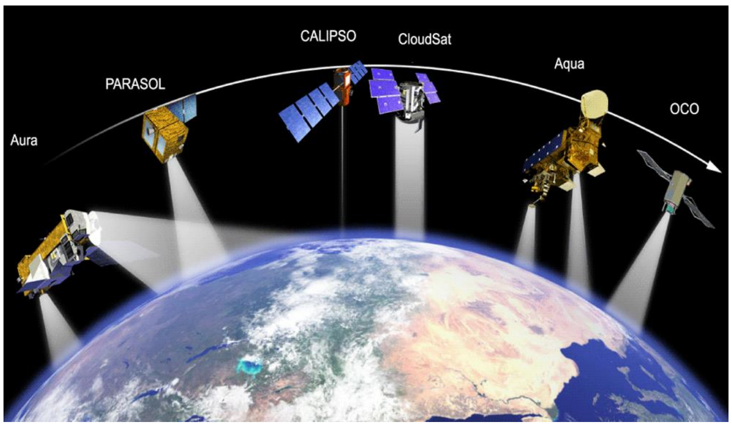
What is a Satellite?

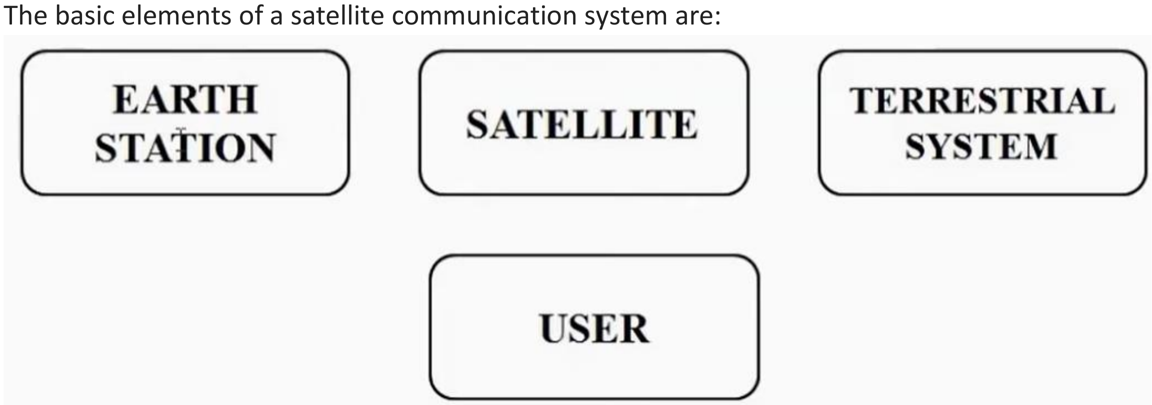
- A satellite is an object in space that orbits or circles around a larger object.
- An artificial satellite is an object that has been intentionally placed into orbit that relays and amplifies radio telecommunications signals.
- Applications:
    - Voice/Telephone
    - Television/Radio Broadcast
    - Network/Internet
    - Navigation and GPS
    - Scientific research
    - Meteorology

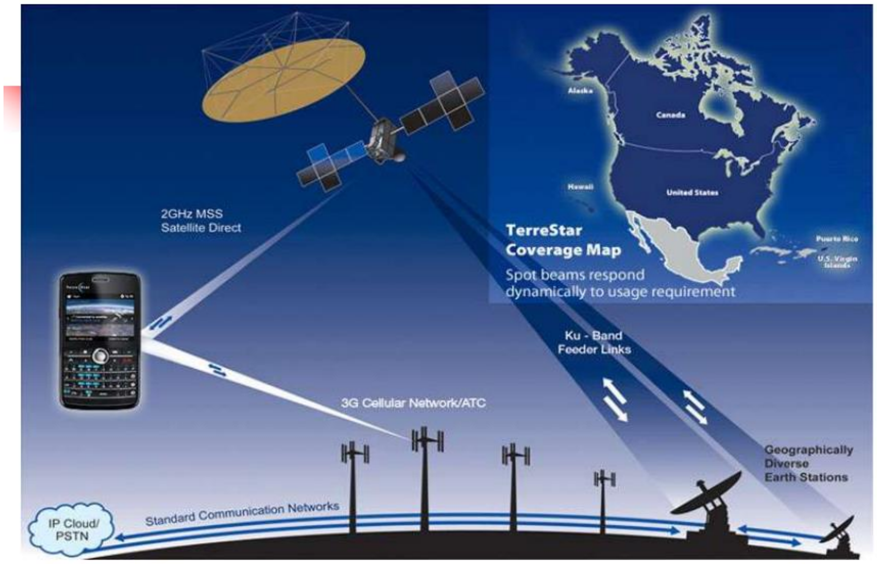


- In simple terms, a satellite is a smaller object or body that revolves around a much larger object in space in a fixed well defined path.
- They are of two types:
    - Natural Satellites
    - Artificial Satellites
- For example – earth revolves around the sun, so it is a satellite. Moon revolves around earth, so it is also a satellite. But they are Natural Satellites.
- Artificial satellites are specifically designed and launched into space for a variety of purposes such as weather monitoring, navigation, tv and mobile communication, planetary research etc. Ex-INSAT, IRS, GSAT etc.

Basic Elements of Satellite Communication System

- The basic elements of a satellite communication system are:





Satellite Introduction

- **Satellite:** In **astronomical terms**, a satellite is a celestial body that orbits around a planet.
  - **Example:** The moon is a satellite of Earth.
- In **aerospace terms**, a satellite is a space vehicle launched by humans and orbits around Earth or another celestial body.

What is a satellite system?

- A **satellite system** consists of one or more satellites, a ground-based station to control the operation of the system, and a user network earth stations that provides the interface facilities for the transmission and reception of terrestrial communications traffic.

Communications Satellite: It is a microwave repeater in the sky that consists of a diverse combination of one or more components including transmitter, receiver, amplifier, regenerator, filter onboard computer, multiplexer, demultiplexer, antenna, waveguide etc.

A satellite radio repeater is also called **transponder**. This is usually a combination of transmitter and receiver.

How a satellite works?

- A satellite stays in orbit because the gravitational pull of the earth is balanced by the centripetal force of the revolving satellite.
- One Earth station transmits the signals to the satellite at **Up link frequency**. Up link frequency is the frequency at which Earth station is communicating with a satellite.
- The satellite transponder process the signal and sends it to the second Earth station at another frequency called **downlink frequency**.

Advantages of Satellite Communications over Terrestrial Communications

- The coverage area greatly exceeds.
- Transmission cost of a satellite is independent of the distance from the center of the coverage area.
- Satellite-to-satellite communication is very precise.
- Higher bandwidths are available for use.

Disadvantages of Satellite Communications

- Launching satellites into orbits is costly.
- Satellite bandwidth is gradually becoming used up.
- The propagation delay is larger.

Regions of Space

Space is defined as a place *free from obstacles*
It can be divided into three regions:

- Air Space -> region below 100 km from earth's surface
- Outer Space -> also called cosmic space and ranges from 100 km up till 42, 000 km. It is mostly used by communication satellites.
- Deep Space -> Regions beyond 42,000 km fall in this category

Active and Passive Satellites

→Active satellites are used for linking and also for processing the signals.

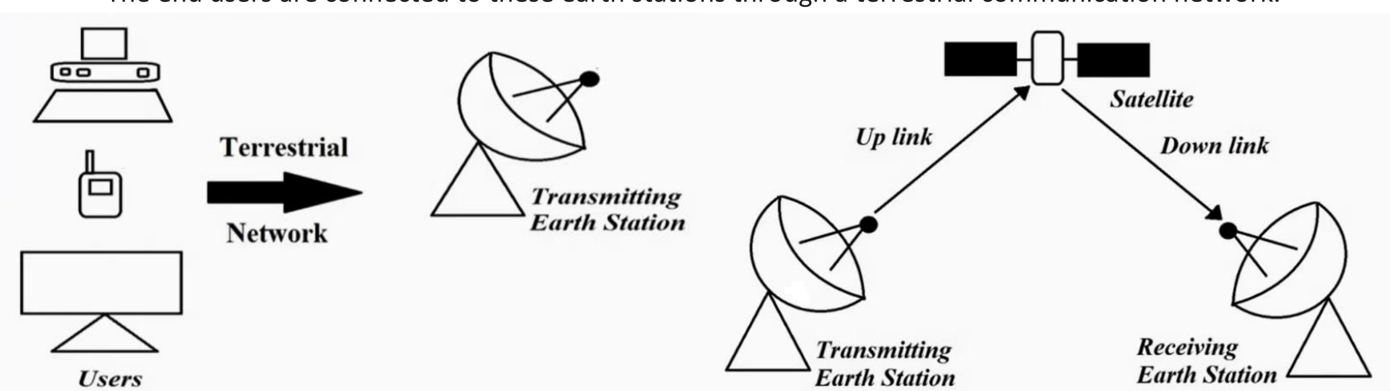
The linkage is known as bent pipe technology where processing like frequency translation, power amplification etc take place.
Active satellites employ 'Regenerative Technology' which consists of demodulation, processing, frequency translation, switching and power amplification are carried out. Block used for this purpose is called transponder.

→ Passive satellites do-not have on-board processing and are just used to link two stations through space.

Low cost - Loss of power – not useful for communication applications.

Principle:

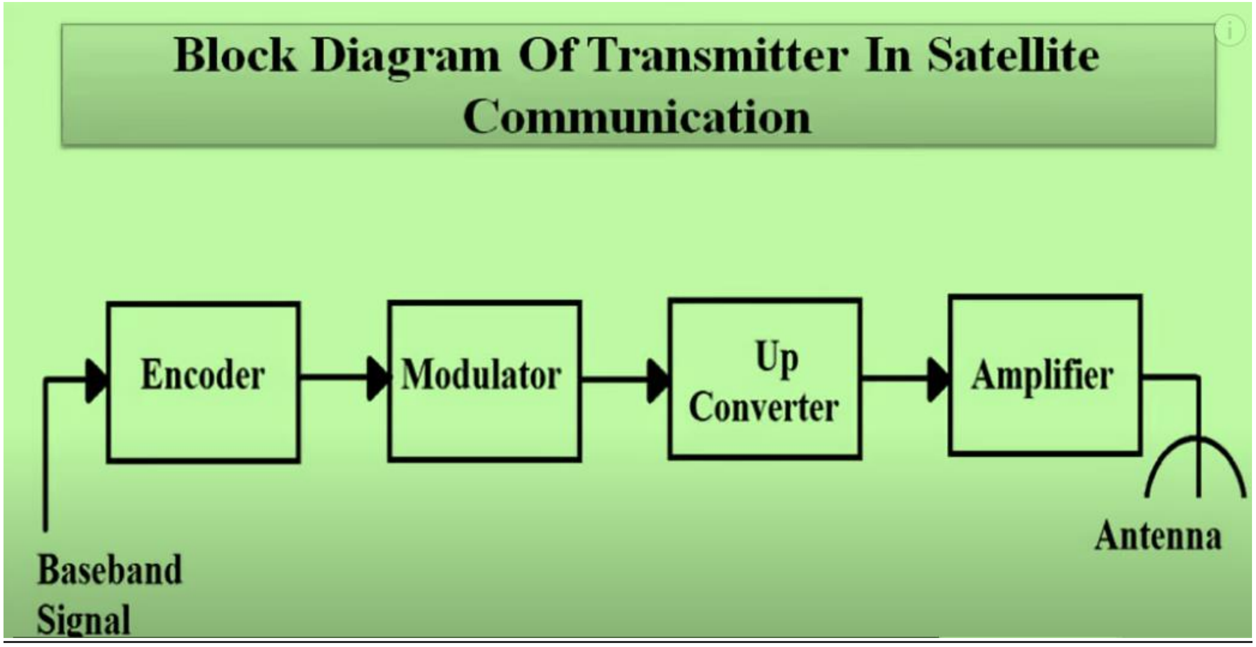
- The network consists of several earth stations on ground which are linked with a satellite in space.
- The end users are connected to these earth stations through a terrestrial communication network.

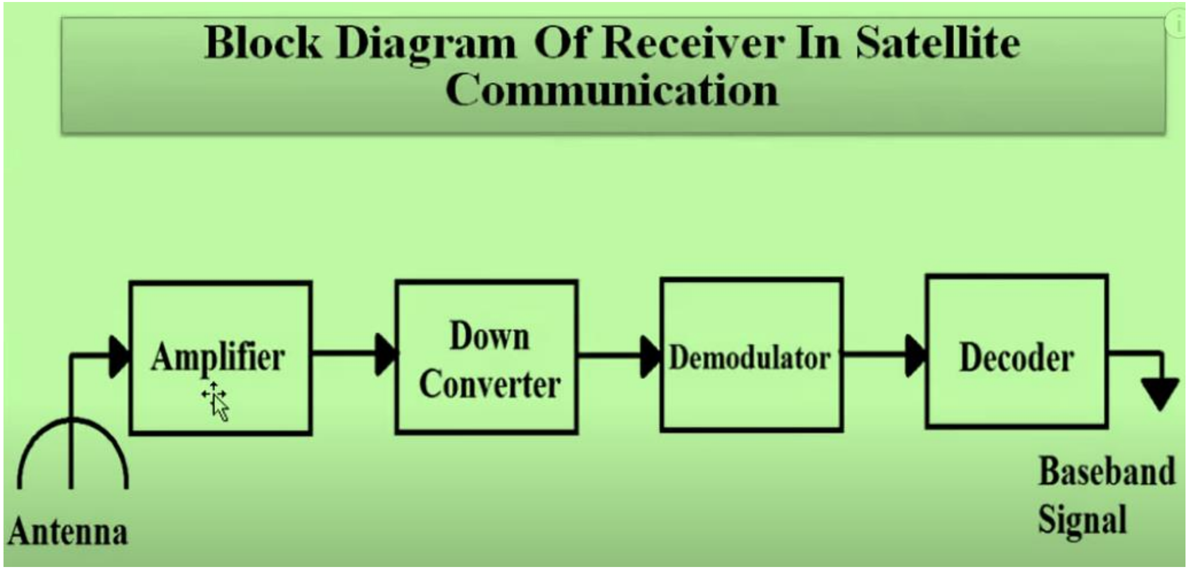


- The user generates a message signal which is passed and processed through the terrestrial communication network to the earth station.

- The earth station modulates the signal and sends that signal to the satellite in space on the uplink frequency spectrum.
- The satellite amplifies and processes the signal and retransmits it back on the downlink frequency spectrum.

Block Diagram of Transmitter and Receiver in Satellite Communication





1. **Baseband Signal:** A baseband signal or lowpass signal is a signal which is directly generated by users that can include frequencies that are very near zero, by comparison with its highest frequency (for

example, a sound waveform can be considered as a baseband signal, whereas a radio signal or any other modulated signal is not).

2. **Encoder:** Encoding means converting the incoming message signal into suitable form for transmission. It consists in changing the information into some form of logical and coded message. The encoding process is based on the purpose of communication and the relation between the sender and the receiver. In receiving side decoding is performed.

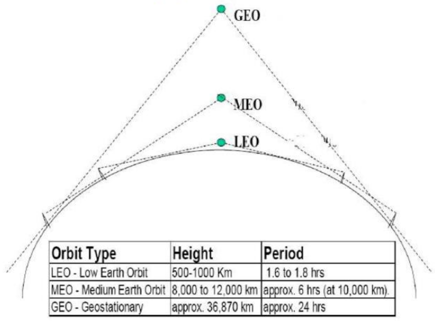
3. **Modulator:** Modulation is the process of combining the wanted data on a Radio Frequency (RF) carrier which is then conveyed over the satellite link and demodulated at the receiving terminal. The modulation translation a baseband spectrum in lower frequency range to a carrier spectrum at a much higher frequency range. In receiving side demodulation is performed.

4. **Up convertor:** Up conversion simply translates a signal to a higher center frequency. However, modulation is best defined as the process of selecting a waveform type or shape such as Amplitude, phase or frequency. Modulation might entail up conversion, as is the case for wireless radio applications. But the application might be machine-to-machine requiring baseband modulation (no up conversion needed). In receiving side down conversion should be performed.

5. **Amplifier:** The role of power amplifiers is to amplify the microwave signal converted at the antenna's output. The output power of the transmitter at these frequencies must be high, as the satellites only receive a tiny portion of the power transmitted in their direction. An amplifier is **an electronic device that increases the voltage, current, or power of a signal**. Amplifiers are used in wireless communications and broadcasting, and in audio equipment of all kinds. They can be categorized as either weak-signal amplifiers or power amplifiers.

   In transmitting side signal amplification is performed right before it gets transmitted through the antenna. In receiving side signal amplification is performed once receiver receives the signal. Noise suppression and received signal amplification is happened in this stage.

Orbital Types



Orbit Type	Height	Period
LEO - Low Earth Orbit	500-1000 Km	1.6 to 1.8 hrs
MEO - Medium Earth Orbit	8,000 to 12,000 km	approx. 6 hrs (at 10,000 km).
GEO - Geostationary	approx. 36,870 km	approx. 24 hrs

Major problems for satellites

- Positioning in orbit
- Stability
- Power
- Communications
- Harsh environment

Positioning

- This can be achieved by several methods
- One method is to use small rocket motors
- These use fuel - over half of the weight of most satellites is made up of fuel
- Often it is the fuel availability which determines the lifetime of a satellite
- Commercial life of a satellite typically 10-15 years

Stability

- It is vital that satellites are stabilised
  - to ensure that solar panels are aligned properly
  - to ensure that communications antennae are aligned properly
- Early satellites used spin stabilisation
  - Either this required an inefficient omni-directional aerial
  - Or antennae were precisely counter-rotated in order to provide stable communications

Stability (2)

- Modern satellites use reaction wheel stabilisation - a form of gyroscopic stabilisation Other methods of stabilisation are also possible
- including:
  - eddy currrent stabilisation
  - (forces act on the satellite as it moves through the earth's magnetic field)

Reaction wheel stabilisation

- Heavy wheels which rotate at high speed - often in groups of 4.
- 3 are orthogonal, and the 4th (spare) is a backup at an angle to the others
- Driven by electric motors - as they speed up or slow down the satellite rotates
- If the speed of the wheels is inappropriate, rocket motors must be used to stabilise the satellite - which uses fuel

Power

- Modern satellites use a variety of power means
- Solar panels are now quite efficient, so solar power is used to generate electricity
- Batteries are needed as sometimes the satellites are behind the earth - this happens about half the time for a LEO satellite
- Nuclear power has been used - but not recommended

Harsh Environment

- Satellite components need to be specially "hardened"
- Circuits which work on the ground will fail very rapidly in space
- Temperature is also a problem - so satellites use electric heaters to keep circuits and other vital parts warmed up - they also need to control the temperature carefully

Alignment

- There are a number of components which need alignment
  - Solar panels
  - Antennae
- These have to point at different parts of the sky at different times, so the problem is not trivial

Antennae alignment

- A parabolic dish can be used which is pointing in the correct general direction
- Different feeder "horns" can be used to direct outgoing beams more precisely
- Similarly for incoming beams
- A modern satellite should be capable of at least 50 differently directed beams

Satellite - satellite communication

- It is also possible for satellites to communicate with other satellites
- Communication can be by microwave or by optical laser

Communication frequencies

- Microwave band terminology
  - L band 800 MHz - 2 GHz
  - S band 2-3 GHz
  - C band 3-6 GHz
  - X band 7-9 GHz
  - Ku band 10-17 GHz
  - Ka band 18-22 GHz

Early satellite communications

- Used C band in the range 3.7-4.2 GHz
- Could interfere with terrestrial communications
- Beamwidth is narrower with higher frequencies

Rain fade

- Above 10 GHz rain and other disturbances can have a severe effect on reception
- This can be countered by using larger receiver dishes so moderate rain will have less effect
- In severe rainstorms reception can be lost
- In some countries sandstorms can also be a problem

What Is a Link Budget

- It is a theoretical calculation of end-to-end performance for a communications path under a specific set of conditions.
- Sometimes the conditions are stated; most often at least some of them are implied or assumed.
- Every link budget implies everything not included is irrelevant.
- Sometimes this is true

Why is a Link Budget Important

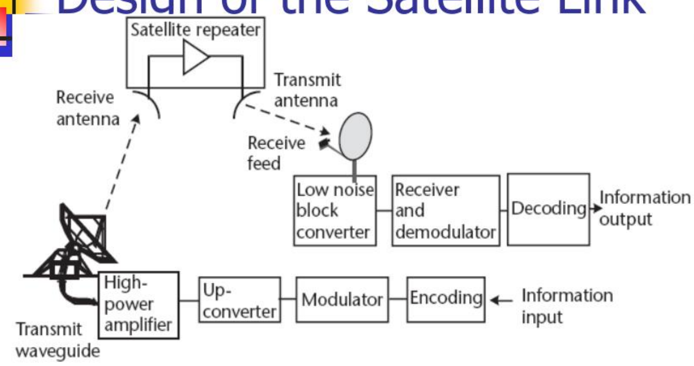
- A link budget is used to predict performance before the link is established.
  - Show in advance if it will be acceptable
  - Show if one option is better than another
  - Provide a criterion to evaluate actual performance

Link Budget Components

- A satellite link budget should include the following parts:

UPLINK
DOWNLINK
COMBINE 1 AND 2
DEFINE PERFORMANCE LIMIT(S)
COMPARE CALCULATED AND DESIRED PERFORMANCE

Design of the Satellite Link



- Figure 2.1: Critical Elements of the Satellite Link

Design of the Satellite Link

The example shows a large hub type Earth station in the uplink and a small VSAT in the downlink; the satellite is represented by a simple frequency translating type repeater (e.g., a bent pipe).

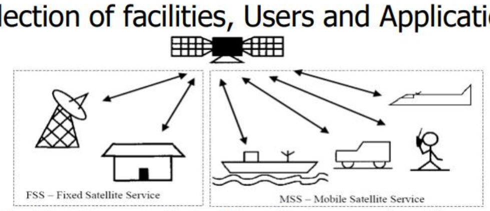
- Most geostationary satellites employ bent-pipe repeaters since these allow the widest range of services and communication techniques.

Design of the Satellite Link

- The result in the overall performance is presented in terms of the ratio of carrier power to noise (the carrier-to-noise ratio, C/N) and, ultimately, information quality (bit error rate, video impairment, or audio fidelity).
- Done properly, this analysis can predict if the link will work with satisfactory quality based on the specifications of the ground and space components.
- Any uncertainty can be covered by providing an appropriate amount of link margin, which is over and above the C/N needed to deal with propagation effects and nonlinearity in the Earth stations and satellite repeater.

Ground Segment

- Collection of facilities, Users and Applications



- Earth Station = Satellite Communication Station
- (Fixed or Mobile)

Why Two Frequencies for Uplink and Downlink in Satellite Com

- The reason the uplink and downlink frequencies are different in satellites is because otherwise the satellite's transmitter and receiver would interfere with one another. The signals have to operate on different frequencies.
- If you could send a signal, then wait, the receiver could be protected from the transmitted signal on the same frequency, but with high speed, continuous transmission, the receiver cannot be turned off while the transmitter is transmitting. (an example of something that transmits and receives on the same frequency is pulsed RADAR, where the transmitter sends out a pulse, and then the echo is picked up by the receiver)

Design of the Satellite Link

- Bidirectional (duplex) communication occurs with a separate transmission from each Earth station.
- Due to the analog nature of the radio frequency link, each element contributes a gain or loss to the link and may add noise and interference as well.

Link Budget and their Interpretation

- The link between the satellite and Earth station is governed by the basic microwave radio link equation:

$$p_r = \frac{p_t g_t g_r c^2}{(4\pi)^2 R^2 f^2}$$

- where p_r is the power received by the receiving antenna; p_t is the power applied to the transmitting antenna; g_t is the gain of the transmitting antenna; g_r is the gain of the receiving antenna; c is the speed of light (i.e., approximately 300 × 10^6 m/s); R is the range (path length) in meters; and f is the frequency in hertz.

Satellite Uplink and Downlink

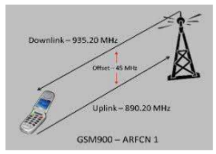
- Downlink
  - The link from a satellite down to one or more ground stations or receivers
- Uplink
  - The link from a ground station up to a satellite.
- Some companies sell uplink and downlink services to
  - television stations, corporations, and to other telecommunication carriers.
  - A company can specialize in providing uplinks, downlinks, or both.

Why Uplink Frequency is Higher than Downlink Frequency

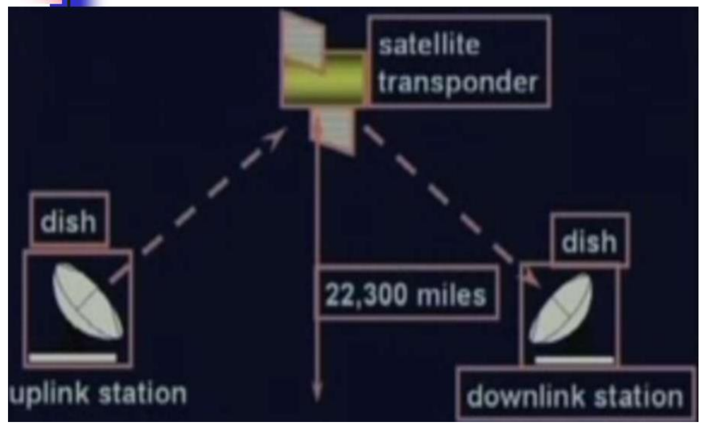
- The signals have to cross the atmosphere which presents a great deal of attenuation. The higher the frequency, the more is the signal loss and more power is needed for reliable transmission.
- A satellite is a light-weight device which cannot support high-power transmitters on it. So, it transmits at a lower frequency (higher the frequency, higher is the transmitter power to accommodate losses) as compared to the stationary earth station which can afford to use very high-power transmitters. This is compensated by using highly sensitive receiver circuits on the earth station which is in the line-of-sight (LOS) of the satellite.

Uplink/Downlink Mobile/Satellite

A mobile is a portable device which cannot afford high-power transmission as it has a small battery with limited power. The 'free space path loss' comes to play. The higher the transmitting frequency, the higher is the loss. Since a mobile station (cellphone) cannot afford to transmit at high power to compensate for this loss, it must transmit on a lower frequency as a lower frequency presents lesser free space path loss. Therefore, mobile-to-base station (uplink) frequencies are lower than base station-to-mobile(downlink) frequencies.



Satellite Uplink and Downlink



Satellite Signals

- Used to transmit signals and data over long distances
  - Weather forecasting
  - Television broadcasting
  - Internet communication
  - Global Positioning Systems

Disadvantages of Satellite Communication

- Large up front capital costs (space segment and launch)
- Terrestrial break even distance expanding (now approx. size of Europe)
- Interference and propagation delay
- Congestion of frequencies and orbits

When to use Terrestrial

- PSTN - satellite is becoming increasingly uneconomic for most trunk telephony routes
- but, there are still good reasons to use satellites for telephony such as: thin routes, diversity, very long distance traffic and remote locations.
- Land mobile/personal communications - in urban areas of developed countries new terrestrial infrastructure is likely to dominate (e.g. GSM, etc.)
- but, satellite can provide fill-in as terrestrial networks are implemented, also provide similar services in rural areas and underdeveloped countries

Advantages of Satellite Communication

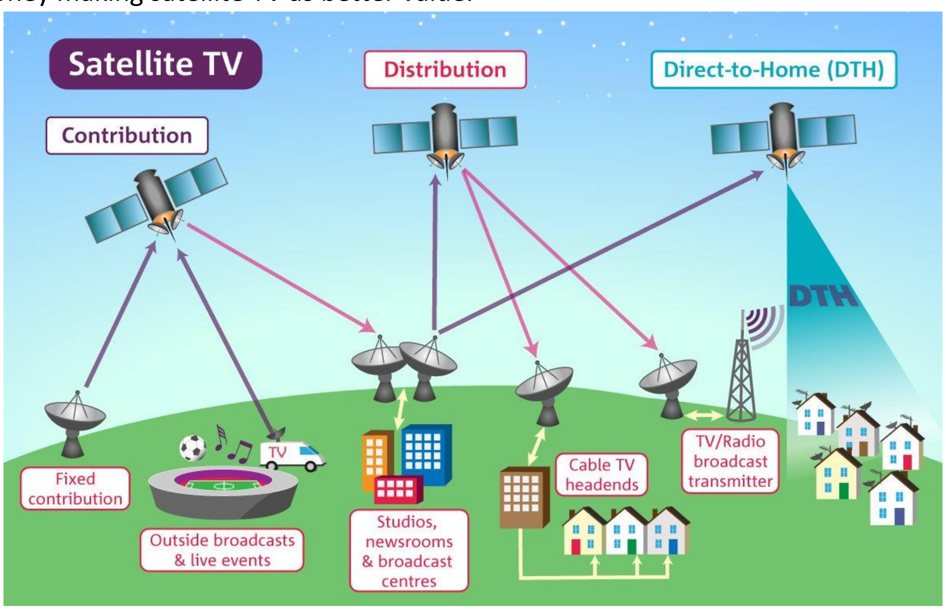
- Can reach over large geographical area
- Flexible (if transparent transponders)
- Easy to install new circuits
- Circuit costs independent of distance
- Broadcast possibilities
- Temporary applications (restoration)
- Niche applications
- Mobile applications (especially "fill-in")
- Terrestrial network "by-pass"
- Provision of service to remote or underdeveloped areas
- User has control over own network
- 1-for-N multipoint standby possibilities

When to use Satellites

- When the unique features of satellite communications make it attractive
- When the costs are lower than terrestrial routing
- When it is the only solution
- Examples:
  - Communications to ships and aircraft (especially safety communications)
  - TV services - contribution links, direct to cable head, direct to home
  - Data services - private networks
  - Overload traffic
  - Delaying terrestrial investments
  - 1 for N diversity
  - Special events

Question 1. How does the Satellite TV or Dish TV works?

- Satellite television just like broadcast TV, but instead of sending signals from towers to antennas attached to your television set, signals are sent through space using satellites. The signals originate with the programmers – TV channels – who send their feeds to DISH.
- DISH collects all of these feeds at a center, called an uplink center, and uses satellites on the ground at the center to beam a single stream of data at 270 Mbps to our satellites in space.
- The data sent from our centers is picked up by our satellites that orbit the Earth 23000 miles above the ground. Those satellites take that single feed of data and use a different band to send the signal to the satellite dishes on your house.
- A separate band is used for the signal to your home to prevent interference. The dish on your house collects the signal and sends it to a receiver in your house where it is decrypted and converted to audio and video. This all happens at the speed of light.
- Is Satellite TV as good as Cable TV? → Yes! Satellite TV uses the same signals from the programmers as cable, it just uses a different way of getting the signal into your house. In fact, most cable companies use satellites to get feeds from programmers or to send feeds to centers that broadcast the signals using cable, so all TV is satellite TV to some extent. Satellite TV has the advantage of being available across the entire country and often offers more channels for the same money making satellite TV as better value.



Global Positioning System (GPS)

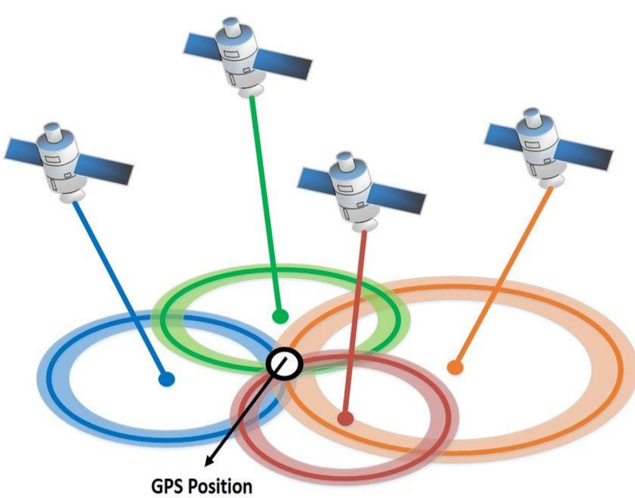
- GPS, which stands for Global Positioning System, is the only system today able to show you your exact position on the Earth anytime, in any whether, anywhere.
- The three parts of GPS are:
    - Space Segment
    - User Segment
    - Ground Control Segment

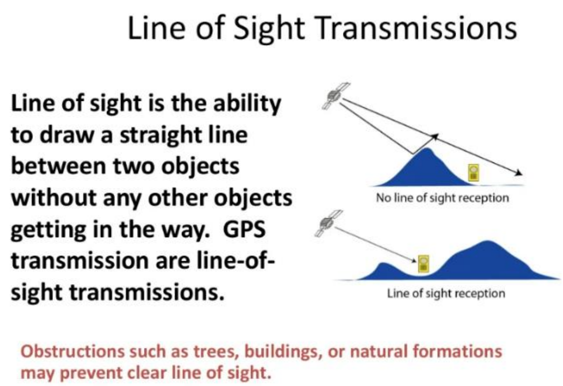
Application of GPS Technology

- Location – determining a basic position
- Navigation – Getting from one location to another
- Tracking – Monitoring the movement of people and things
- Mapping – Creating maps of the world
- Timing – Bringing precise timing to the world

The receiver collects satellite signals, decodes and processes them. The basic receiver doesn't include a transmitter. Different levels of precision are available. The receiver determines its location by trilateration.

GPS Trilateration: Knowing its distance from three satellites, the receiver can determine its location because there is only two possible combinations and one of them is out in space. The more satellite that are used, the greater the potential accuracy of the position location.





Satellite Link Budget Numerical Problem

Question: Suppose we have satellite system operates at 12.5GHz, with transmit carrier power of 120W, and transmit antenna gain 34dB, IF Bandwidth 20MHz. The receiving dish have gain of 33.5dB, with receiver noise figure 1.1dB, locates 39000km from the satellite. Calculate the received carrier power at receiver terminal and Signal to Noise Ratio (SNR).

Solution:

Given, frequency (f) = 12.5 GHz = 12.5×10^9 Hz

Transmit Power(p_t) = 120W

Tx Antenna Gain(g_t) = 34 dB = 2512

Rx Antenna Gain(g_r) = 33.5 dB = 2239

Distance, R = 39000km = 39000×10^3m

Noise at receiver (N) = 1.1dB = 1.288W

$$p_r = \frac{p_t g_t g_r c^2}{(4\pi)^2 R^2 f^2}$$

$$= \frac{120 * 2512 * 2239 * (3 * 10\hat{}8)\hat{}2}{(4\Pi)^2 * (39000 * 10^3)^3 * (12.5 * 10^9)\hat{}2}$$

= 1.62×10^{-12}W

Signal to Noise Ratio = S/N = 1.62×10^{-12}W/1.2888