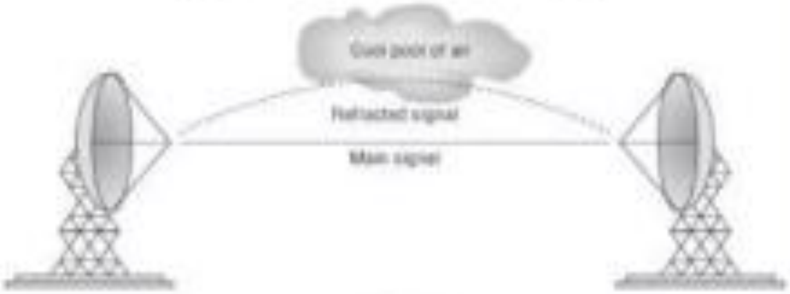
Causes:

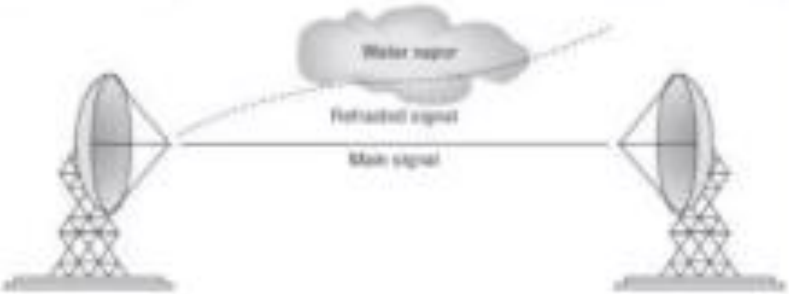
- ✓ Water vapor
- ✓ Changes in air temperature
- ✓ Changes in air pressure

Impact:

- ✓ May cause lower data rates, re-transmissions and lead to reduced capacity.







- ✓ One of the layers in the Earth's atmosphere is called the **ionosphere.**
- ✓ Radio waves can be reflected from the **ionosphere.**
- ✓ **Water** is also able to reflect radio waves, but land masses are not such good reflectors.
- ✓ The propagation of radio signals from one place to another because of reflection from the ionosphere is known as sky wave propagation.
- ✓ Radio waves in the ionosphere behave in a similar way to light rays in an optical fibre – they undergo total internal reflection.
- ✓ As a radio wave travels up in the ionosphere, it passes from a denser to a less dense medium.
- ✓ It continuously bends away from its path until it is totally reflected back to Earth.
- ✓ Coupled with reflection from the oceans, radio signals can be received well beyond line of sight.
- ✓ **Microwaves are not reflected back to the surface of the Earth.**
- ✓ **They pass through the ionosphere and are received by satellites orbiting the Earth.**
- ✓ **The satellite amplifies the signal and then re-transmits the signal back to Earth.**

Diffraction:

- ✓ A change in the direction of propagation of a radio wave resulting from the presence of an obstacle, a restricted aperture, or other object in the medium.
- ✓ Diffraction is the bending and spreading around of an RF signal when it encounters an obstruction.
- ✓ The waves that encounter the object bend around the object, taking a longer and different path.
- ✓ The waves that do not encounter the object do not bend and maintain a shorter and original path.
- ✓ Radio waves are diffracted when they meet an obstruction.
- ✓ The diffraction is only significant if the size of the obstacle is similar to the wavelength

Causes:

Conditions that must be met for diffraction to occur.

Characteristics of the obstructing object:

- Shape
- Size
- Material

Characteristics of the RF signal:

- Polarization
- Phase
- Amplitude

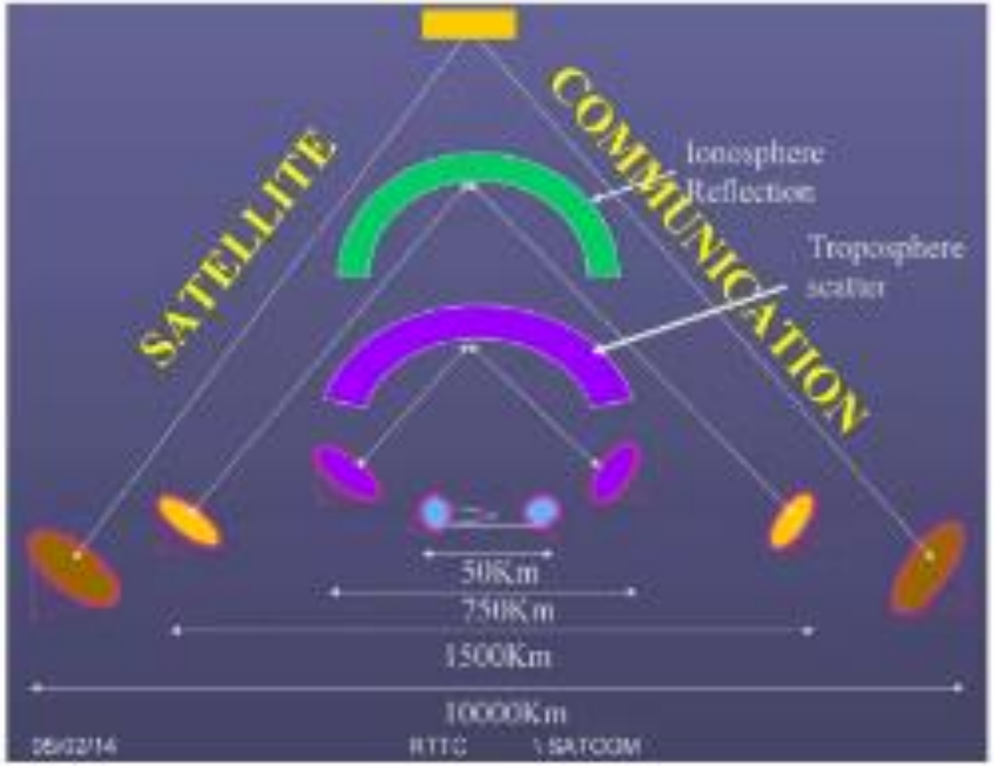
Diffraction is caused by some sort of partial blockage such as a small hill or building that is between a transmitting radio and receiver.

Impact:

RF shadow can occur causing dead coverage zones or receive degraded signals.

Scattering:

- ✓ A process in which the energy of a radio wave is dispersed due to interaction with elements in the medium.
- ✓ Occurs when a signals wavelength is larger than pieces of a medium the signal is reflecting from or passing through.



Impact:

RF encounters some type of uneven surface and is reflected into multiple directions. The main signal dissipates into multiple reflected signals causing substantial signal downgrade and may cause loss of received signal.

Tropospheric scatter

- ✓ Method of transmitting and receiving microwave radio signals over considerable distances often up to 300 km.
- ✓ This method of propagation uses the tropospheric scatter phenomenon, where radio waves at particular frequencies are randomly scattered as they pass through the upper layers of the troposphere .
- ✓ Radio signals are transmitted in a tight beam aimed at the tropopause, midway between the transmitter and receiver site, as the signals pass through the troposphere they are scattered, allowing the receiver station to pick up the signal

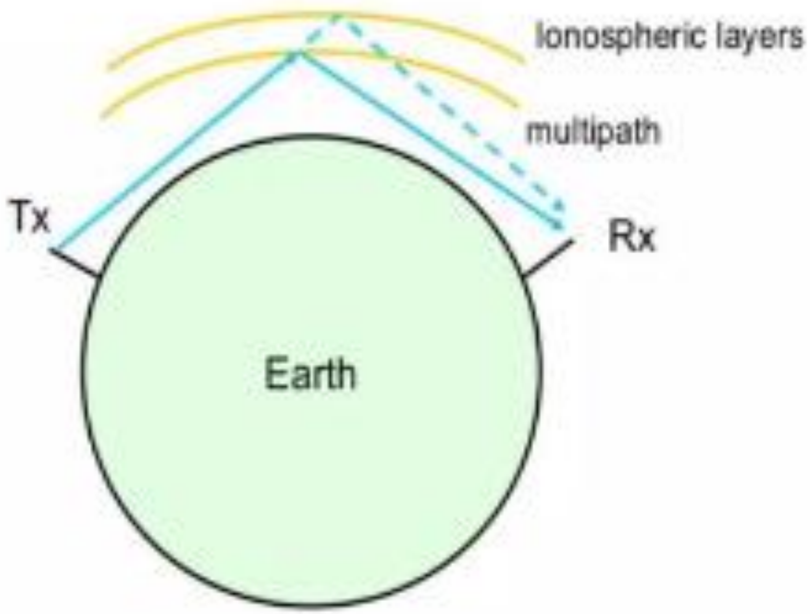
- ✓ The scattering mode of propagation enables vhf and uhf signals to be transmitted far beyond the normal line-of-sight.
- ✓ When the space wave is transmitted, it undergoes very little attenuation within the line-of-sight horizon.
- ✓ When it reaches the horizon, the wave is diffracted and follows the Earth's curvature.
- ✓ Beyond the horizon, the rate of attenuation increases very rapidly and signals soon become very weak and unusable.
- ✓ Tropospheric scattering, on the other hand, provides a usable signal at distances beyond the point where the diffracted space wave drops to an unusable level. This is because of the height at which scattering takes place.

- ✓ The turbulence that causes the scattering can be visualized as a relay station located above the horizon. It receives the transmitted energy and then reradiates it in a forward direction to some point beyond the line of sight distance.
- ✓ A high gain receiving antenna aimed toward this scattered energy can then capture it.
- ✓ The magnitude of the received signal depends on the number of turbulences causing scatter in the desired direction and the gain of the receiving antenna.
- ✓ The scatter area used for tropospheric scatter is known as the scatter volume. The angle at which the receiving antenna must be aimed to capture the scattered energy is called the scatter angle.

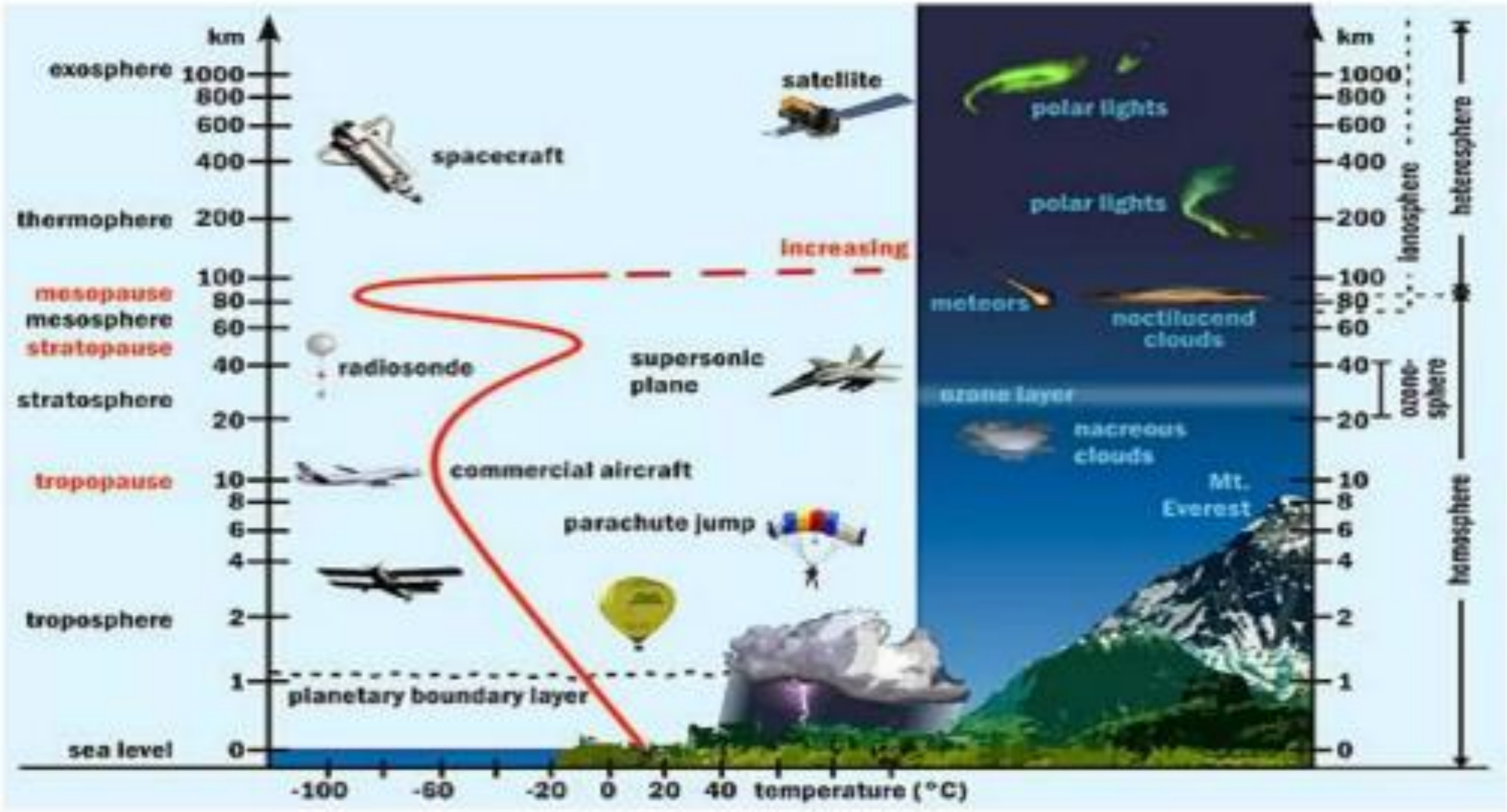
Multipath:

- ✓ This occurs when a transmitted radio wave reaching the receiving antenna by two or more propagation paths. Multipath can result from refractive index irregularities in the troposphere or ionosphere; or from structural and terrain scattering on the earth's surface.

- ✓ Causes of multipath include atmospheric ducting, ionospheric reflection and refraction, and reflection from water bodies and terrestrial objects such as mountains and buildings.



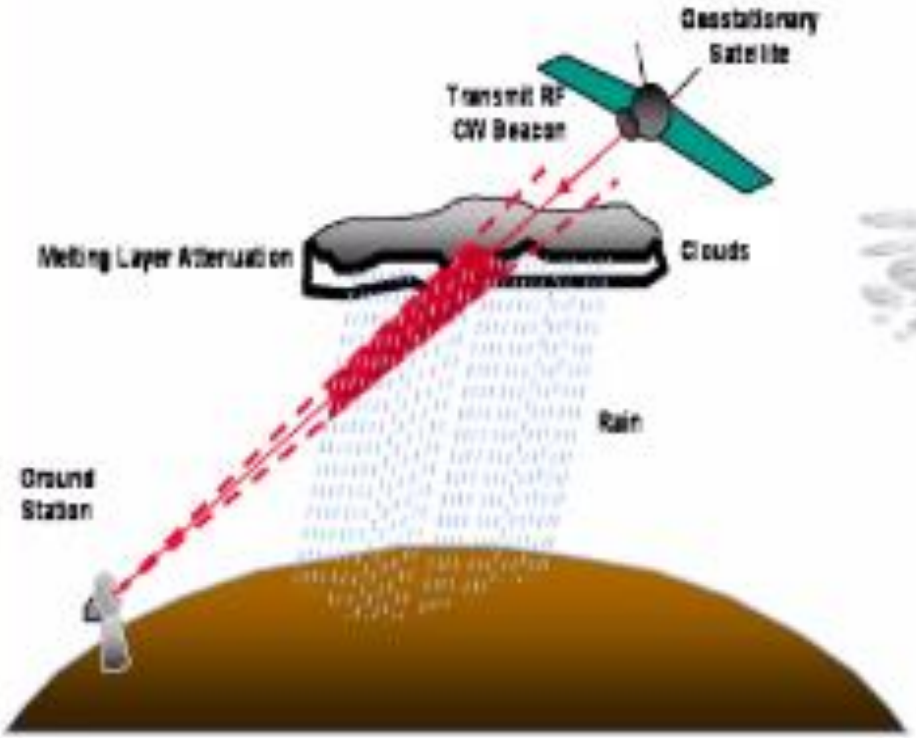
Earth's Atmosphere

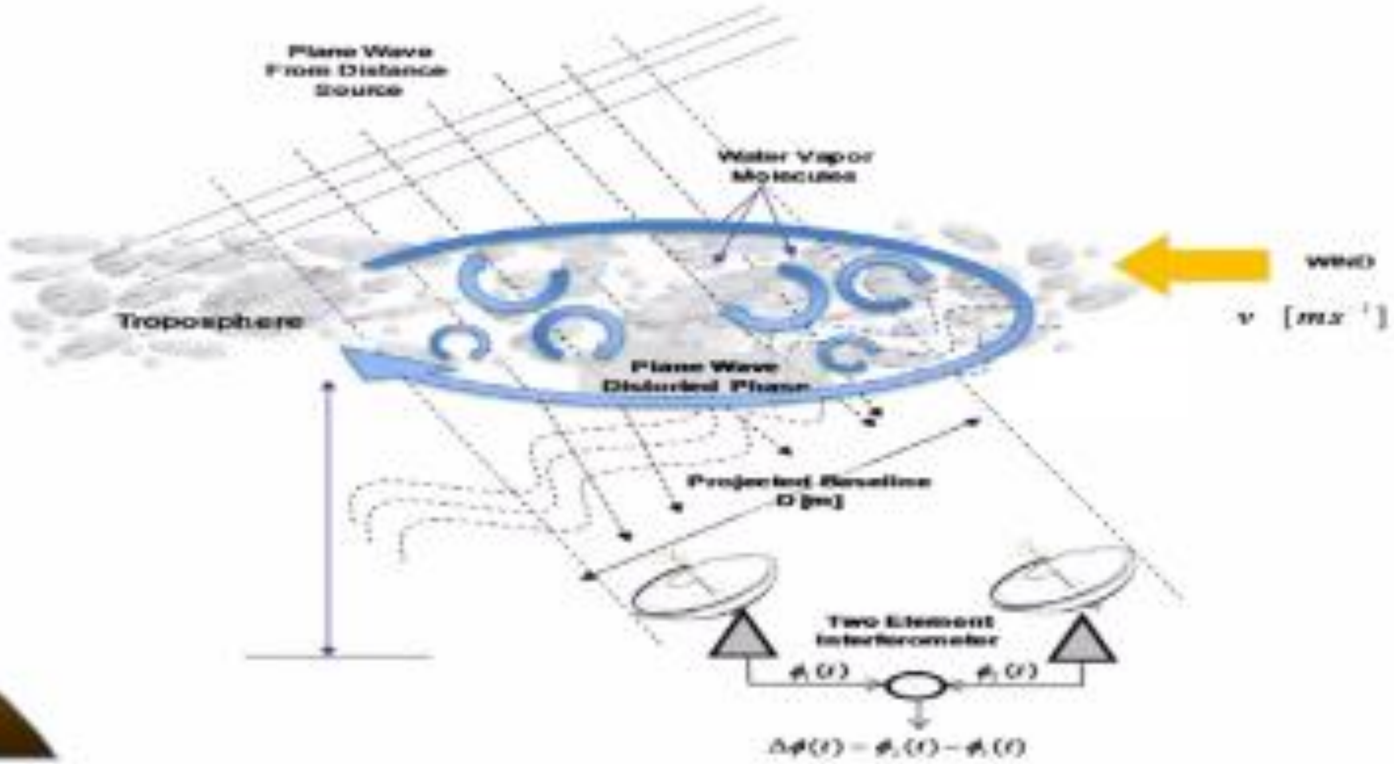


Atmospheric Losses

Different types of atmospheric losses can disturb radio wave transmission in satellite systems:

- ✓Atmospheric absorption
- ✓Atmospheric attenuation
- ✓Traveling ionospheric disturbances

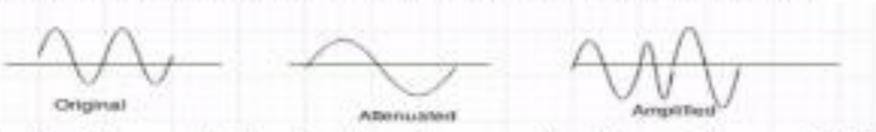




Note: What is Attenuation?

Attenuation is the loss of signal strength in networking cables or connections. This typically is measured in decibels (dB) or voltage and can occur due to a variety of factors. It may cause signals to become distorted or indiscernible. An example of this is Wi-Fi signal and strength getting noticeably weaker the further that your device is from the router.

It means loss of energy. The strength of signal decreases with increasing distance which causes loss of energy in overcoming resistance of medium. This is also known as attenuated signal. Amplifiers are used to amplify the attenuated signal which gives the original signal back.



When measuring attenuation in a wired network, the greater the signal strength over a long distance, the more effective the cable is. Less efficient cables will struggle with signal attenuation, and networking administrators may need to adjust the cable or insert amplifiers or repeaters in order to boost the signal strength. However, the more signal amplifiers applied, the slower the signal speed will become between endpoints, due to the extra components that have been added.

Attenuation results from absorption by atmospheric molecules or scattering by aerosols in the atmosphere between the microwave sensor on board a spacecraft or aircraft and the target to be measured. The attenuation of the microwave will take place as a function of the exponential with respect to the transmitted distance mainly due to absorption and scattering. Therefore the attenuation will increase in proportion to the distance, under homogeneous atmospheric conditions. The attenuation per unit of distance is called specific attenuation.

While attenuation is the loss of signal strength, amplification boosts the strength of a signal. However, amplification can also affect the noise in the transmission, potentially degrading the quality of the signal. Noise can come in the form of electromagnetic frequencies, electrical currents, wire leakage or wireless signals.

In computer networking, internal software can help reduce the overall noise so that the signal isn't too distorted. Management of both attenuation and amplification is among the key skills and troubleshooting tasks of networking professionals.

Amplification can happen in a few different ways. Network or signal repeaters are common methods of amplifying signals. Repeaters take in the signal being sent, process it and then send out the signal stronger than before to the next waypoint (either another repeater or the end user).

Another method is signal boosters, which are common with wireless signals. Antennas typically work well with, or are required for, booster equipment.

Attenuation

- The first, and most well known, effect of rain is that it attenuates the signal. The attenuation is caused by the scattering and absorption of electromagnetic waves by drops of liquid water. The scattering diffuses the signal, while absorption involves the resonance of the waves with individual molecules of water. .
- Absorption increases the molecular energy, corresponding to a slight increase in temperature, and results in an equivalent loss of signal energy.
- Attenuation is negligible for snow or ice crystals, in which the molecules are tightly bound and do not interact with the waves.
- The standard method of representing rain attenuation is through an equation of the form

$$\mathbf{L_r = \alpha R^b L = \gamma L}$$

Where,

L_r is the rain attenuation in decibels (dB)

R is the rain rate in millimeters per hour

L is an equivalent path length (km)

α and b are empirical coefficients that depend on frequency and to some extent on the polarization.

The factor γ is called the specific rain attenuation, which is expressed in dB/km. The equivalent path length depends on the angle of elevation to the satellite, the height of the rain layer, and the latitude of the earth station.

Atmospheric Attenuation

Causes:

- ✓ Rain is the main cause of atmospheric attenuation (hail, ice and snow have little effect on attenuation because of their low water content). [Oxygen and Water – primary causes]
- ✓ Angle of Elevation

Elevation:

- ✓ Angle ε between center of satellite beam and surface of the earth.

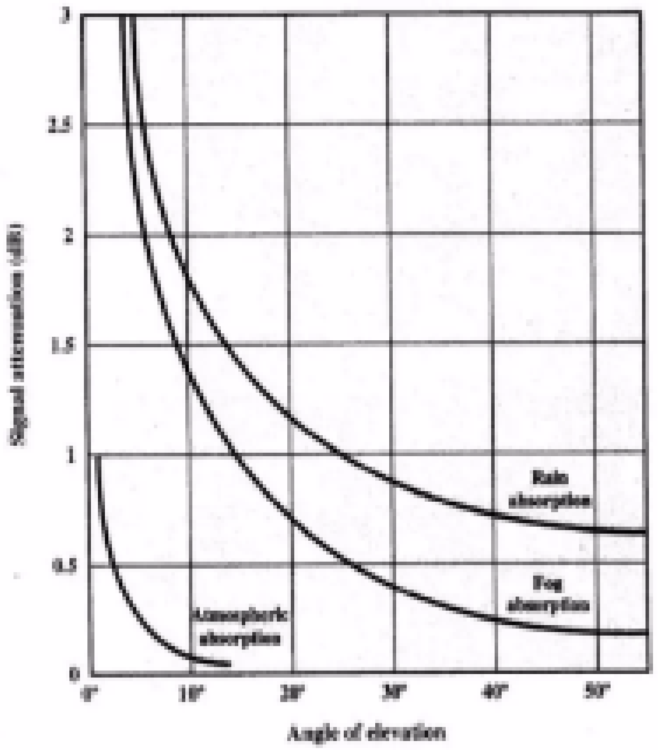
Minimal elevation:

- ✓ Elevation needed to at least communicate with the satellite.
- ✓ The elevation angle between the satellite beam and the surface of earth has an impact on the illuminated area (footprint).

Total attenuation from rain can be determined by:

$$A = \alpha L \text{ [dB]}$$

- ✓ where α [dB/km] is called the specific attenuation, and can be calculated from specific attenuation coefficients in tabular form that can be found in a number of publications
- ✓ where L [km] is the effective path length of the signal through the rain; note that this differs from the geometric path length due to fluctuations in the rain density.

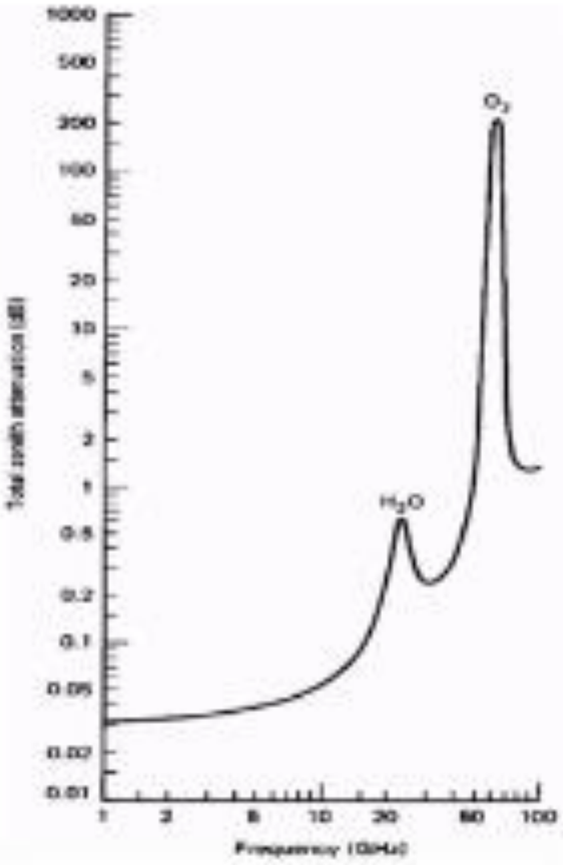


Atmospheric absorption

- The propagation are primarily due to the effects of the Earth as atmosphere and their impact on system availability and margin. Distortions due to multipath propagation do not affect the millimeter wave.
- However, some atmospheric effects at the millimeter wavelengths are gaseous absorption, cloud attenuation, rain attenuation, and tropospheric scintillation.
- Gaseous absorptions are mainly due to atmospheric gaseous components (predominantly oxygen and water vapor) and typically have a small contribution to the total path attenuation in the W/V band.
- Cloud attenuation at the W/V bands can contribute to significant loss(>10dB).
- Rain attenuation has the most dominant contribution to the total propagation loss when dealing with higher frequencies.
- Troposphere scintillation is the rapid fluctuations in the refractive index of owing to turbulence and produces random fades and enhancements of the received signal amplitude.
- This phenomenon can seriously affect satellite-earth links at frequencies above 10 GHz and at very low elevation angles (<=5 degrees).

Atmospheric Absorption

- Energy absorption by atmospheric gases, which varies with the frequency of the radio waves.
- Two absorption peaks are observed (for 90º elevation angle):
    - 22.3 GHz from resonance absorption in water vapour (H2O)
    - 60 GHz from resonance absorption in oxygen (O2)
- For other elevation angles:
    - [AA] = [AA]90 cosec θ



Traveling Ionospheric Disturbances

Traveling ionospheric disturbances are clouds of electrons in the ionosphere that provoke radio signal fluctuations which can only be determined on a statistical basis.

The disturbances of major concern are:

- ✓ Scintillation;
- ✓ Polarisation rotation.

Ionospheric scintillations:

- ✓ Are variations in the amplitude, phase, polarization, or angle of arrival of radio waves.
- ✓ Caused by irregularities in the ionosphere which changes with time.
- ✓ Effect of scintillations is fading of the signal. Severe fades may last up to several minutes.

What is Polarization?

✓ Polarization is the property of electromagnetic waves that describes the direction of the transverse electric field.

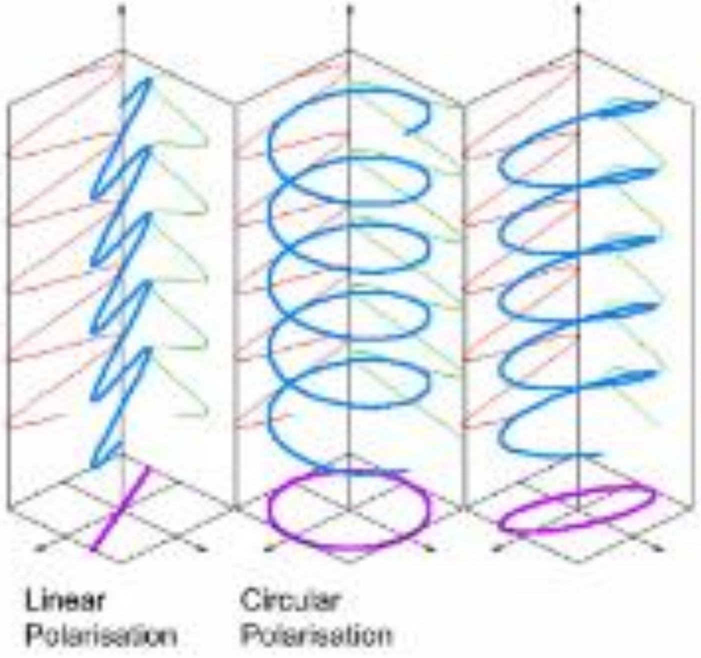
✓ Since electromagnetic waves consist of an electric and a magnetic field vibrating at right angles to each other.

✓ It is necessary to adopt a convention to determine the polarization of the signal.

✓ Conventionally, the magnetic field is ignored, and the plane of the electric field is used.

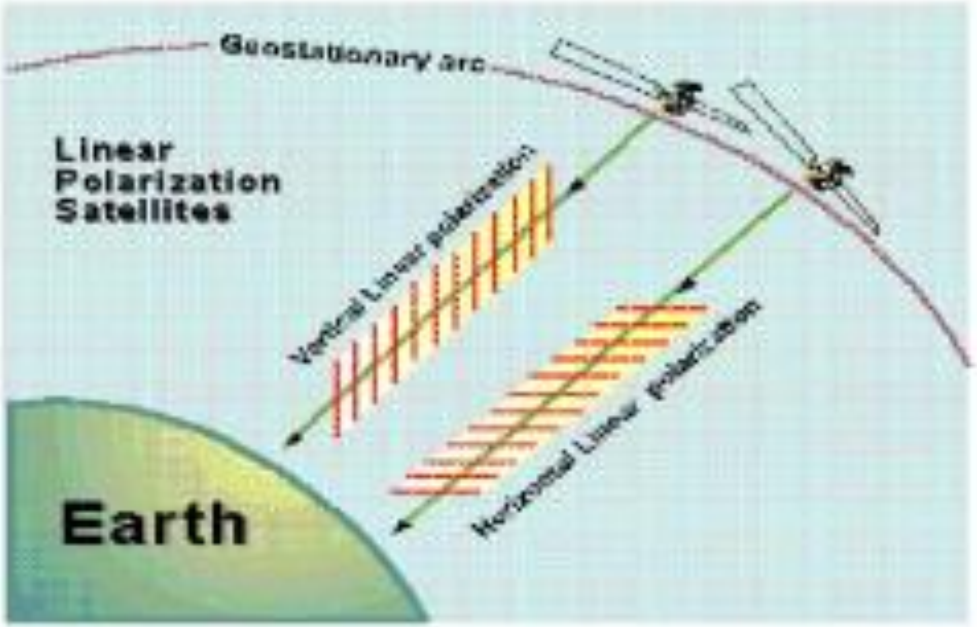
Types of Polarization

- Linear Polarization (horizontal or vertical):
  - the two orthogonal components of the electric field are in phase;
  - The direction of the line in the plane depends on the relative amplitudes of the two components.
- Circular Polarization:
  - The two components are exactly 90° out of phase and have exactly the same amplitude.
- Elliptical Polarization:
  - All other cases.



Satellite Communications

- Alternating vertical and horizontal polarization is widely used on satellite communications
- This reduces interference between programs on the same frequency band transmitted from adjacent satellites (One uses vertical, the next horizontal, and so on)
- Allows for reduced angular separation between the satellites.



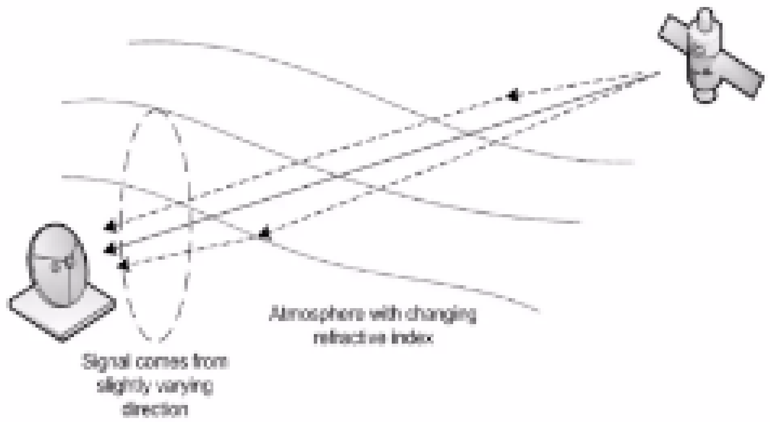
Polarization rotation:

- ✓ Produce rotation of the polarization of a signal (Faraday rotation)
- ✓ When linearly polarized wave traverses in the ionosphere, free electrons in the ionosphere are sets in motion a force is experienced, which shift the polarization of the wave.
- ✓ Inversely proportional to frequency squared.
- ✓ Not a problem for frequencies above 10 GHz.

Tropospheric scintillation

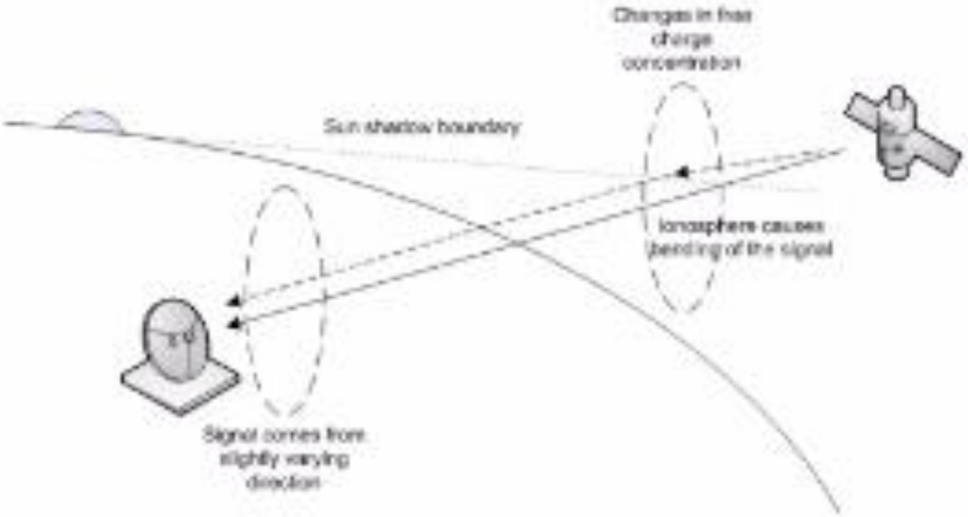
- ✓ Losses associated with variations of the atmosphere close to the ground
- ✓ Due to weather conditions (heating and cooling), the refractive index of the atmosphere changes
- ✓ Change of refractive index changes the direction of signal propagation
- ✓ Change of direction of arrival is "modulated" by antenna pattern -> causes signal fluctuation
- ✓ Scintillation is more pronounced for higher frequencies
- ✓ Scintillation does not cause depolarization
- ✓ At low elevation angles (< 10 deg), scintillation may cause path loss behavior similar to terrestrial multipath fading.

Physical explanation of atmospheric scintillation



Ionospheric scintillation

- ✓ Energy from the sun causes variations to total electron content in the ionosphere
- ✓ Typical range 10^{18} during day, 10^{16} during night
- ✓ At the local sunsets/sunrises there are rapid changes of concentration that cause changes of magnitude and phase of radio waves
- ✓ The changes are further modulated by the antenna pattern
- ✓ The net result are variations of the RSL at sunset and down
- ✓ Magnitude of the ionosphere scintillation varies with sun activity



Faraday rotation – polarization loss

- ✓ Radio waves propagate through Earths magnetic field
- ✓ Magnetic field changes the polarization of the wave
- ✓ Two negative effects:
  - ✓ Increased losses due to polarization mismatch between RX antenna and radio wave
  - ✓ Increased adjacent channel interference
- ✓ The rotation angle depends on
  - ✓ Length of the path through ionosphere
  - ✓ Concentration of ionosphere charges
  - ✓ Operating frequency
- ✓ The effects becomes smaller with frequency increase

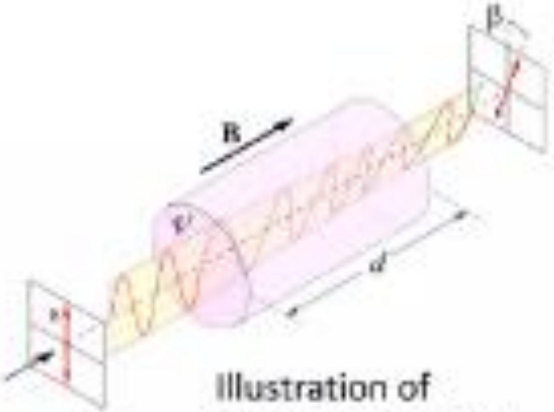
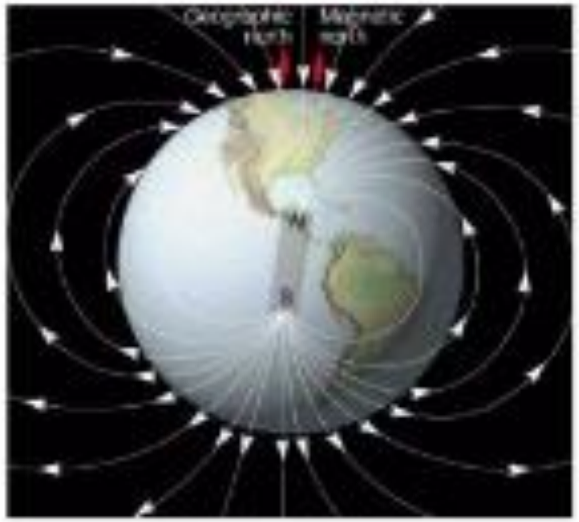


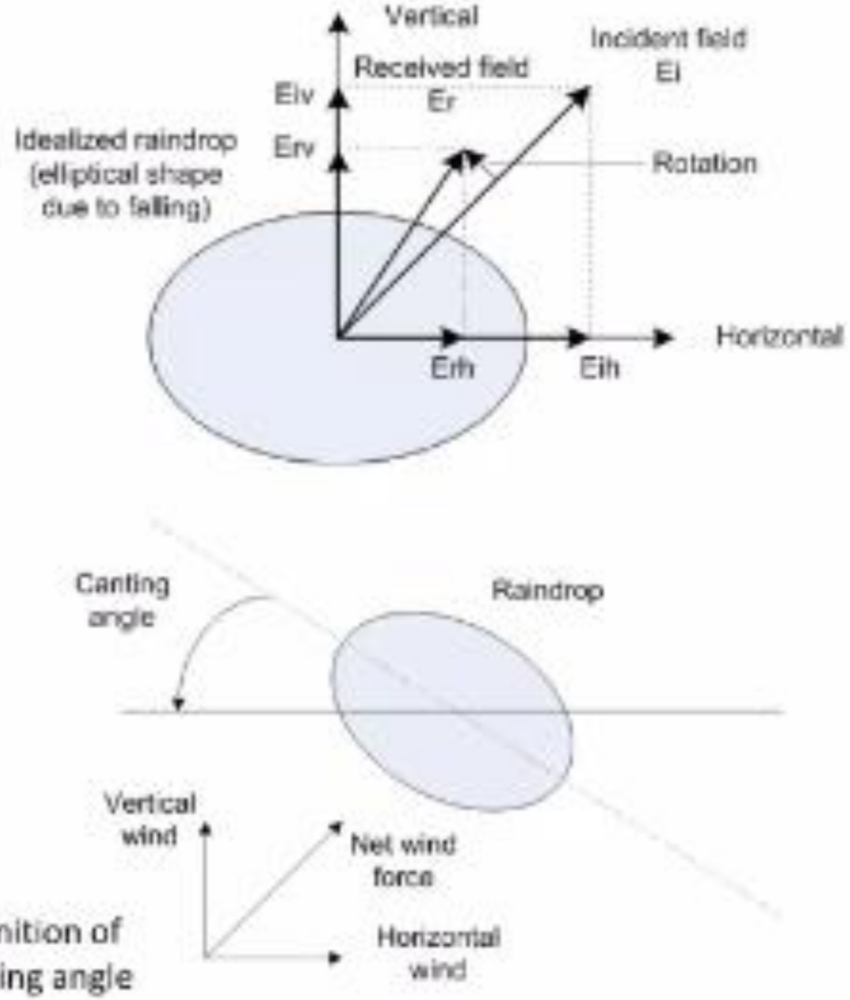
Illustration of Faraday's rotation



Magnetic field of the Earth

Depolarization losses

- Rain affects two polarizations in a different way
- Rain attenuates horizontal component more than the vertical one
- If a linearly polarized wave has a general orientation w.r.t. rainfall, the wave tilts towards vertical polarization
- In a non-wind condition, raindrops have elliptical shape with minor axis in the vertical direction
- In wind-conditions, the orientation of the raindrop ellipse changes – canting angle



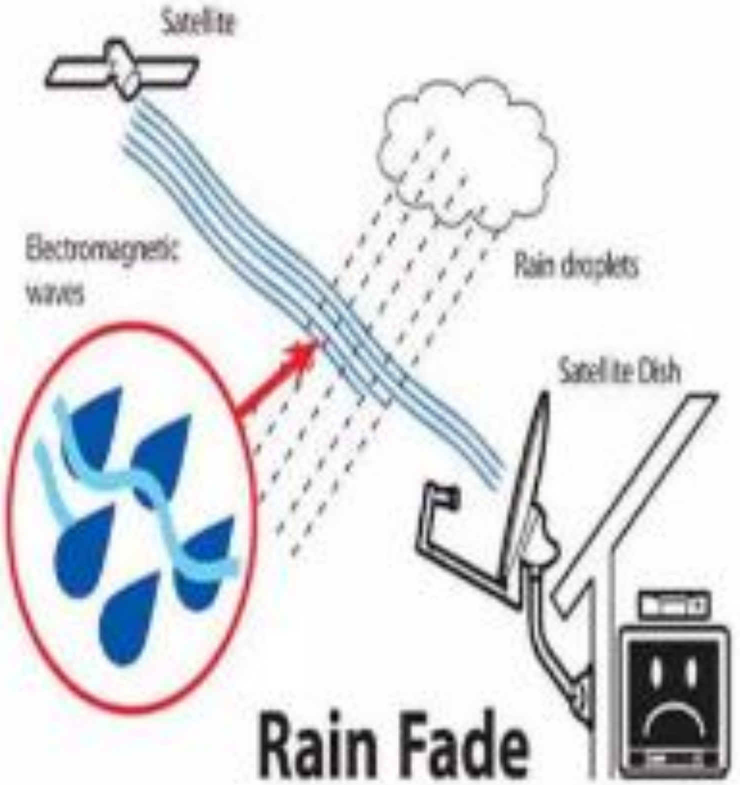
Definition of canting angle

Rain & Ice effects

Rain affects the transmission of an electromagnetic signal in three ways:

(1) It attenuates the signal
(2) it increases the system noise temperature
(3) it changes the polarization.

- ✓ All three of these mechanisms cause a degradation in the received signal quality and become increasingly significant as the carrier frequency increases. As the wavelength decreases and approaches the size of a typical raindrop (approximately 1.5 mm), more scattering and absorption occurs, and the attenuation increases.
- ✓ Also, as the rain rate increases during a heavy downpour, the size of the raindrops, and hence the attenuation, increases.
- ✓ Rain heavily effects the wireless communication above 10 GHz.
- ✓ So Ku band & Ka band will be effected by rain & specially above 20 GHz the Ka Band link can fail during heavy rain fall.
- ✓ From 5% to 20% of rain fade or satellite signal attenuation may also be caused by rain, snow, or ice on the uplink or downlink antenna reflector, or feed horn.

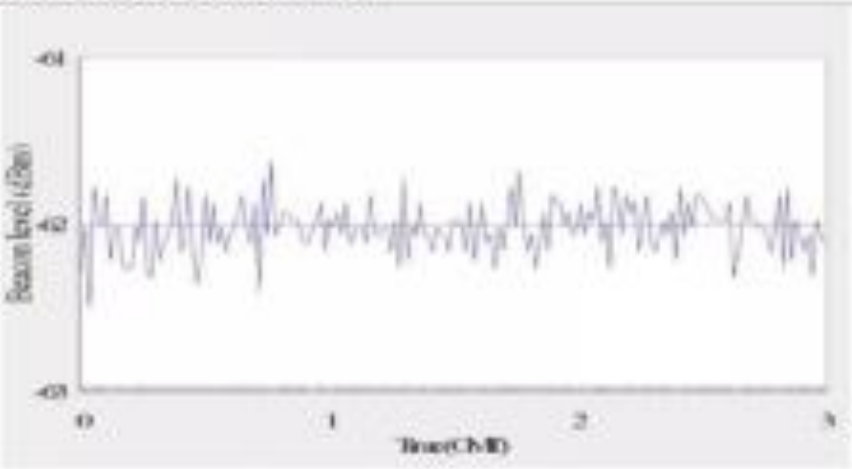


Cloud Effects

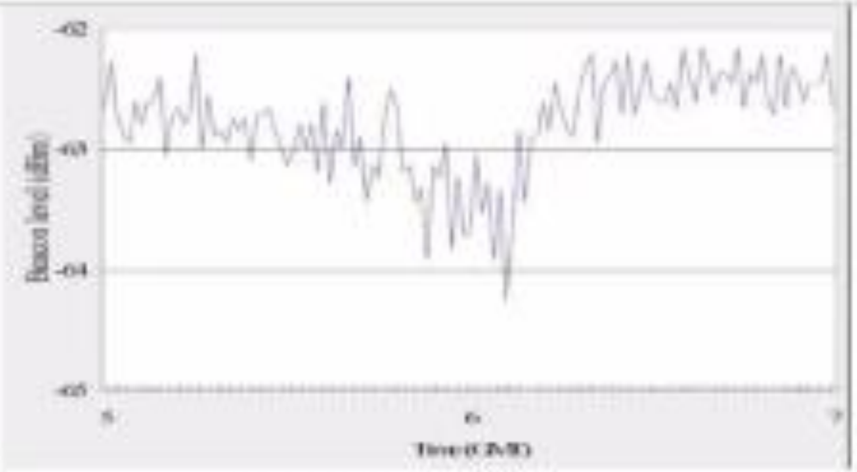
Cloud attenuation becomes increasingly important to consider for reliable satellite communications at frequencies above 10 GHz . For clouds or fog consist of small droplets, less than 0.01 cm, the Rayleigh approximation is valid for frequencies below 200 GHz and it is possible to express the attenuation in terms of the total water content per unit volume . The following equation can be used to obtain the attenuation due to clouds for a given probability:

$$A = L K l \sin\theta \quad dB \text{ for } 90° \geq \theta \geq 5°$$

where L is the total columnar content of liquid water Kl is the specific attenuation by water droplet (kg/m^2), and θ is the elevation angle.



Clear Sky Signal



Cloud Attenuation

Attenuation due to Hydrometeors

- When propagating through rain, snow, hail or ice droplets, radio waves suffer power loss due to hydrometeor scattering.
- Though hydrometeor scattering is the major limiting factor in the EHF band (>30 GHz), hydrometeor absorption is the dominant phenomenon causing power loss in the frequency between 10 GHz and 30 GHz (Panagopoulos et al., 2004).
- The combined effect of hydrometeor scattering and absorption, results in a power loss, proportional in dB to the square of the frequency (Stutzman, 1993).
- It has been found that the transmission attenuation due to hydrometeors like clouds, snow, fog or rain is caused by two factors: the energy absorption by Joule effect by hydrometeors and the wave diffusion induced by the particles.

Prediction of rain attenuation

What is Rain Attenuation ?

The attenuation of a signal due to rain is the extent to which the strength of a signal is reduced when passing through rain from a transmitter to a receiver, Also called rain fade.

Rain causes attenuation in electromagnetic waves through the process absorption and scattering; rainfall attenuation is a phenomenon relative to the rainfall rate and frequency which results in increasing path loss, limiting the coverage area, and consequently degrading the system performance.

ITU-R is an organization which standardized the rule for telecommunication and provided a step by step approach for prediction of rain attenuation on any terrestrial radio link; however, this model does not perform well in tropical region and at high rainfall rate since average radius of raindrop in tropical region is greater than that in nontropical and data for ITU model is based on data collected from temperate region of the world.

Factors Affecting Satellite-Earth Link in Rain

- ✓ Frequency of operation
- ✓ Elevation angle of satellite
- ✓ Slant-path length
- ✓ Rain rate
- ✓ Rain height

How does it affect you ?

All forms of wireless terrestrial and extra-terrestrial mode of communication will be disrupted.

Example: Satellite TV, Satellite data transmission & Mobile communication

Rainfall Classification

Stratiform Rain – medium & low intensity, wide area, long duration.

Convective Rain – high intensity, small area, short duration.

Rain Attenuation Prediction Models

Two methods for prediction of rain attenuation on radio wave path have been grouped into two categories: Physical method and Empirical method.

Physical Methods:

- Physical methods are referred to theoretical models (analytical models) which make attempts to reproduce physical behavior involved in the attenuation process.
- When physical approach is used not all the input parameters are required for analysis, while analytical models offer an insight into the physical processes involved in radio wave propagation through atmosphere; however they invariably require the use of numerical analysis methods to provide solutions to intractable mathematical formulations.
- A physical method to calculate attenuation is used by practical implementation of labs, and a complete set up is needed before starting the experiments.
- It is quite hard to establish set-up, and this kind of experiments costs a lot.
- Most of the time, these models took a lot of time to give the precise results.
- These are more reliable because the results which we achieved out of the experiments are real problems based and these kinds of experiments required very high experienced person to perform them.

Empirical Method:

- ✓ Empirical model is based on measurement database stations in different climatic zones within a given zone.
- ✓ The main advantages of these models lie in the simplicity of the mathematical expressions describing them, leading to their straightforward applications like Seville, Paulsen, Seville, Excell model, Cranes two-component model, two-component modified exponential model, fitted ITU-R model, Stephens and its derivatives, and specific attenuation model (SAM) by Stutzman and Dishmna among others, to give best fits to measured data, which can be found in literature and comprehensive information on these models can be obtained from COST.
- ✓ Although they do not consider the physical processes underlying propagation in vegetation, they are based on knowledge of the qualitative behavior of absorption and scatter in homogeneous scattering media.
- ✓ These models are relatively new and have been formulated using measured data mostly obtained recently.
- ✓ They have however many drawbacks, not least of which are their strict dependence on specific measured data and their failure to relate to physical process involved.

Multiple Access Techniques

Multiple Access Types

- Multiple access scheme allows many users to share satellite's resource (Capacity).
- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)

FDMA

- It is the simplest and most established technique employed in satellite communications.
- The available transponder bandwidth is divided into channels and then assigned to users. The users are separated in the frequency domain. FDMA assign particular frequency slices to different wireless terminals.
- Types:
  - Single Channel per Carrier (SCPC)
  - Multiple Channel per Carrier (MCPC)

FDMA

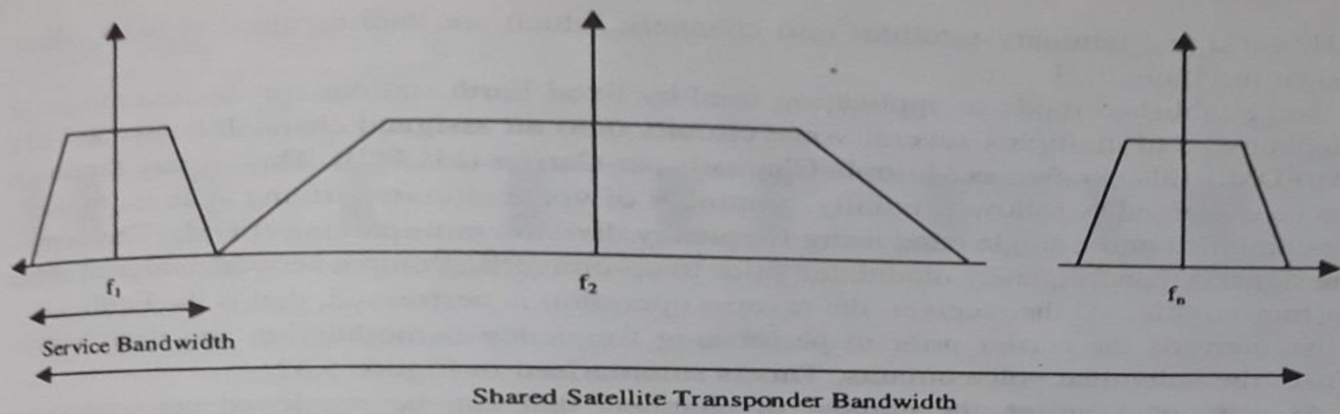
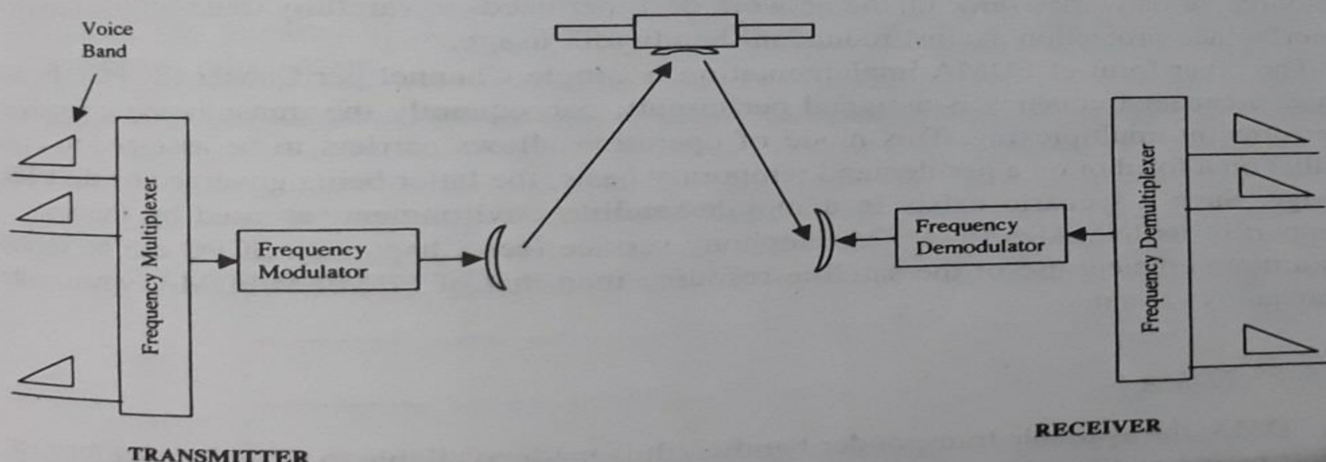


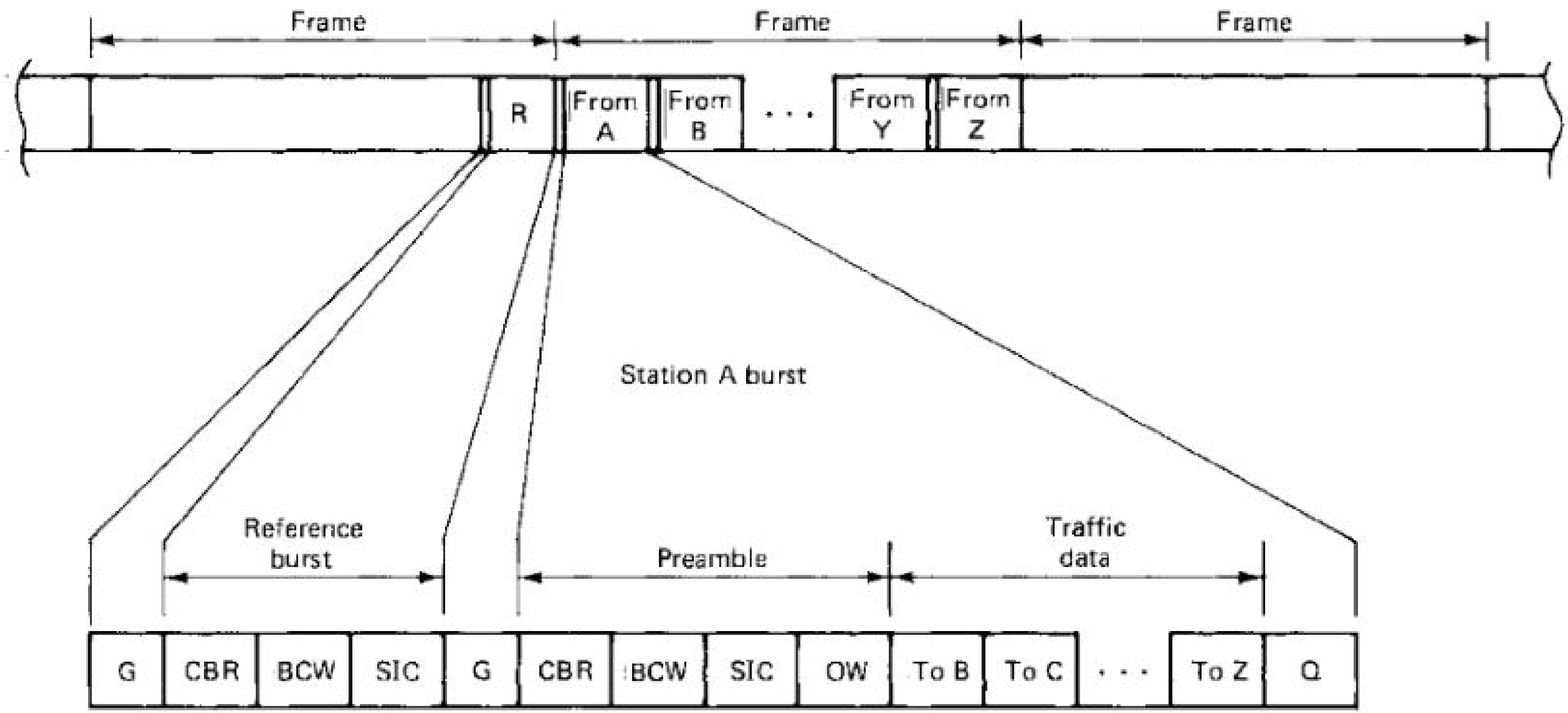
Figure 5.31 Multi-carrier usage of shared transponder bandwidth.



TDMA

- The available transponder bandwidth is made available to an active user for a very short period of time, known as burst. In TDMA the users are separated in time domain. TDMA assign particular time slices to different wireless terminals.
- In the short period of time data are rapidly transmitted.
- The total available transponder bandwidth is shared with other users during different time slots.
- Reference burst is used to ensure that each user transmits within a specific time slot. Reference burst is made up of three parts namely, i. Carrier and Bit Timing Recovery, ii. Unique Word and iii. Control Information.

TDMA Frame Structure



Legend:
G – guard time
CBR – carrier and bit-timing recovery
BCW – burst code word (also known as a unique word or UW)
SIC – station identification code
Q – postamble

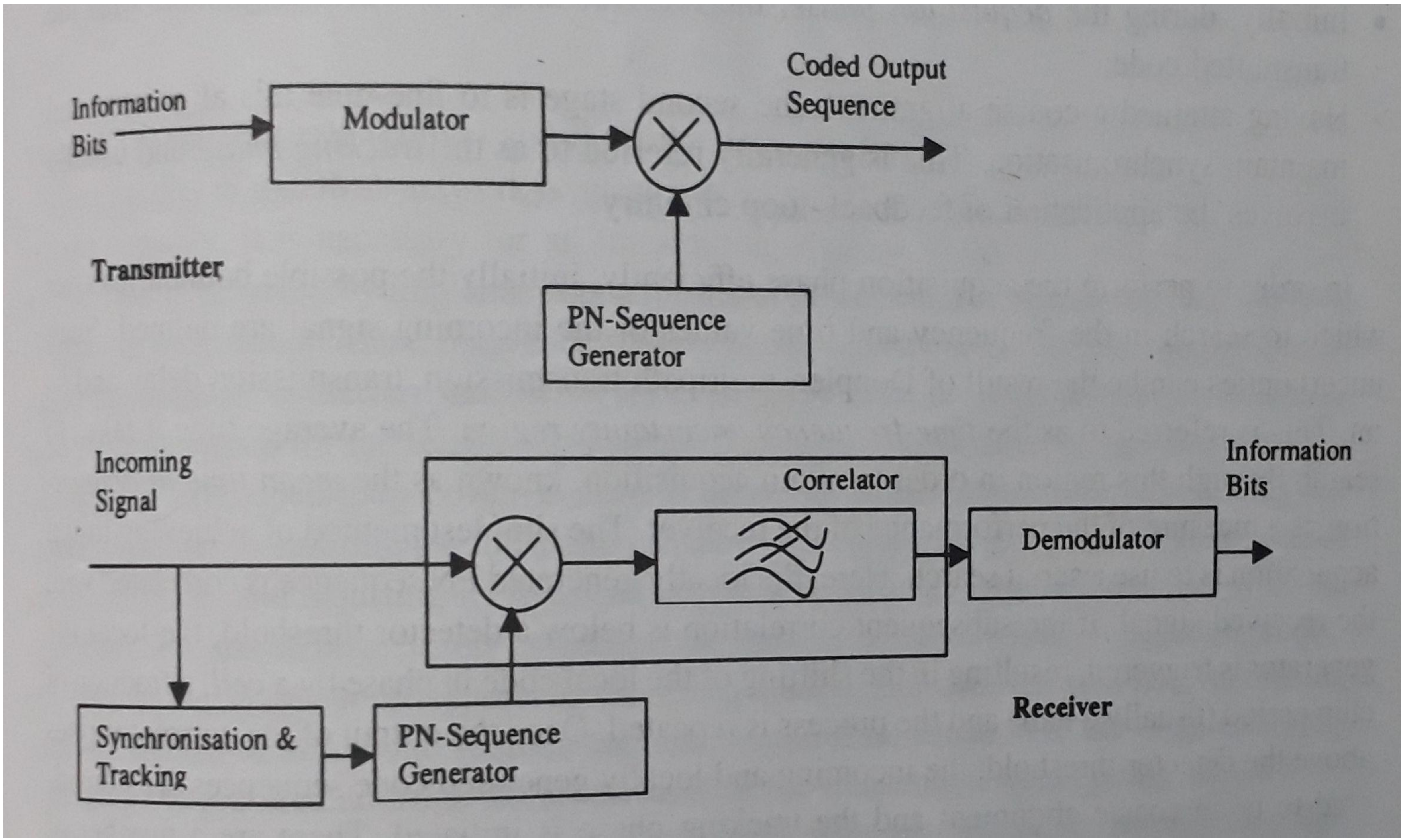
CDMA

- CDMA is a digital wireless technology that was pioneered and commercially developed by QUALCOMM in 1995.
- In CDMA the total available bandwidth is made accessible to all active users at the same time. This is achieved with a unique code known only to the transmitter and receiver.
- Code generation is achieved by using a linear feedback multi-stage shift register and a modulo 2 adder. The output produces a code sequence with noise like properties termed as pseudo noise.
- CDMA techniques are Direct Sequence, Frequency Hopping and Time Hopping.

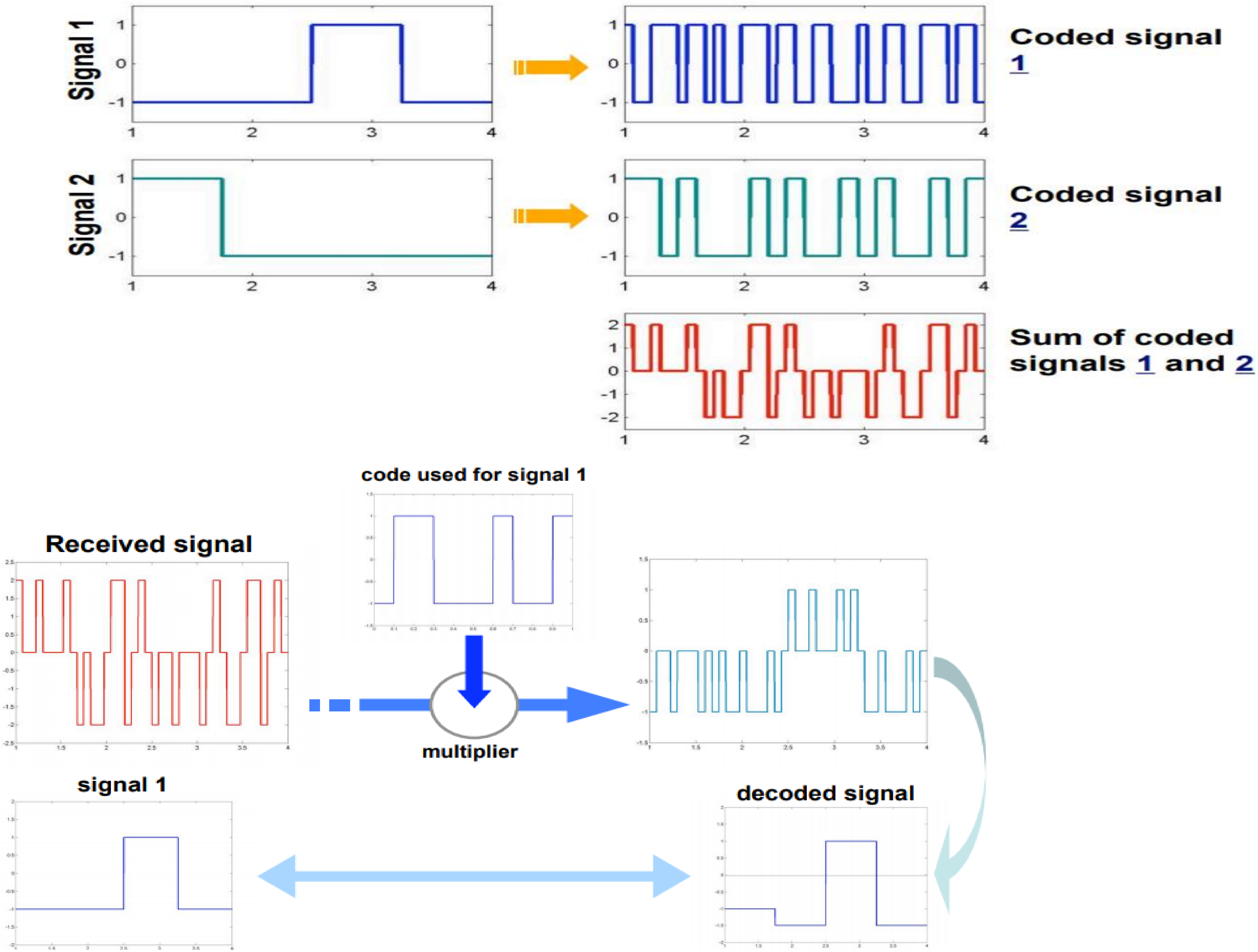
- CDMA allows multiple users to simultaneously use a common channel for transmission of information.
- A CDMA transmitter will code its information with a code or spreading sequence particularly allocated for the user.
- The transmitter sends the coded signal to the receiver. Using the same code sequence, the receiver decodes the received signal. The coding process is also called as spread spectrum modulation. The coded signal is called as spread spectrum signal.

Direct Sequence CDMA

The original data signal is multiplied by the high chip rate spreading code.

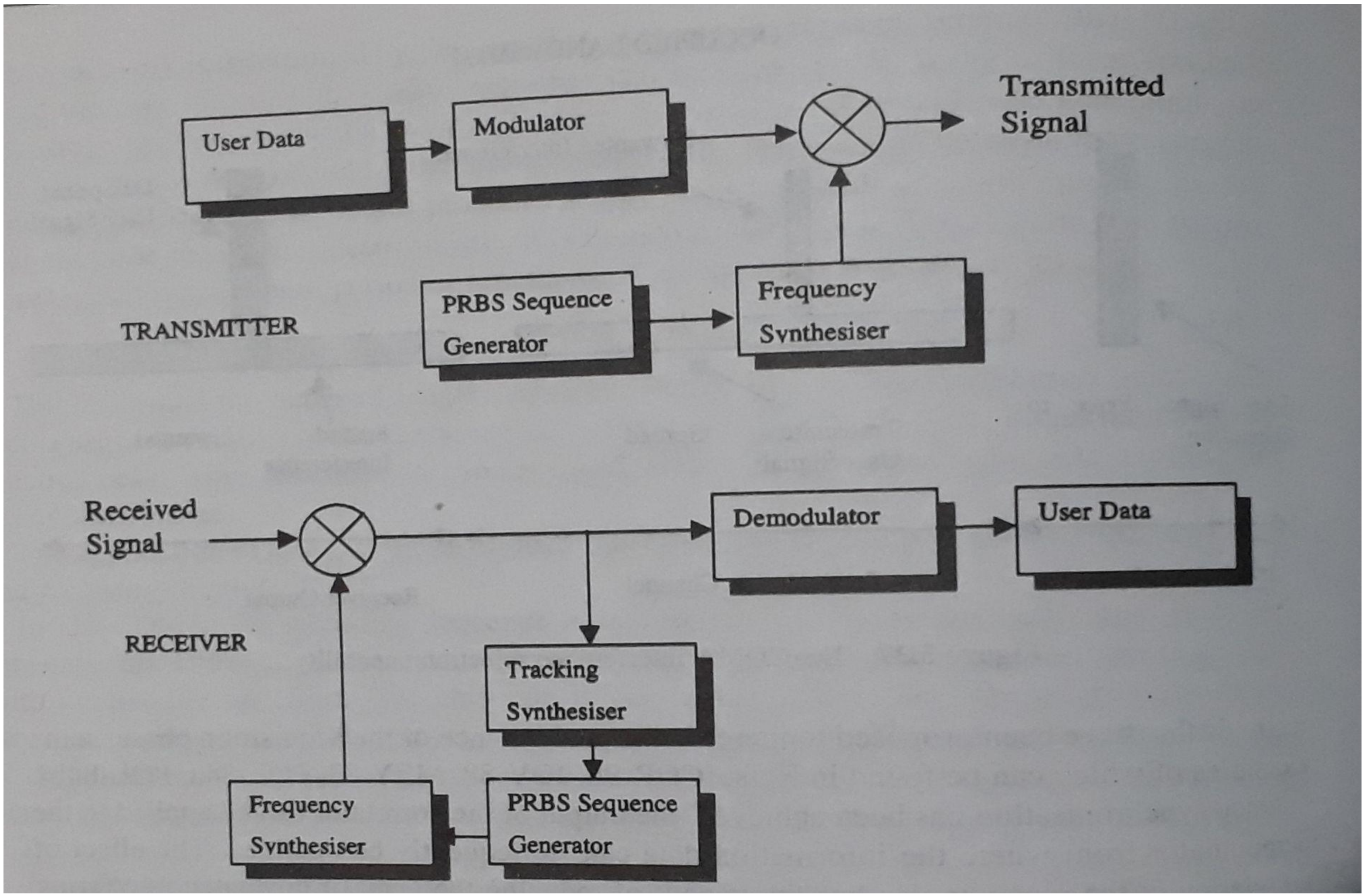


Direct Sequence Spread Spectrum



FH-CDMA

The carrier frequency at which the original data signal is transmitted is rapidly changed according to the spreading code.



TH-CDMA

- The original data signal is not transmitted continuously. Instead, the signal is transmitted in short bursts where the times of the bursts are decided by the spreading code.

DAMA

Demand Assigned Multiple Access is used when the link between the station and satellite is not a constant one.

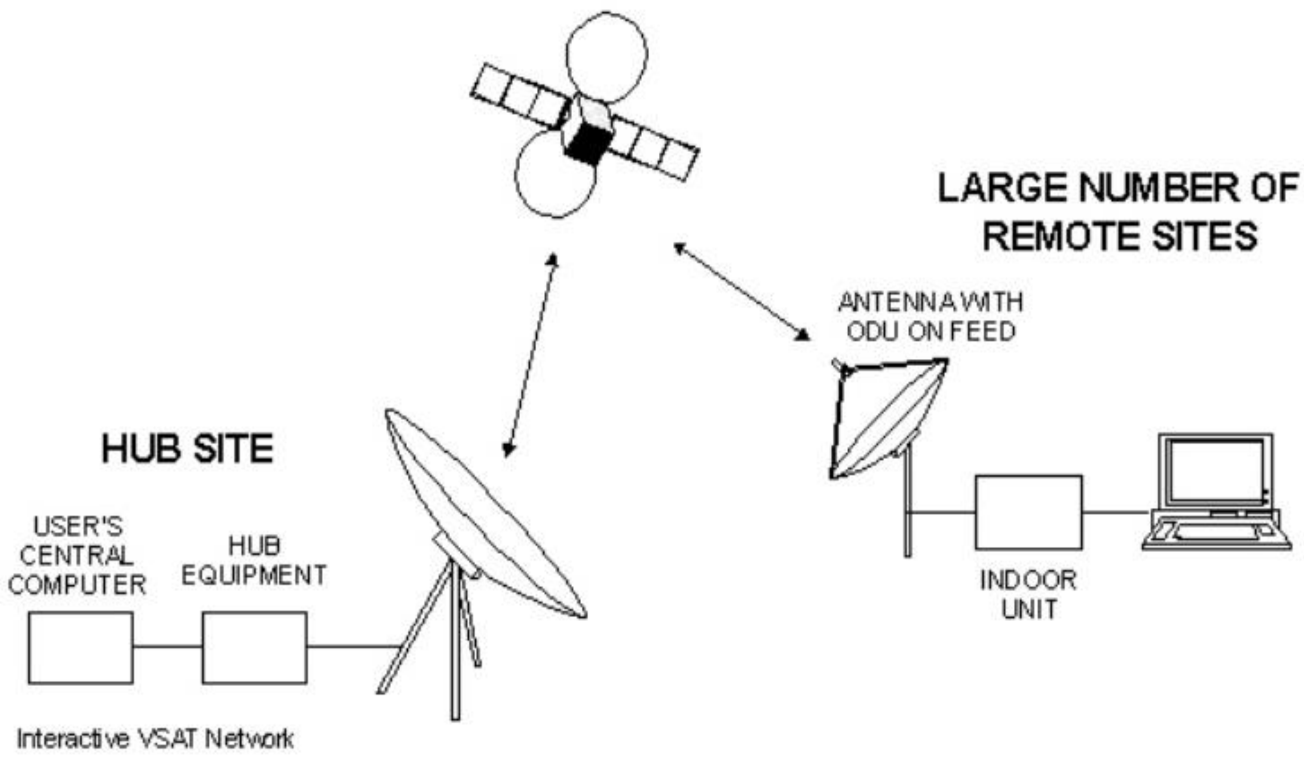
This helps assign bandwidth according to the demand.

This can be implemented on TDMA or FDMA or combination of both.

It is commonly used in VSAT (Very Small Aperture Terminal) Systems.

DAMA

- It is often used in military environments due to the relative simplicity of implementation.
- It can operate with bent pipe transponders.



Technique	FDMA	TDMA	CDMA	SDMA
Concept	Divide the frequency band into disjoint sub-bands	Divide the time into non-overlapping time slots	Spread the signal with orthogonal codes	Divide the space in to sectors
Active terminals	All terminals active on their specified frequencies	Terminals are active in their specified slot on same frequency	All terminals active on same frequency	Number of terminals per beam depends on FDMA/ TDMA/ CDMA
Signal separation	Filtering in frequency	Synchronization in time	Code separation	Spatial separation using smart antennas
Handoff	Hard handoff	Hard handoff	Soft handoff	Hard and soft handoffs
Advantages	Simple and robust	Flexible	Flexible	Very simple, increases system capacity
Disadvantages	Inflexible, available frequencies are fixed, requires guard bands	Requires guard space, synchronization problem	Complex receivers, requires power control to avoid near-far problem	Inflexible, requires network monitoring to avoid intra cell handoffs
Current applications	Radio, TV and analog cellular	GSM and PDC	2.5G and 3G	Satellite systems, LTE

Satellite Packet Communications

- Every communications satellite in its simplest form performs the task of transmitting information from a source earth station to the satellite (this is called the uplink). This is followed by a retransmission of the received and processed information from the satellite back to the ground (this is called the downlink).
- The downlink may either be to a select number of ground stations or it may be broadcast to all receiving terminals in the satellite's footprint. Here, we focus on specific protocols or methods guiding access to the medium used for transmission and retransmission of packets (messages) to and from the satellites.
- These protocols are referred to as Medium Access Schemes. Medium Access Control (MAC) schemes are mechanisms for sharing a single link. MAC schemes are essentially multiplexing schemes. Message access on any system can be of three types:
- Conflict-free Scheme.
- Contention (random access) Scheme.
- Reservation (controlled access) Scheme

Message Transmission by FDMA: M/G/1 Queue

a. M/G/1 QUEUE

Consider a queuing system, in which arrivals occur according to a Poisson process with parameter and in which x is the service rendered to the customers, is distributed according to a distribution *B(t)*. In such a queuing system, an outside observer sees the number of customers in the system as equal to that seen by an arriving customer, which equals that seen by a departing customer. The following holds for an M/G/1 queuing system:

$$D = x + W = x + \frac{\lambda x^2}{2(1-\lambda T)}$$

Where D = Average delay time, p = λx = Load factor, W = Queuing time.

Therefore, for an FDMA system, considering a typical user that generates packets according to a Poisson process with rate λ packets/sec and its buffering capabilities are not limited, the time required for the transmission of a packet is . Each node can therefore be viewed as an M/G/1 queue since each packet size is not constant. Thus, using the known system delay time formula for M/G/1 queuing systems we get that the expected delay of a packet is:

$$D = T + \frac{\lambda T^2}{2(1-\lambda T)}$$

And the delay is distribution is given by,

$$D^* = X^*(s)\,\frac{s(1-p)}{s-\lambda+\lambda X*(s)}$$

Where X*(s) is the laplace transform of the transmission time.

ALOHA (Additive Links On-line Hawaii Area)

- Message transmission by TDMA can be done using the ALOHA protocol, packet reservation and tree algorithm.
- The ALOHA scheme was invented at the University of Hawaii for the purpose of interconnecting remote stations and data terminals to a central server over a packet radio network.
- Its simplest mode of operation consists of earth stations randomly accessing a particular resource that is used to transmit packets.
- Earth stations can detect whether their transmission has been correctly received at the satellite by either monitoring the re-transmission from the satellite or by receiving an acknowledgement message from the receiving station.

Slotted ALOHA

- The Pure Aloha implemented with a slotted channel variation is known as the slotted Aloha protocol. For the slotted Aloha variant, all packets are of equal length and time is slotted.
- Packets are only transmitted in the next subsequent slot to their arrival slot. It also assumes that there is no buffering, i.e. a station never has more than one packet to transmit in a single time slot, in which case, the station would have needed to buffer one or more packets for subsequent transmission.
- To accommodate the “no buffering” assumption, it assumes that there is an infinite number of stations, with each new arrival from a new 'source' station. Inevitable collision occurs if more than one station venture to transmit packets in one and the same time slot, and consequently the receivers cannot receive the packets correctly.
- Successful transmission happens only when there is exactly one packet transmitted in a slot. If no packet is transmitted in a slot, the slot is called idle. If there is a collision, the colliding packets are retransmitted at a later slot after a randomly chosen back-off period. Such packets are also called backlogged packets.

Coding Schemes

- Coding techniques are used for several reasons: reduction of dc wandering, suppression of intersymbol interference, and self-clocking capability.
- The coding schemes are for error detection and correction, specifically forward error correction (FEC) techniques. FEC codes may be divided into two classes of codes, namely, linear block codes and convolutional codes. Depending on the intended use of codes, FEC enables the receiver not only to detect errors but also to facilitate their correction.

Linear Block Codes:

In linear block codes, the encoder splits up the incoming data stream into blocks of k digits and processes each block individually by adding redundancy as a parity check according to a predefined algorithm.

The output of the encoder is a code word with n digits, where n > k. The general form of a linear block code word is Y = GX.

where G is a generator matrix that creates the check bits from the data bits, while the input message vector X and code (output) vector Y have components defined as

X = (x1; x2; x3; ... ; xk) Y = (y1; y2; y3; ... ; yn)

Cyclic Codes:

Cyclic codes are a subset of linear block codes. They are the most useful and popular because encoding and decoding can be implemented by using simple shift registers: error detection and correction are achieved with shift registers and some additional logic gates

BCH Codes:

The BCH (Bose–Chaudhuri–Hocquenghem) codes are the most powerful and flexible group of cyclic error correction codes available. Their design is straightforward: it uses shift register and logic circuits for coding and decoding.

Convolutional Codes:

A convolutional coder is a finite memory system. The name ‘‘convolutional’’ refers to the fact that the added redundant bits are generated by mod-2 convolutions. A generalized convolutional encoder consists of an L-stage shift register, n mod-2 adders, a commutator, and network of feedback connections between the shift register and the adders.

A very important parameter in the consideration of convolutional encoding is the constraint or memory length. The constraint length is defined as the number of shifts over which a single message bit can influence the encoder output. For example, if input message data are in groups of k bits and are fed into the L-stage shift register, then the register can hold (L=k) groups.