Chapter 11

Satellite Systems

Outline

- Introduction
- Types of Satellite
- Characteristic of Satellite Systems
- Satellite System Infrastructures
- Call Setup
- GPS
  - Limitations of GPS
  - Beneficiaries of GPS
  - Applications of GPS

Introduction

- Satellites being above the earth can cover a larger area.
- The information to be transmitted from a mobile user should be correctly received by a satellite and forwarded to one of the earth stations (ESs).
- This puts the limitation that only *Line of Sight* (LOS) communication is possible.

Application Areas of Satellite System

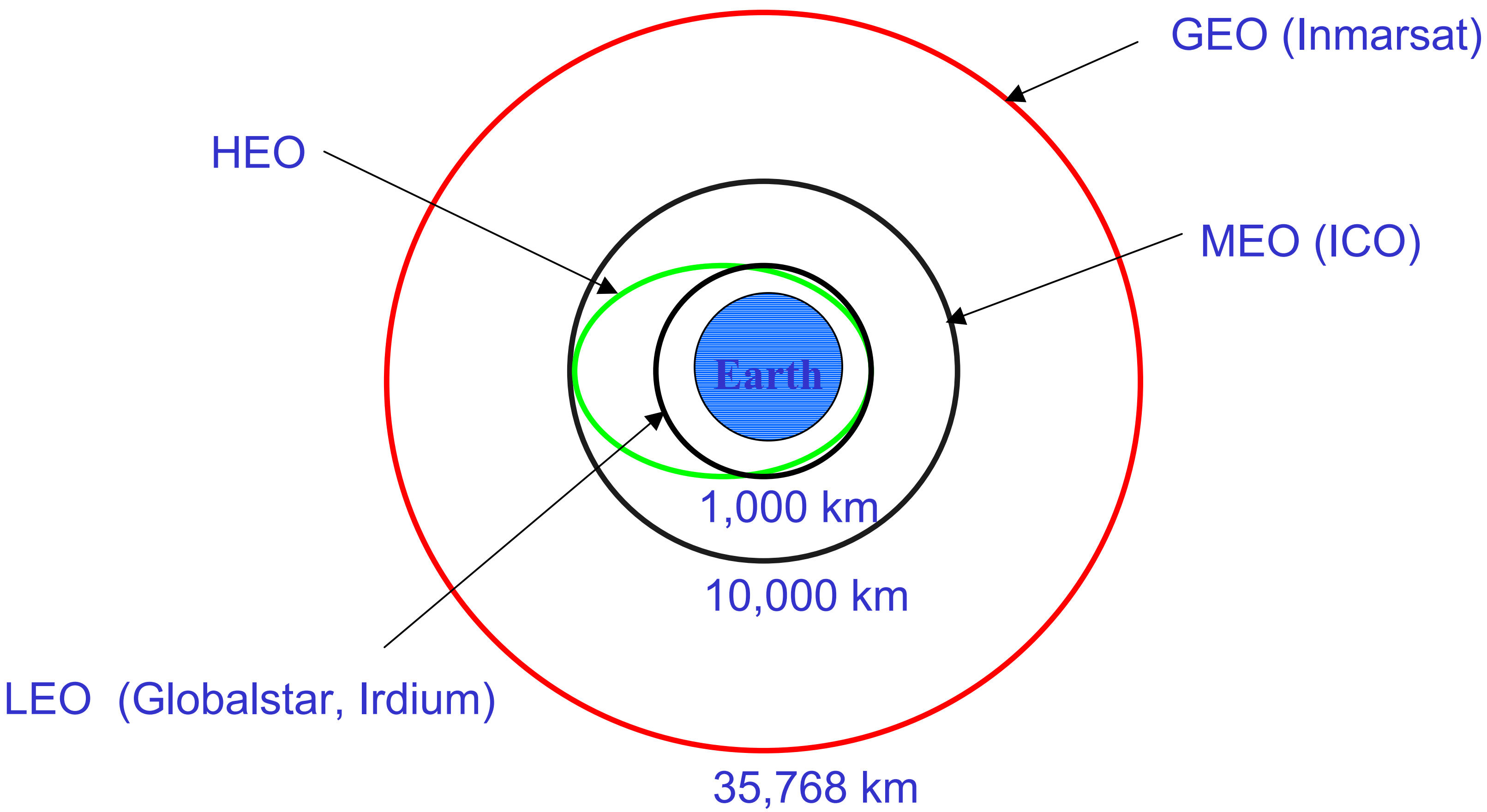
- Traditionally
  - Meteorological satellites
  - Radio and TV broadcast satellites
  - Military satellites
  - Satellites for navigation and localization (e.g GPS)
- Telecommunications
  - Global telephone connections
  - Backbone for global networks
  - Connections for communication in remote places
  - Global mobile communication

Types of Satellite Systems

Four different types of satellite orbits have been identified depending on the shape and diameter of each orbit:

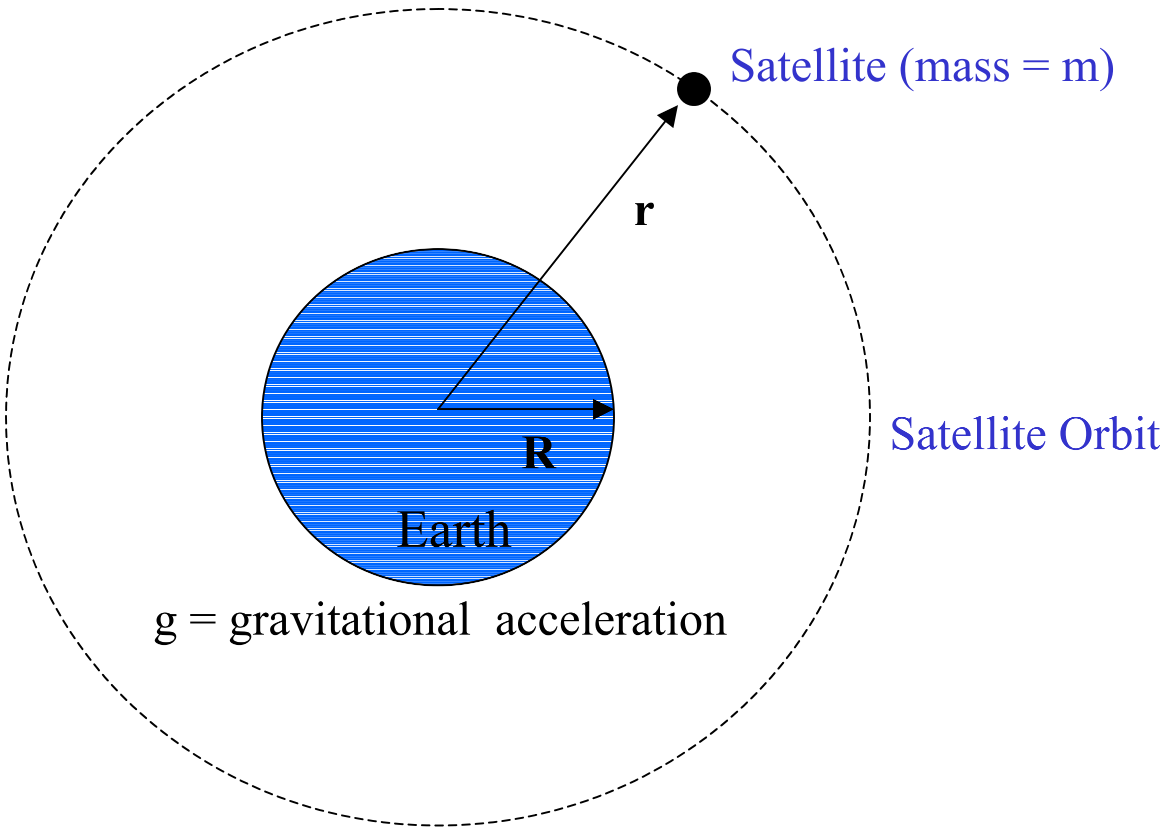
- GEO (Geostationary Earth Orbit) at 36,000 kms above earth's surface.
- LEO (Low Earth Orbit) at 500-1500 kms above earth's surface.
- MEO (Medium Earth Orbit) or ICO (Intermediate Circular Orbit) at 6000-20000 kms above earth's surface.
- HEO (Highly Elliptical Orbit).

Orbits of Different Satellites



Orbits of different satellites

Earth-satellite Parameters for a Stable Orbiting Path



Earth-Satellite Parameters (Cont'd)

- The orbits could be elliptical or circular.
- Rotation time depends on the distance between the satellite and the earth.
- For satellites following circular orbits, applying Newton's gravitational law:

F_g (attractive force) = $mg\,(R/r)^2$

F_c (centrifugal force) = $mr\omega^2$

$\omega = 2\pi f$

Where, m = *mass of the satellite*

g = *gravitational acceleration (9.81 m/s²)*

R = *radius of the earth (6,370 kms)*

r = *distance of the satellite to the center of earth*

ω = *angular velocity of satellite*

f = *rotational frequency*

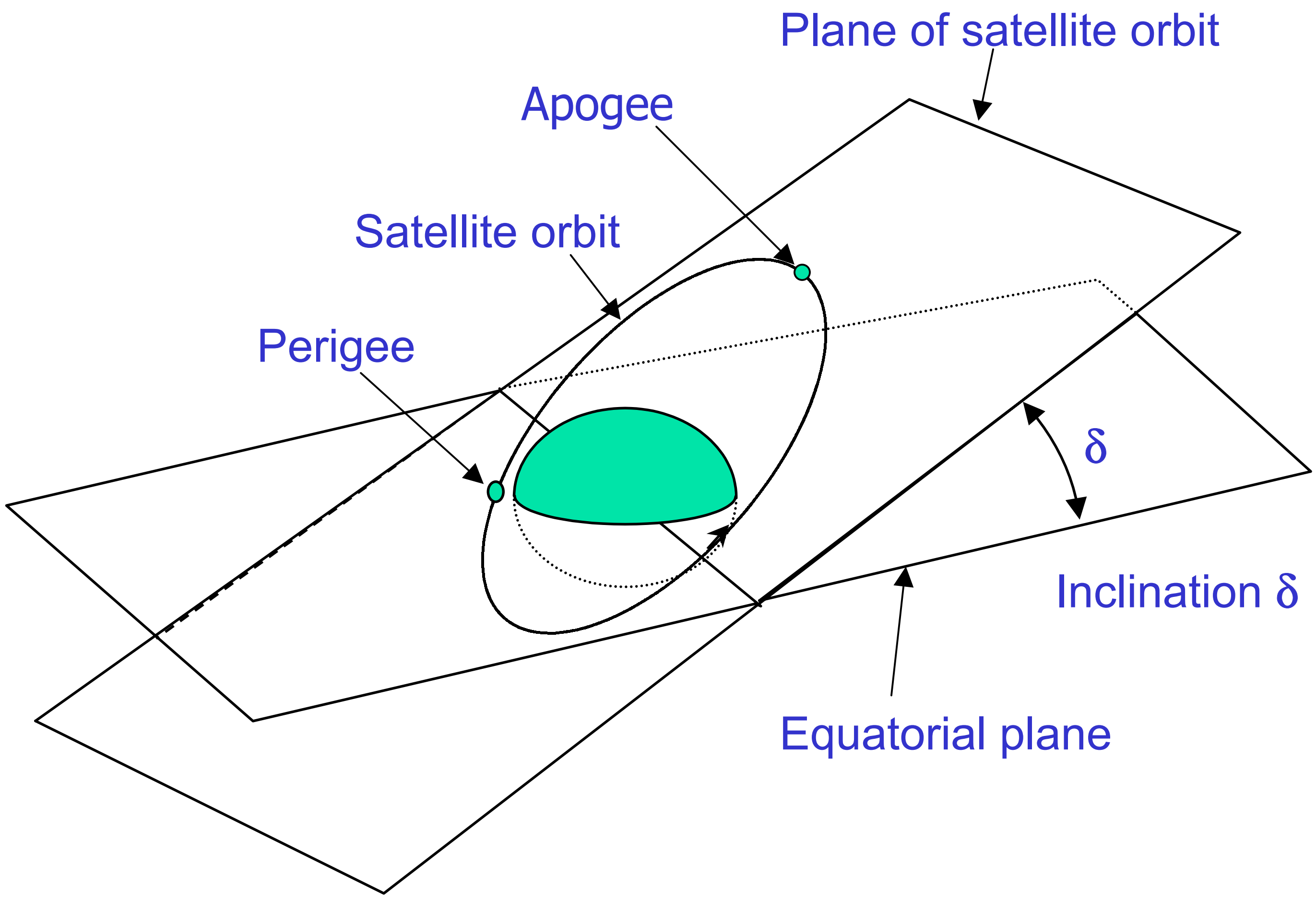
Earth-Satellite Parameters (Cont'd)

- For the orbit of the satellite to be stable, we need to equate the two forces.

Thus,

$$\gamma = \sqrt[3]{\frac{gR^2}{(2\pi f)_2}}$$

Inclination

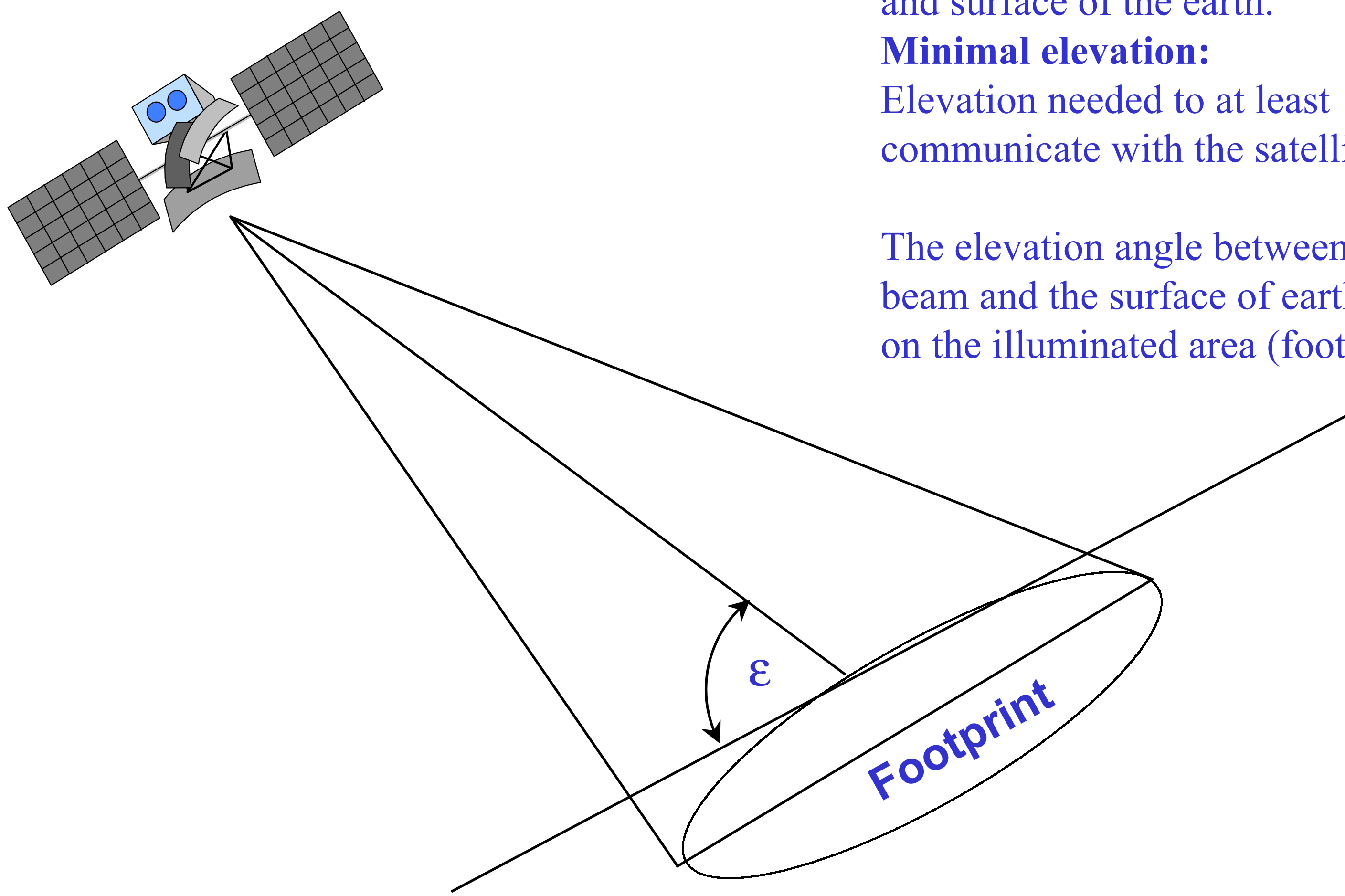


The plane of the satellite orbit with respect to earth

Footprint

- The area inside the circle is considered to be an isoflux area and this constant intensity area is taken as the footprint of the beam.
- A satellite consists of several illuminated beams. These beams can be seen as cells of the conventional wireless system.

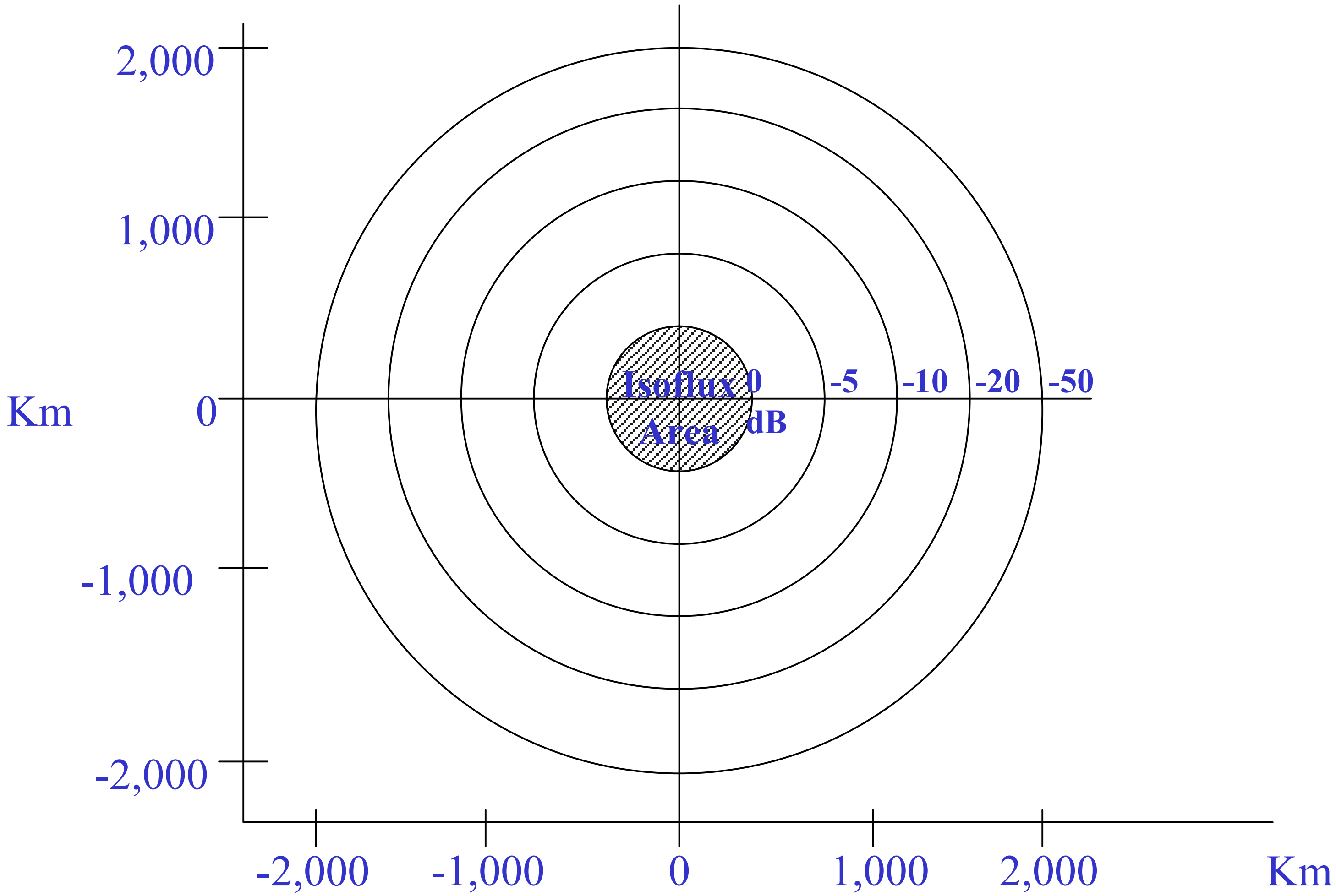
Elevation and Footprint



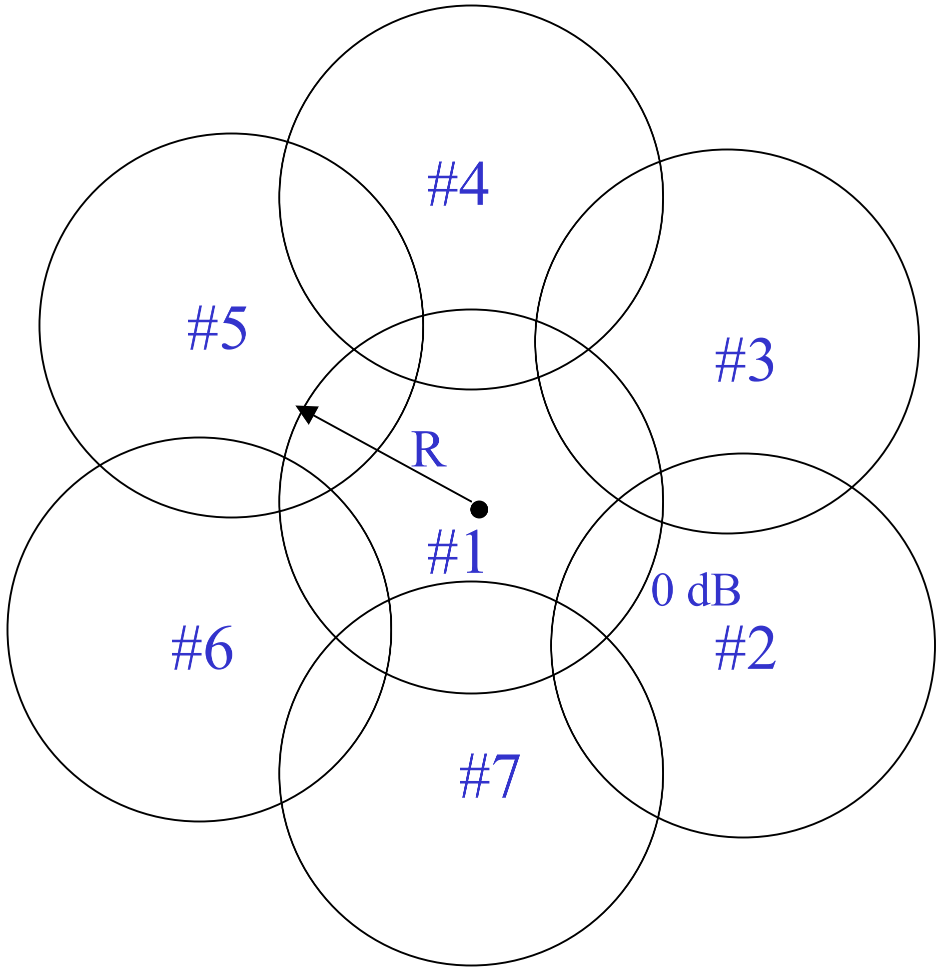
Elevation:
Angle ε between center of satellite beam and surface of the earth.
Minimal elevation:
Elevation needed to at least communicate with the satellite.

The elevation angle between the satellite beam and the surface of earth has an impact on the illuminated area (footprint)

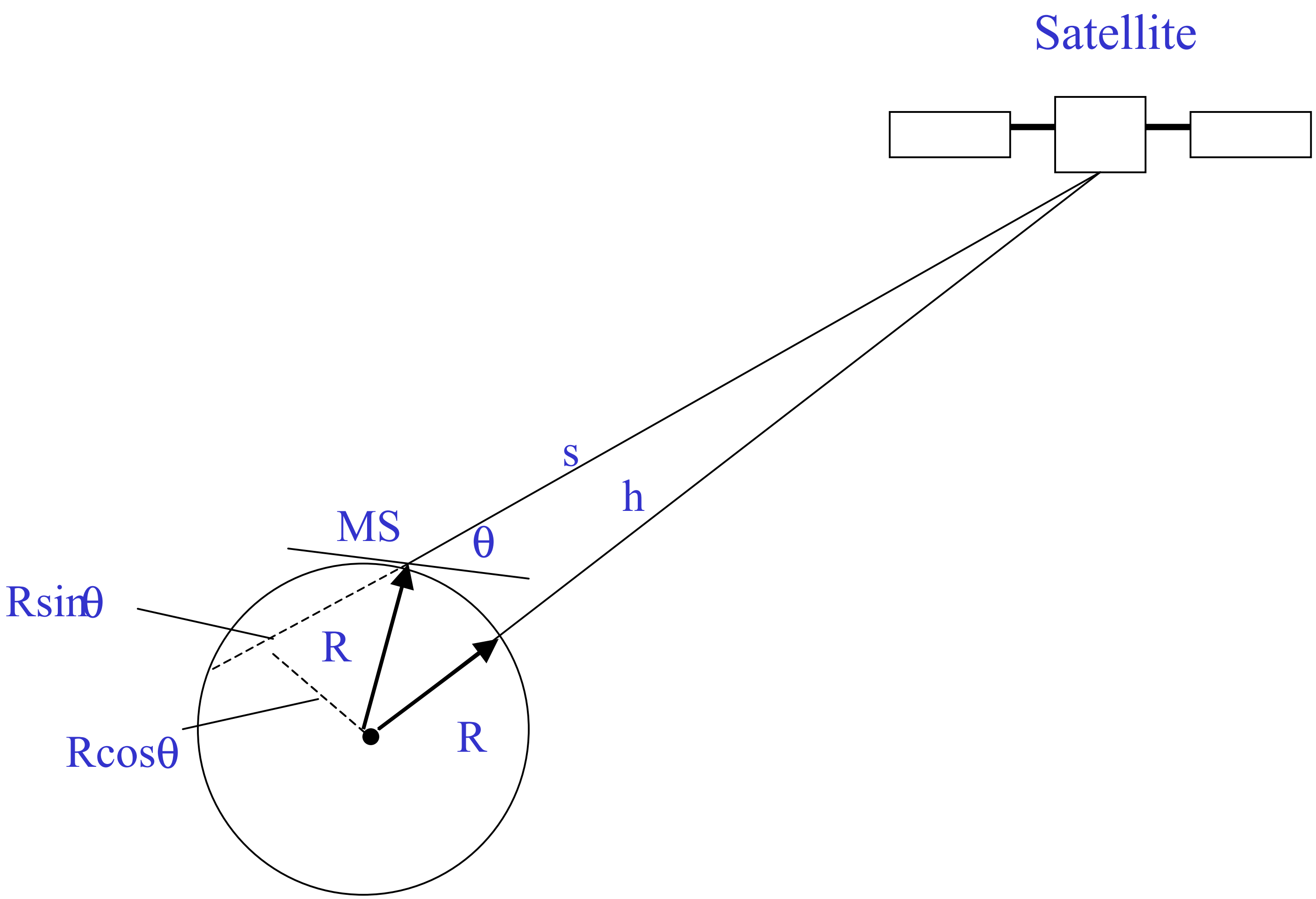
Intensity Level of the Footprint of GEO Satellites



Satellite Beam Geometry



Satellite Communication



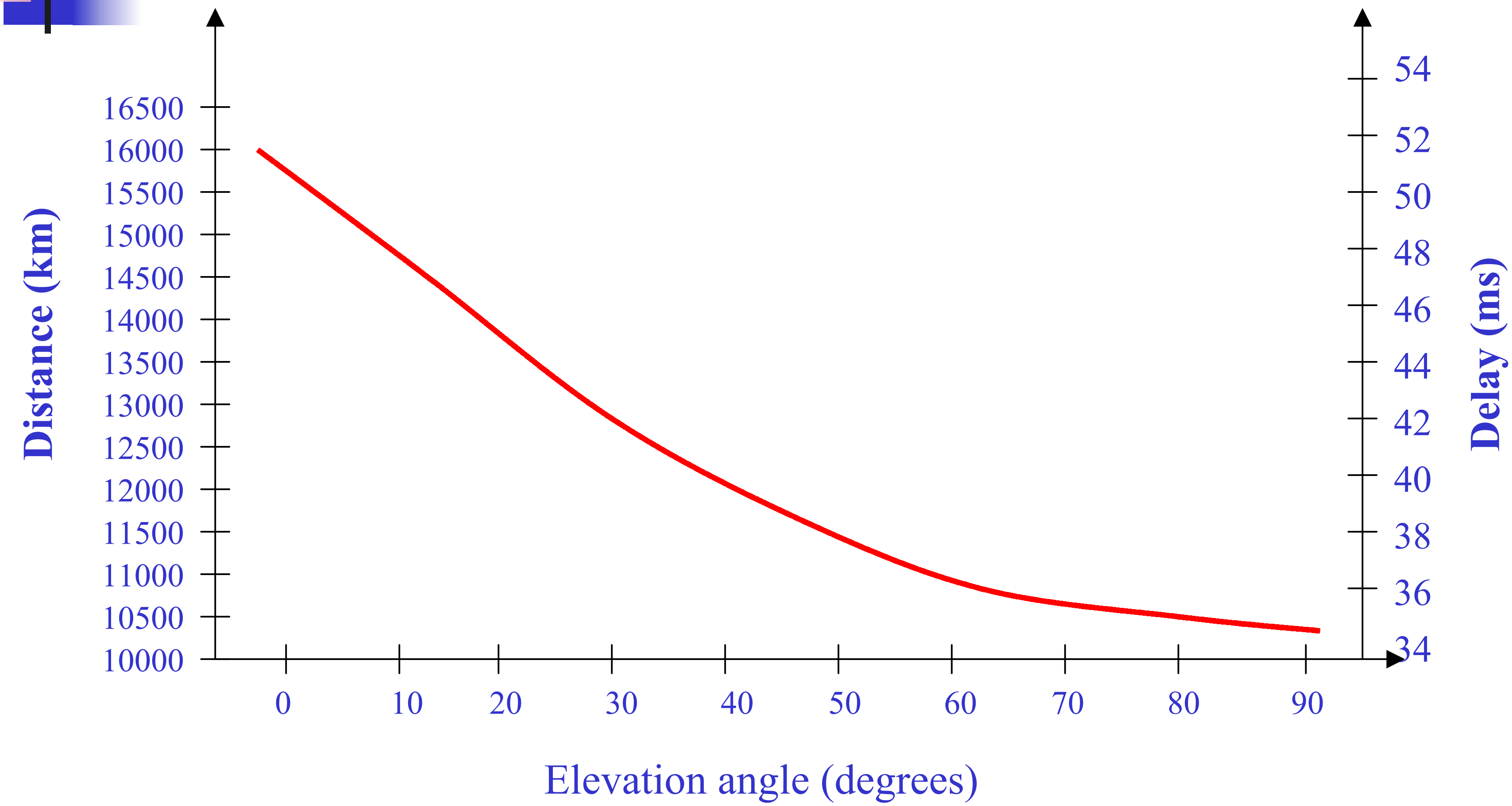
Satellite Communication

- The figure shows the path s taken for communication from a MS to the satellite.
- The time delay is a function of various parameters and is given by:

$$Delay = \frac{s}{c} = \frac{1}{c}\left[\sqrt{(R+h)^2 - R^2\cos^2\theta} - R\sin\vartheta\right]$$

$$\begin{aligned} \text{where, } R &= \text{radius of the earth} \\ h &= \text{orbital altitude} \\ \theta &= \text{satellite elevation angle} \\ c &= \text{speed of light} \end{aligned}$$

Variation of Delay in MS as A Function of Elevation Angle



Variation of delay in MS as a function of elevation angle when the satellite is at an elevation of 10,355 kms

Different Frequency Bands

The satellites operate in different frequencies for the uplink and the downlink

Band	Uplink (GHz)	Downlink (GHz)
C	3.7-4.2	5.925-6.425
Ku	11.7-12.2	14.0-14.5
Ka	17.7-21.7	27.5-30.5
LIS	1.610-1.625	2.483-2.50

Different Frequency Bands (Cont'd)

- C band frequencies have been used in the first generation satellites and has become overcrowded because of terrestrial microwave networks employing these frequencies.
- Ku and Ka bands are becoming more popular, even though they suffer from higher attenuation due to rain

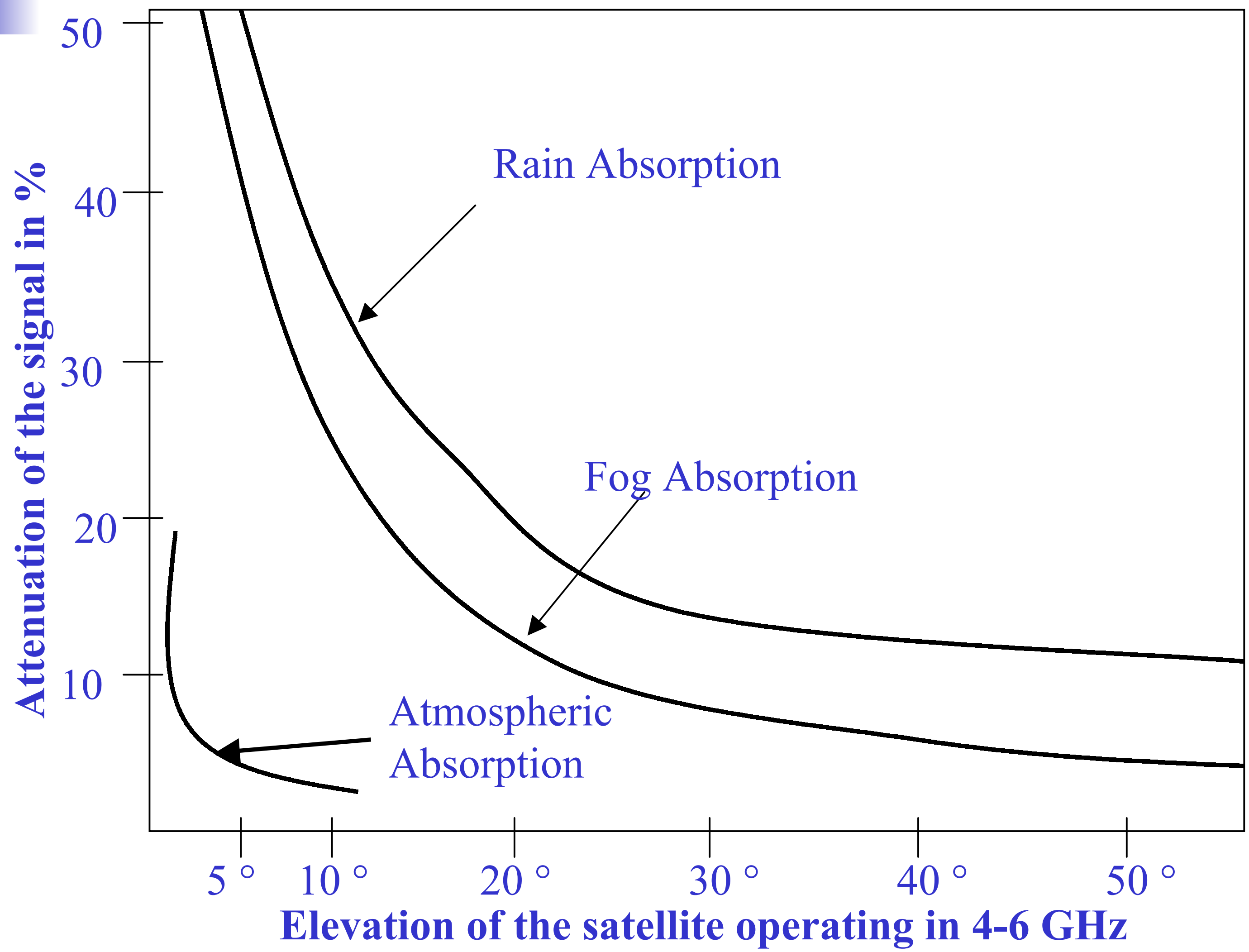
Transmission Power Characteristics

- Satellites receive signals at very low power levels (less than 100 picowatts) which is one to two orders of magnitude lower than the terrestrial receivers (1 to 100 micro watts)
- The received power is determined by four parameters:
  - Transmitting Power
  - Gain of transmitting antenna
  - Distance between transmitter and receiver
  - Gain of receiving antenna
- The atmospheric conditions cause attenuation to the transmitted signal and the loss is given by:

$$L = (4\pi rf/c)^2$$

where r is the distance, f is the carrier frequency

Atmospheric Attenuation



Atmospheric Attenuation as a function of the elevation angle

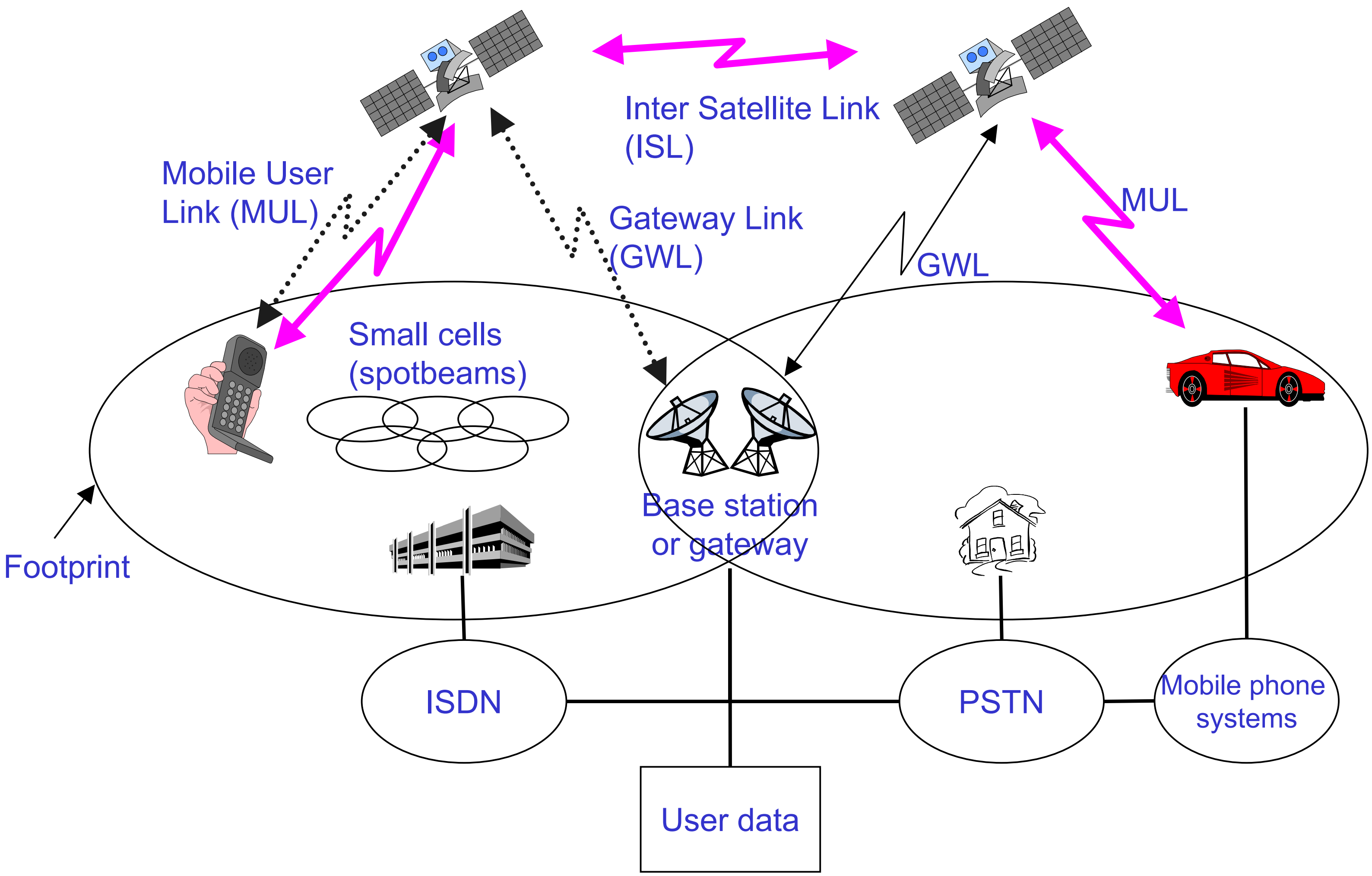
Characteristics of Satellite Systems

- Satellites weigh around 2,500 kgs.
- The GEO satellites are at an altitude of 35,768 kms which orbit in equatorial plane with 0 degree inclination.
- They complete exactly one rotation per day.
- The antennas are at fixed positions and use an uplink band of 1,634.5-1,660.5 MHz and downlink in the range of 1,530-1,559 MHz.
- Ku band frequencies (11 GHz and 13 GHz) are employed for connection between the BS and the satellites.

Characteristics of Satellite Systems (Cont'd)

- A satellite typically has a large footprint – 34% of earth's surface is covered. Therefore it is difficult to reuse frequencies.
- There is a high latency (about 275 ms) due to global coverage of mobile phones.
- LEO satellites are divided into little and big satellites.
- Little LEO satellites are smaller in size, in the frequency range 148-150.05 MHz (uplink) and 137-138 MHz (downlink).They support only low bit rates (1 kb/s) for two way messaging.
- Big LEO satellites have adequate power and bandwidth to provide various global mobile services like data transmission, paging etc.
- Big LEO satellites transmit in the frequency range of 1,610-1,626.5 MHz (uplink) and 2,483.5-2,500 MHz (downlink).
- It orbits around 500-1,500 kms above the earth's surface.
- The latency is around 5-10 ms and the satellite is visible for 10-40 min

A Typical Satellite System



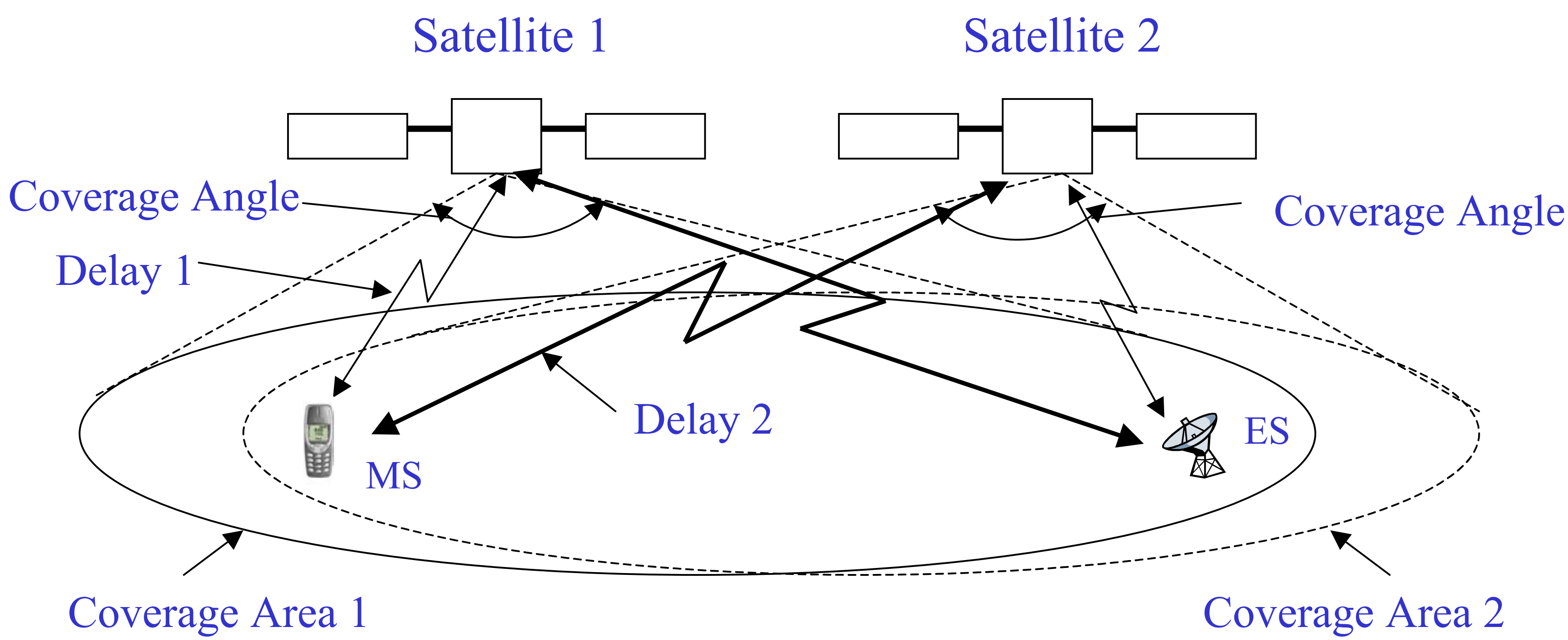
Satellite System Infrastructure

- Once contact has been established between a MS and a satellite using a LOS beam, the rest of the world can be accessed using the underlying wired backbone network.
- The satellites are controlled by the BS located at the surface of the earth which serves as a gateway.
- Inter satellite links can be used to relay information from one satellite to another, but they are still controlled by the ground BS.
- The illuminated area of a satellite beam, called the footprint, is the area where a mobile user can communicate with the satellite.

Satellite System Infrastructure (Cont’d)

- There are losses in free space and also due to atmospheric absorption of the satellite beams.
- Rain also causes attenuation to signal strength when 12-14 GHz and 20-30 GHz bands are used to avoid orbital congestion.
- The satellite’s beam may be temporarily blocked due to flying objects or the terrain of the earth’s surface.
- Therefore a concept known as “diversity” is used to transmit the same message through more than one satellite.

Satellite Path Diversity



Satellite Path Diversity (Cont'd)

- Idea behind diversity is to provide a mechanism that combines two or more correlated information signals.
- These signals have uncorrected noise and/or fading characteristics.
- A combination of the two signals improves the signal quality.
- The receiving end has the flexibility to select one of the better signals received while the other is lost due to temporary LOS problem, or attenuated because of excessive absorption in the atmosphere.
- The net effect of diversity is to utilize twice the bandwidth and therefore it is desirable to employ this in as small a fraction of time as possible.

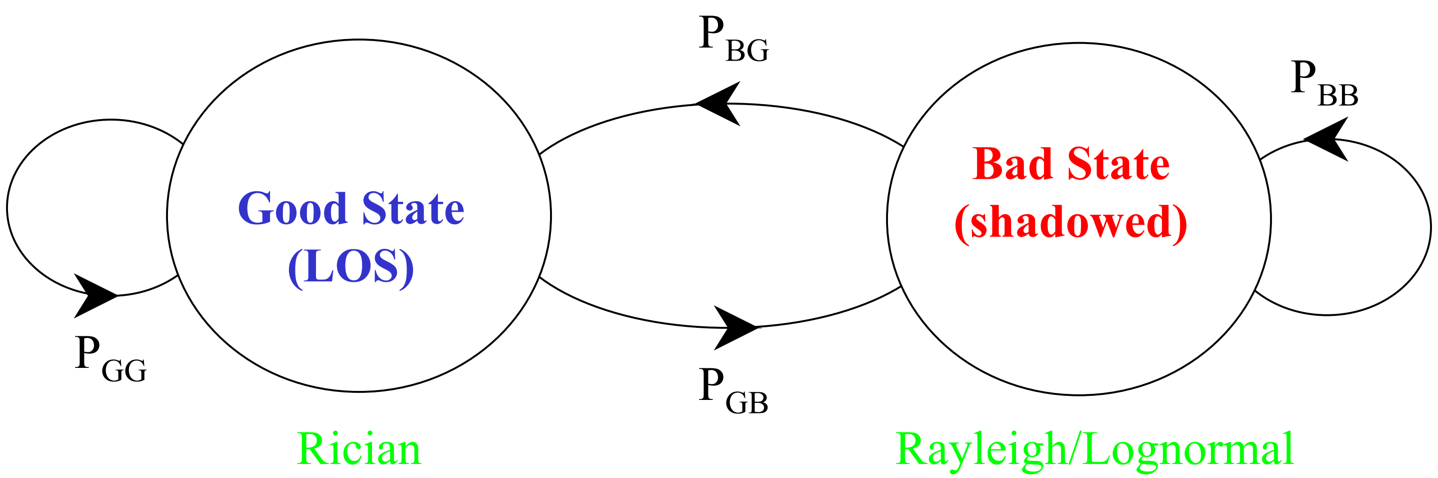
Satellite Path Diversity (Cont'd)

- The use of diversity can be initiated by either the MS or BS located on the earth.
- The use of a satellite path diversity is done due to the following conditions:
  - Elevation Angle: Higher elevation angle decreases shadowing problems. So, one approach is to initiate path diversity when the elevation angle is less than some predefined threshold value.
  - Signal Quality: If the average signal level quality fades beyond some threshold, then this could force the use of path diversity.
  - Stand-by option: A channel could be selected and reserved as a stand by option, when obstruction of the primary channel occurs. Several MSs can share the same stand-by channel.
  - Emergency Handoff: Whenever the connection of an MS with a satellite is lost, the MS tries to have an emergency handoff.

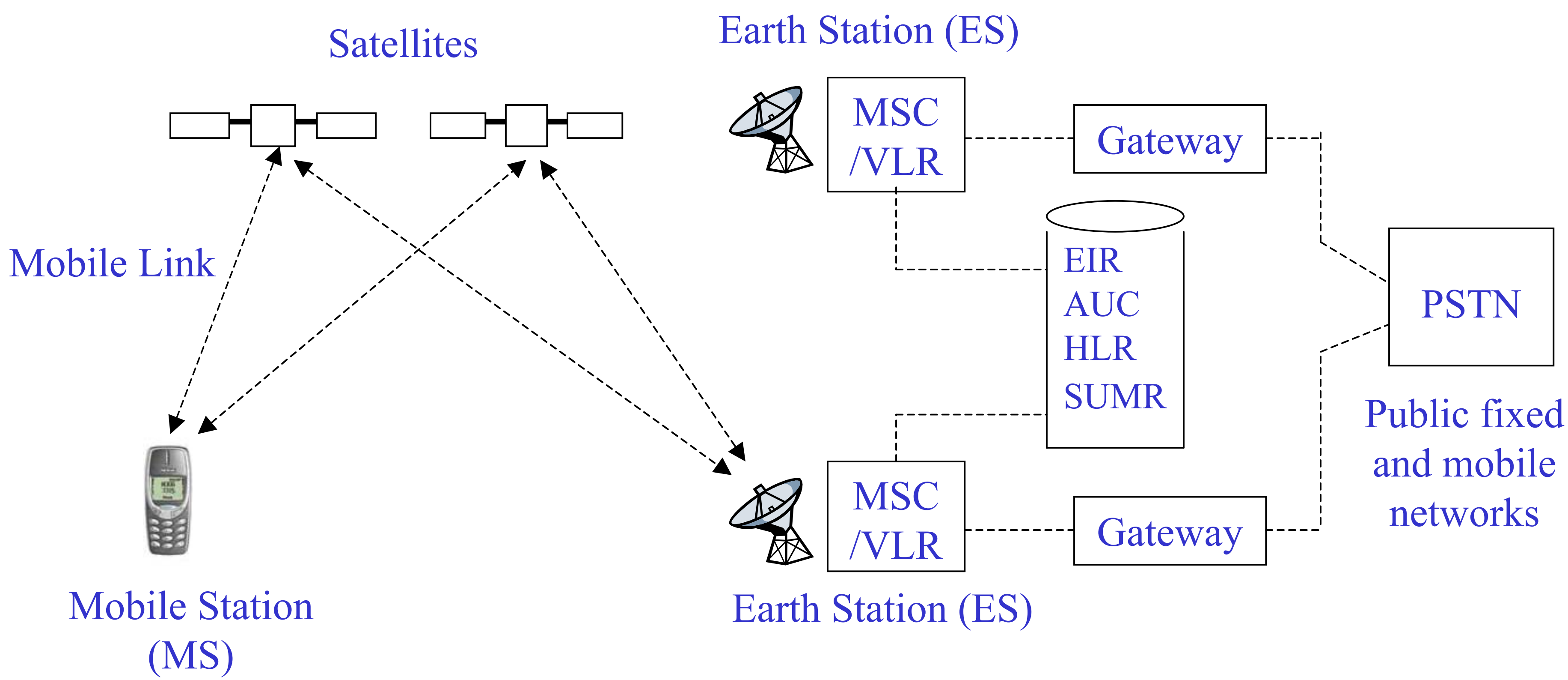
Channel Model for MS

- The channel of a satellite system is usually represented by a two state Markov model.
- The MS in the good state has Rician fading.
- A bad or shadowed state indicates Rayleigh/Lognormal fading.

Channel Model for the MS



Satellite System Architecture



Call Setup

- ES is the heart of the overall system control.
- ES performs functions similar to the Base Station Subsystem (BSS) of a cellular wireless system.
- ES keeps track of all MSs, located in the area and controls the allocation and de-allocation of radio resources.
- The MSC/VLR are important parts of the ES, providing functions similar to those of a cellular network.
- The HLR-VLR pair supports the basic process of Mobility management.
- The Satellite User Mapping Register (SUMR) in ES lists the positions of all satellites and indicate the satellite assigned to each MS.

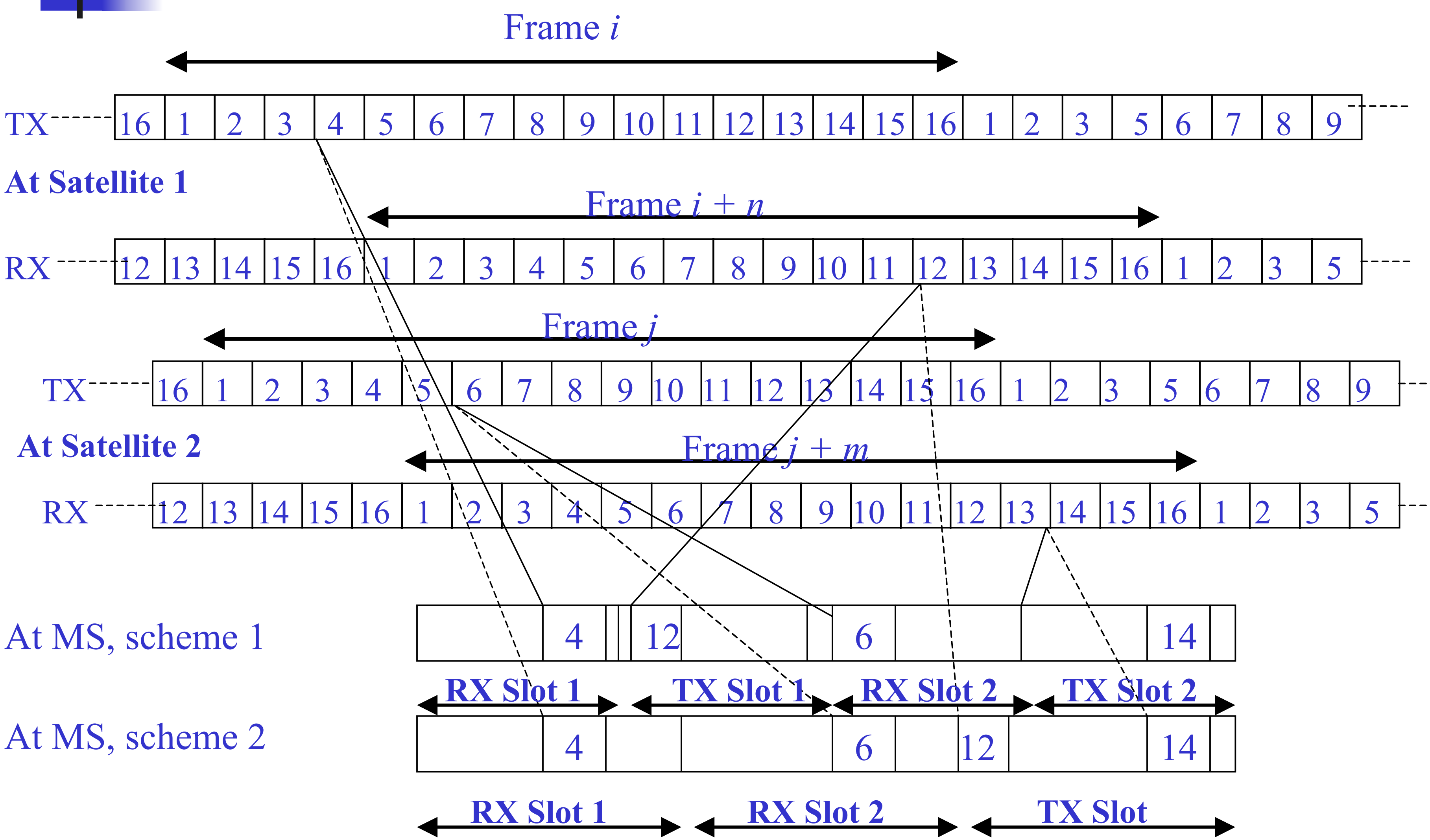
Call Setup (Cont'd)

- These ESs are also connected to the PSTN and ATM backbone so that calls to regular household phones can also be established.
- For an incoming call, the gateway helps to reach the closest ES, that in turn, using the HLR/VLR pair indicates the satellite serving the most recently known location of the MS.
- The satellite employs a paging channel to inform the MS about an incoming call and the radio resource to use for the uplink connection.
- For a call originated from a MS, the MS accesses the shared control channel of an overhead satellite and the satellite in turn informs the ES for authentication of the user/MS.
- The ES then allocates a traffic channel to the MS via the satellite and also informs the gateway about additional control information.

Call Setup (Cont'd)

- Similar to cellular systems whenever a MS moves to a new area served by another satellite, then the MS has to go through the registration process.
- The only difference is the use of ES in all intermediate steps.

System Timings for the Satellite



System Timings for the Satellite (Cont'd)

- Scheme-1 employs half of the 16 burst half rate while the second half is for the TDMA frame of satellite 2.
- Diversity is employed in scheme-2 and the TDMA frame is split into 3 parts, the first 2 for reception from satellites 1 and 2 and the third for the communication with the satellite which has the best signal.

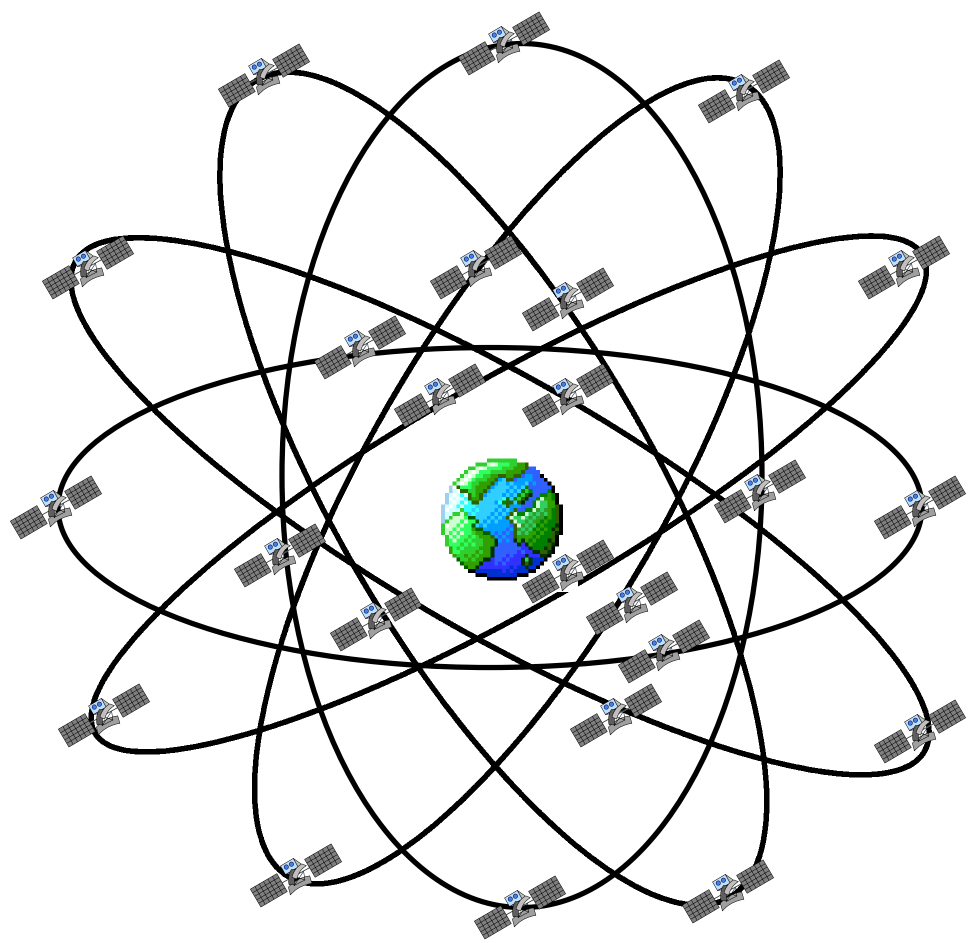
Types of Handoff

- *Intra Satellite handoff*: Handoff from one spot beam to another due to relative movement of the MS with respect to the satellites as MS needs to be in the footprint area to be able to communicate with a satellite.
- *Inter Satellite handoff*: As the MS is mobile and most satellites are not geo-synchronous, the beam path may change periodically. Therefore there could be a handoff from one satellite to another under control of ES.
- *ES handoff*: This may happen because of frequency rearrangement occurring due to traffic balancing in neighboring beams. There could be situations where a satellite control may change from one ES to another.This may cause handoff at ES level.
- *Inter System Handoff*: Handoff from a satellite network to a terrestrial cellular network.

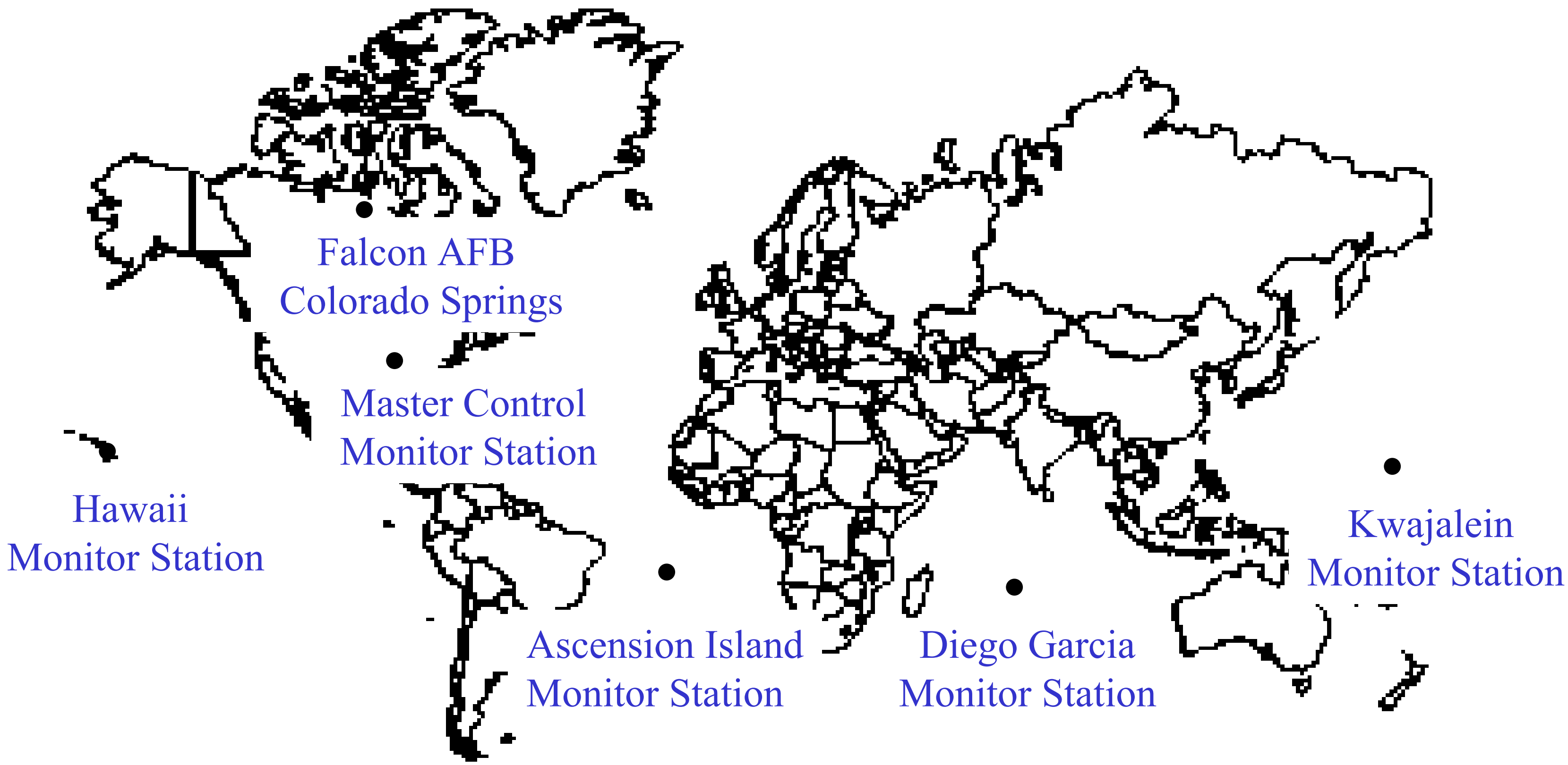
Global Positioning System (GPS)

- Used in applications such as military targeting, navigation, tracking down stolen vehicles, guiding civilians to the nearest hospital, exact location of the callers for E-911 emergency.
- GPS system consists of a network of 24 orbiting satellites called “NAVSTAR” placed in 6 different orbital paths with 4 satellites in orbital plane.
- The orbital period of these satellites is 12 hours.
- The first GPS satellite was launched in Feb. 1978.
- Each satellite is expected to last approx. 7.5 years.

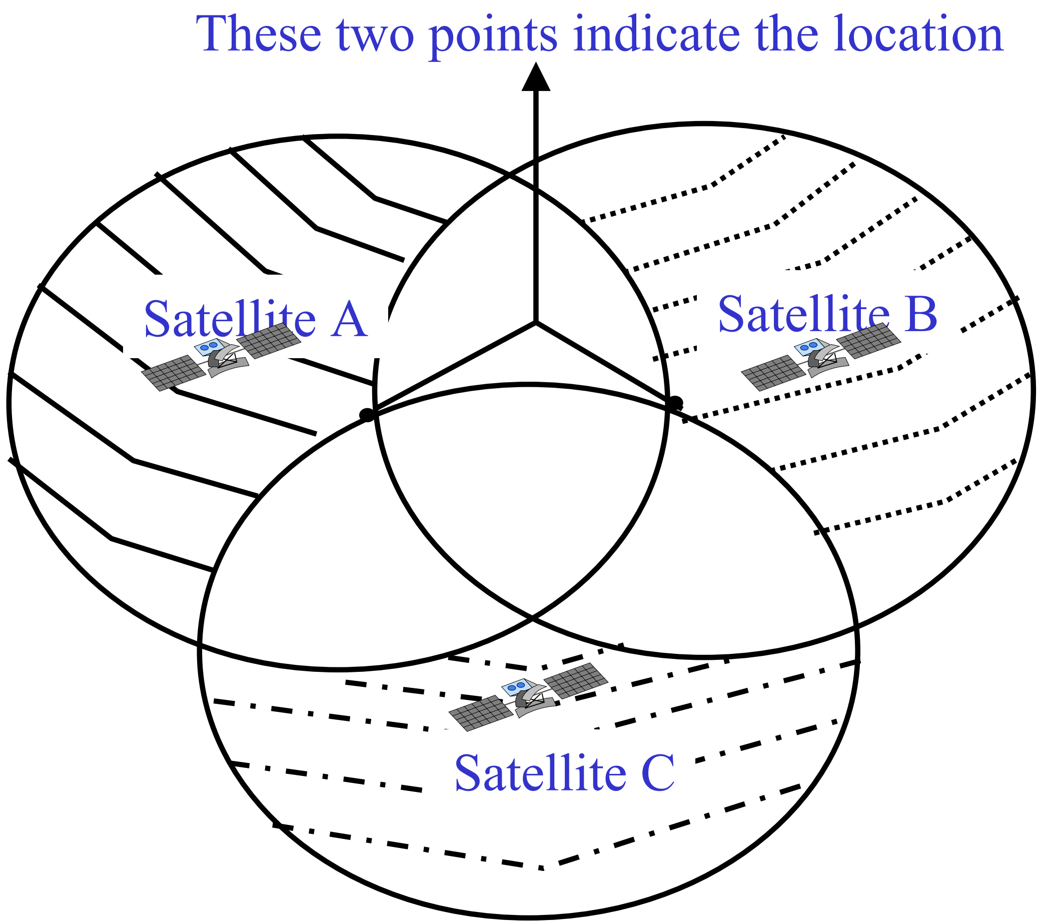
GPS Nominal Constellation of 24 Satellites in 6 Orbital Planes [2]



GPS Master Control and Monitor Station Network [2]



The Triangulation Technique [©2002 IEEE]



GPS

- GPS is based on the “Triangulation Technique”.
- Consider the GPS receiver (MS) to be placed at a point on an imaginary sphere of radius equal to the distance between Satellite ‘A’ and the receiver on the ground.
- The GPS receiver MS is also a point on another imaginary sphere with a second satellite ‘B’ at its center.
- The GPS receiver is somewhere on the circle formed by the intersection of 2 spheres.
- Then with the measurement of distance from a third satellite ‘C’ the position of the receiver is narrowed down to just 2 points on the circle. One of these points is imaginary and is eliminated.
- Therefore the distance measured from 3 satellites is sufficient to determine the position of the GPS receiver on earth.

GPS (Cont'd)

- The GPS signal consists of a 'Pseudo-Random Code' (PRN), ephemeris and navigation data.
- The ephemeris data corrects errors caused by gravitational pulls from the moon and sun on the satellites.
- The navigation data is the information about the located position of the GPS receiver.
- The pseudo-random code identifies which satellite is transmitting.
- Satellites are referred to by their PRN ranging from 1-32.

Limitations of GPS

- Distance measurements may vary as the values of signal speed vary in atmosphere.
- Effects of Multi-path fading and shadowing are significant.
- In GPS, multi-path fading occurs when the signal bounces off a building or terrain.
- Propagation delay due to atmospheric condition affects accuracy.

Beneficiaries of GPS

- GPS has become important for nearly all military operations and weapons systems.
- It is used on satellites to obtain highly accurate orbit data and to control spacecraft orientation.
- GPS can be used everywhere except where it is impossible to receive the signal such as inside most buildings, in caves and other subterranean locations.
- There are airborne, land and sea based applications of GPS.
- Anyone who needs to keep track of where he/she is and needs to find his/her way to a specified location, or know what direction and how fast they are going can utilize the GPS service.

Some Applications of GPS

User Group	Application Area
U.S. Military	Maneuvering in extreme conditions and navigating planes, ships, etc.
Building the English channel	Checking positions along the way and making sure that they meet in the middle
General aviation and commercial aircrafts	Navigation
Recreational boaters and commercial fishermen	Navigation
Surveyors	Reduces setup time at survey site and offers precise measurements

Some Applications of GPS (Cont'd)

User Group	Application Area
Recreational users (Hikers, hunters, mountain bikers, etc.)	Keeping track of where they are and finding a specific location
Automobile services	Emergency roadside assistance
Fleet vehicles, public transportation systems, delivery trucks, and courier services	Monitor locations at all times
Emergency vehicles	Determine location of car, truck, or ambulance closest to the accident site
Automobile manufactures	Display of maps in moving cars that can be used to plan a trip