Module 5

Broadcast Communication Networks

Lesson 10

Satellite Networks

Specific Instructional Objectives

At the end of this lesson, the student will be able to:

- Explain different type of satellite orbits
- Explain the concept of footprint of a satellite
- Specify various categories of satellites
- Specify frequency bands used in satellites
- Explain the uses of different categories of satellites
- Specify the MAC techniques used in satellites communications

5.10.1 Introduction

Microwave frequencies, which travel in straight lines, are commonly used for wideband communication. The curvature of the earth results in obstruction of the signal between two *earth stations* and the signal also gets attenuated with the distance it traverses. To overcome both the problems, it is necessary to use a *repeater*, which can receive a signal from one earth station, amplify it, and retransmit it to another earth station. Larger the height of a repeater from the surface of the earth, longer is the distance of line-of-sight communication. Satellite networks were originally developed to provide long-distance telephone service. So, for communication over long distances, satellites are a natural choice for use as *repeaters in the sky*. In this lesson, we shall discuss different aspects of satellite networks.

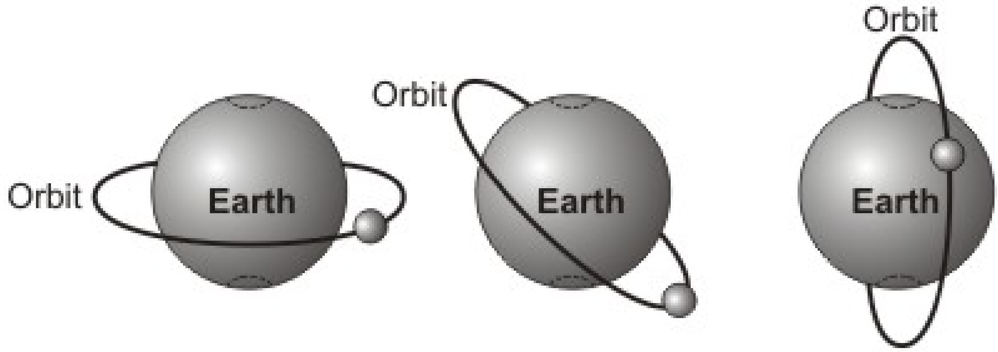
Various types of orbits taken by different satellites are briefly discussed in Sec. 5.10.2. The concept of footprint, the area of earth covered by a satellite, is introduced in Sec. 5.10.3. Different categories of satellites, based on the altitudes from the surface of earth are explained in Sec. 5.10.4. Frequency bands used in satellite networks is covered in Sec. 5.10.5. Low Earth Orbit Satellite systems including Iridium and Teledesic systems are briefly discussed in Sec. 5.10.6. The Global Positioning System, one of the Medium Earth Orbit Satellites, is discussed in Section 5.10.7. Geostationary satellites are introduced in Sec. 5.10.8. The VSAT systems are discussed in detail in Sec. 5.10.9. Medium Access Control (MAC) techniques used in satellite systems have been briefly introduced in Sec. 5.10.10.

5.10.2 Orbits of Satellites

Artificial satellites deployed in the sky rotate around the earth on different orbits. The orbits can be categorized into three types as follows:

- Equatorial
- Inclined
- Polar

Time required to make a complete trip around the earth, known as period, is determined by Kepler's Law of period: $T^2 = (4\pi^2/GM)\ r^3$, where T is the period, G is the gravitational constant, M is the mass of the central body and r is the radius.

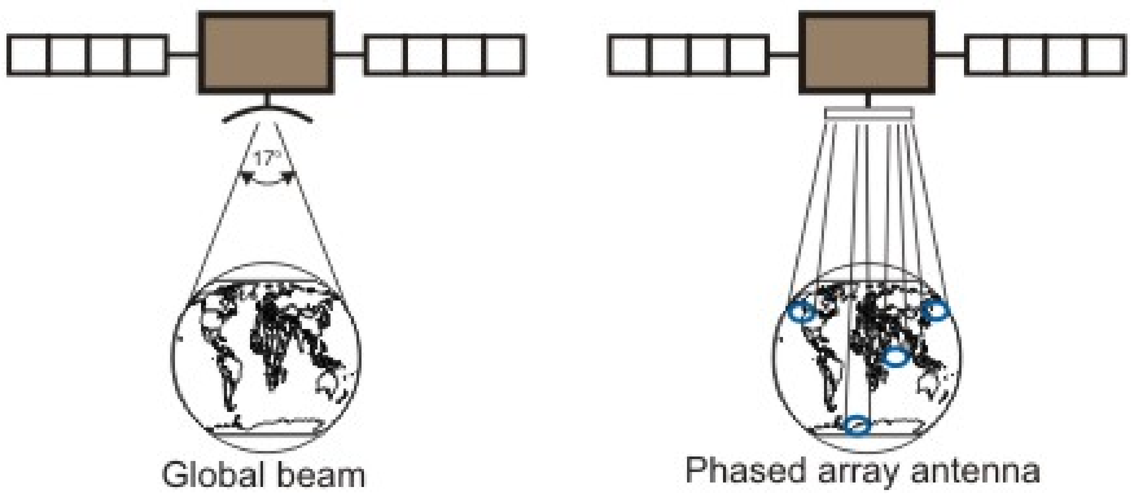


(a) **(b)** **(c)**

Figure 5.10.1 Three different orbits of satellites; (a) equatorial, (b) inclined and (c) polar

5.10.3 Footprint of Satellites

Signals from a satellite is normally aimed at a specific area called the *footprint*. Power is maximum at the center of the footprint. It decreases as the point moves away from the footprint center. The amount of time a beam is pointed to a given area is known as *dwell time*.



(a) (b)

Figure 5.10.2 (a) Footprint using a global beam, (b) Footprint using a phased array antenna

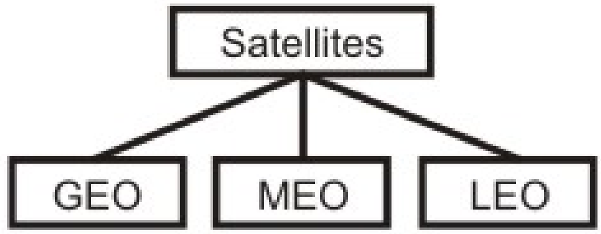
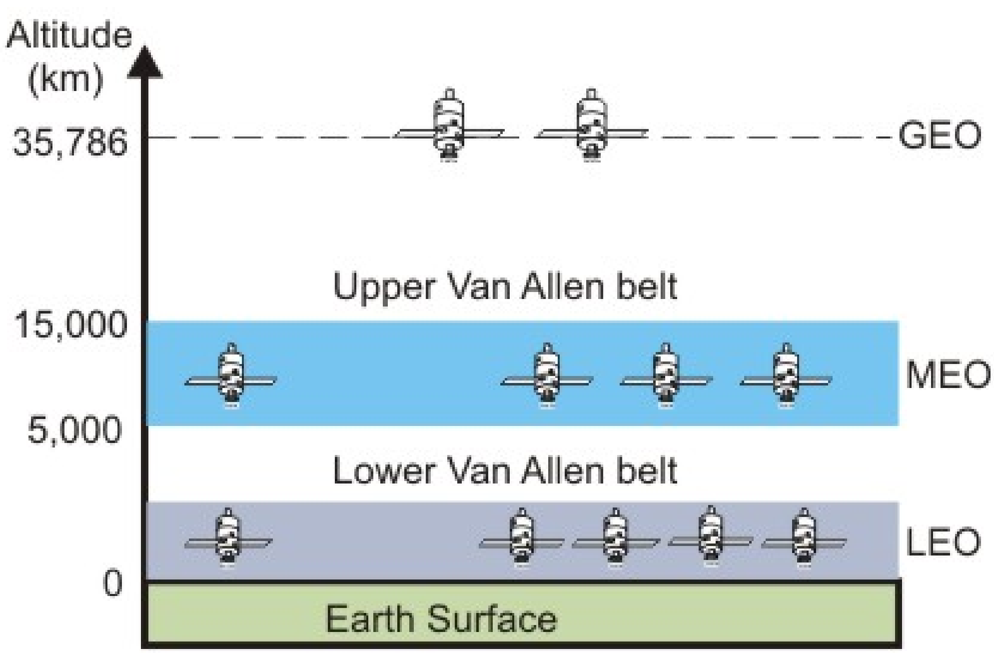


Figure 5.10.3 Categories of satellites

5.10.4 Categories of Satellites

As shown in Fig. 5.10.3, the satellites can be categorized into three different types , based on the location of the orbit. These orbits are chosen such that the satellites are not destroyed by the high-energy charged particles present in the two *Van Allen belts*, as shown in Fig. 5.10.4. The Low Earth Orbit (LEO) is below the lower Van Allen belt in the altitude of 500 to 2000 Km. The Medium Earth Orbit (MEO) is in between the lower Van Allen belt and upper Van Allen belt in the altitude of 5000 to 15000 Km. The Medium Earth Orbit (MEO) is in between the lower Van Allen belt and upper Van Allen belt in the altitude of 5000 to 15000 Km. Above the upper Van Allen belt is the Geostationary Earth Orbit (GEO) at the altitude of about 36,000 Km. Below the Geostationary Earth Orbit and above the upper Van Allen belt is Global Positioning System (GPS) satellites at the altitude of 20,000 Km. The orbits of these satellite systems are shown in Fig. 5.10.5.



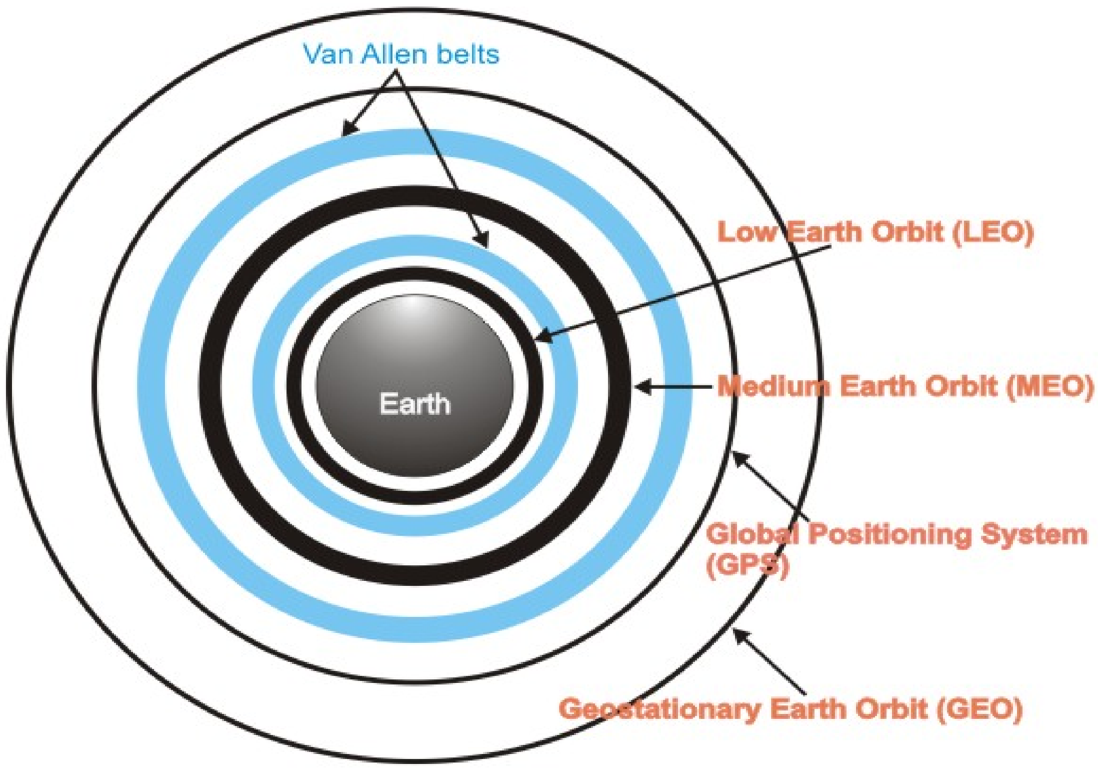


Figure 5.10.5 Orbits of the satellites of different categories

5.10.5 Frequency Bands

Two frequencies are necessary for communication between a ground station and a satellite; one for communication from the ground station on the earth to the satellite called *uplink frequency* and another frequency for communication from the satellite to a station on the earth, called *downlink frequency*. These frequencies, reserved for satellite communication, are divided in several bands such as L, S, Ku, etc are in the gigahertz (microwave) frequency range as shown in Table 5.10.1. Higher the frequency, higher is the available bandwidth.

Table 5.10.1 Frequency bands for satellite communication

Band	Downlink Frequency (GHz)	Uplink Frequency (GHz)	Bandwidth(MHz)
L	1.5	1.6	15
S	1.9	2.2	70
C	4	6	500
Ku	11	14	500
Ka	20	30	3500

5.10.6 Low Earth Orbit Satellites

The altitude of LEO satellites is in the range of 500 to 1500 Km with a rotation period of 90 to 120 min and round trip delay of less than 20 ms. The satellites rotate in polar orbits with a rotational speed of 20,000 to 25,000 Km. As the footprint of LEO satellites is a small area of about 8000 Km diameter, it is necessary to have a constellation of satellites, as shown in Fig. 5.10.6, which work together as a network to facilitate communication between two earth stations anywhere on earth's surface. The satellite system is shown in Fig. 5.10.7. Each satellite is provided with three links; the User Mobile Link (UML) for communication with a mobile station, the Gateway Link (GWL) for communication with a earth station and the Inter-satellite Link (ISL) for communication between two satellites, which are close to each other. Depending on the frequency bands used by different satellites, these can be broadly categorized into three types; the little LEOs operating under 1 GHz and used for low data rate communication, the big LEOs operating in the range 1 to 3 GHz and the Broadband and the broadband LEOs provide communication capabilities similar to optical networks.

Figure 5.10.6 LEO satellite network

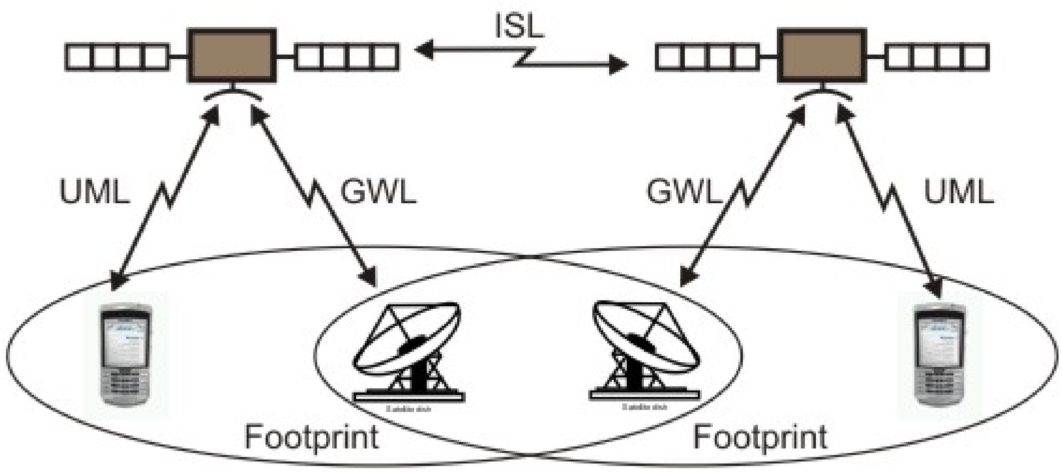


Figure 5.10.7 LEO satellite system

Iridium System

The Iridium system was a project started by Motorola in 1990 with the objective of providing worldwide voice and data communication service using handheld devices. It took 8 years to materialize using 66 satellites. The 66 satellites are divided in 6 polar orbits at an altitude of 750 Km. Each satellite has 48 spot beams (total 3168 beams). The number of active spot beams is about 2000. Each spot beam covers a cell as shown in Fig. 5.10.8.

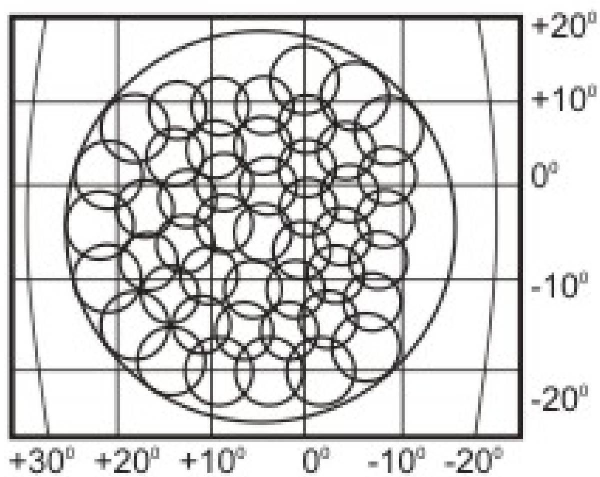


Figure 5.10.8 Overlapping spot beams of the Iridium system

The Teledesic System

The Teledesic project started in 1990 by Craig McCaw and Bill Gates in 1990 with the objective of providing fiber-optic like communication (Internet-in-the-sky). It has 288 satellites in 12 polar orbits, each orbit having 24 satellites at an altitude of 1350 Km. Three types of communications that are allowed in Teledasic are as follows;

- ISL: Intersatellite communication allows eight neighbouring satellites to communicate with each other
- GWL: Communication between a satellite and a gateway

- UML: Between an user and a satellite

The surface of the earth is divided into thousands of cells and each satellite focuses it beams to a cell during dwell time. It uses Ka band communication with data rates of 155Mbps uplink and 1.2Gbps downlink.

5.10.7 Medium Earth Orbit Satellites

MEO satellites are positioned between two Van Allen Belts at an height of about 10,000 Km with a rotation period of 6 hours. One important example of the MEO satellites is the Global Positioning System (GPS) as briefly discussed below:

GPS

The Global Positioning System (GPS) is a satellite-based navigation system. It comprises a network of 24 satellites at an altitude of 20,000 Km (Period 12 Hrs) and an inclination of 55° as shown in Fig. 5.10.9. Although it was originally intended for military applications and deployed by the Department of Defence, the system is available for civilian use since 1980. It allows land, sea and airborne users to measure their position, velocity and time. It works in any weather conditions, 24 hrs a day. Positioning is accurate to within 15 meters. It is used for land and sea navigation using the principle of triangulation as shown in Fig. 5.10.9. It requires that at any time at least 4 satellites to be visible from any point of earth. A GPS receiver can find out the location on a map. Figure 5.10.11 shows a GPS receiver is shown in the caption's cabin of a ship. GPS was widely used in Persian Gulf war.

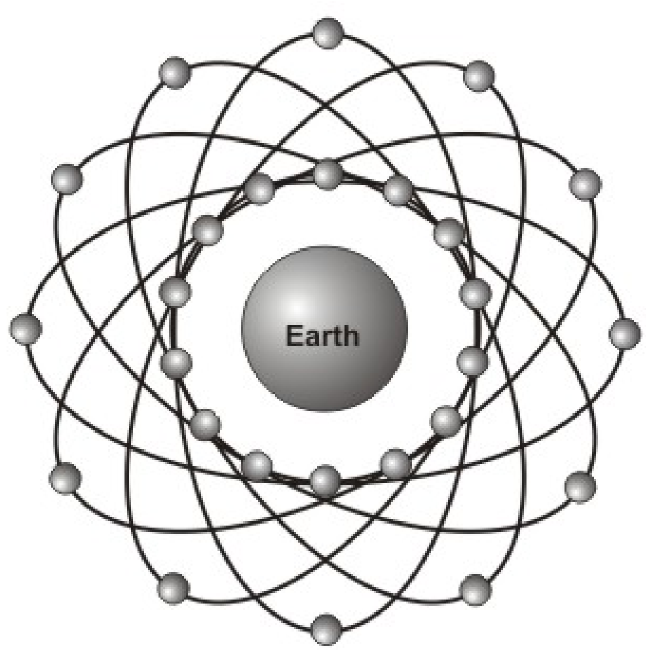


Figure 5.10.9 Global positioning system

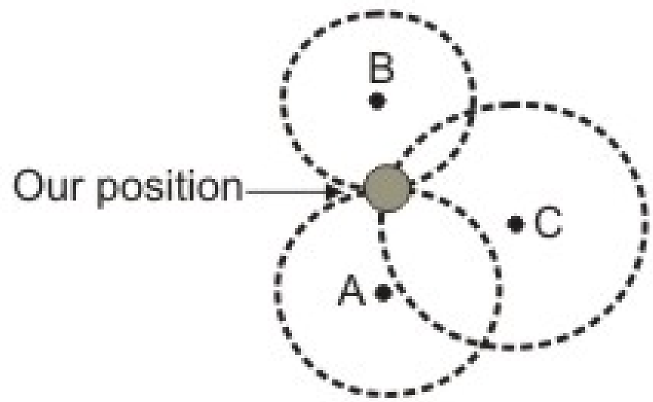


Figure 5.10.10 Triangulation approach used to find the position of an object

Figure 5.10.11 GPS receiver in a ship

5.10.8 GEO Satellites

Back in 1945, the famous science fiction writer Arthur C. Clarke suggested that a radio relay satellite in an equatorial orbit with a period of 24 h would remain stationary with respect to the earth's surface and that can provide radio links for long distance communication. Although the rocket technology was not matured enough to place satellites at that height in those days, later it became the basis of Geostationary (GEO) satellites. To facilitate constant communication, the satellite must move at the same speed as earth, which are known as Geosynchronous. GEO satellites are placed on equatorial plane at an Altitude of 35786Km. The radius is 42000Km with the period of 24 Hrs. With the existing technology, it is possible to have 180 GEO satellites in the equatorial plane. But, only three satellites are required to provide full global coverage as shown 5.10.12

. Long round-trip propagation delay is about 270 msec between two ground stations. Key features of the GEO satellites are mentioned below:

- Inherently broadcast media: It does not cost much to send to a large number of stations
- Lower privacy and security: Encryption is essential to ensure privacy and security
- Cost of communication is independent of distance

The advantages are best exploited in VSATs as discussed in the following section.

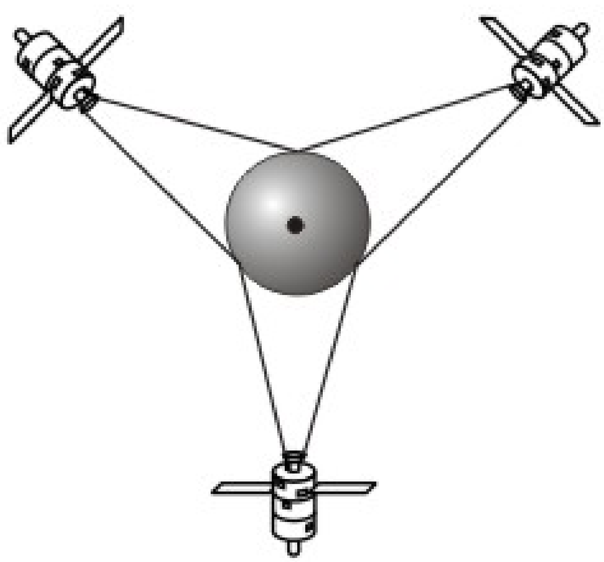


Figure 5.10.12 Three satellites providing full global coverage in GEO system

5.10.9 VSAT Systems:

VSAT stands for Very Small Aperture Terminal. It was developed to make access to the satellite more affordable and without any intermediate distribution hierarchy. Most VSAT systems operate in Ku band with antenna diameter of only 1 to 2 meters and transmitting power of 1 to 2 watts. Possible implementation approaches are: *One-way, Split two-way and two-way*. One-way VSAT configuration is shown in Fig. 5.10.13. In this case, there is a master station and there can be many narrow-banding groups within a large broadcasting area of the satellite. This configuration is used in Broadcast Satellite Service (BSS). Other applications of one-way VSAT system are the Satellite Television Distribution system and Direct to Home (DTH) service as shown in Fig. 5.10.14, which has become very popular in recent times.

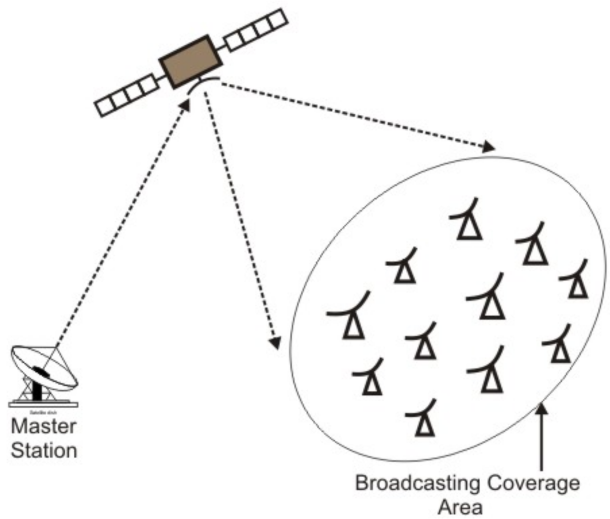


Figure 5.10.13 One-way satellite configurations

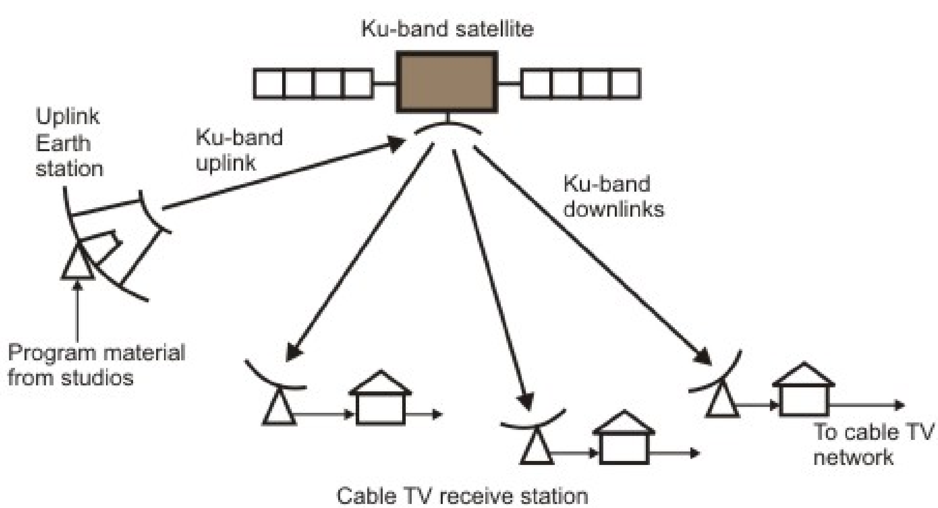
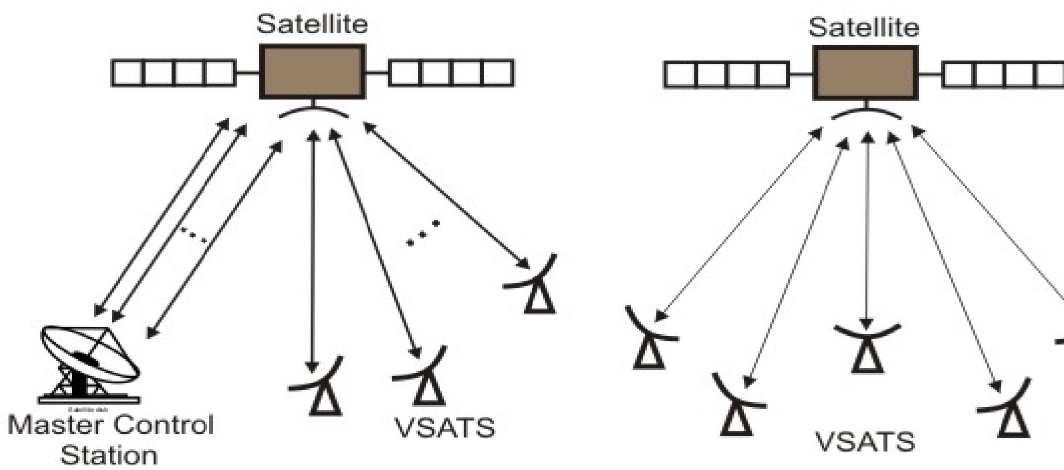


Figure 5.10.14 Satellite Television distribution system

In case of two-way configuration, there are two possible topologies: star and mesh. In the first case, all the traffic is routed through the master control station as shown in Fig. 5.10.15(a). On the other hand, each VSAT has the capability to communicate directly with any other VSAT stations in the second case, as shown in Fig. 5.10.15(b). In case of split two-way system, VSAT does not require uplink transmit capability, which significantly reduces cost.



(a) (b)

Figure 5.10.15 (a) Two-way VSAT configuration with star topology, (b) Two-way VSAT configuration with mesh topology

5.10.10 MAC Protocols

One of the key design issues in satellite communication is how to efficiently allocate transponder channels. Uplink channel is shared by all the ground stations in the footprint of a satellite, as shown in Fig. 5.10.16.

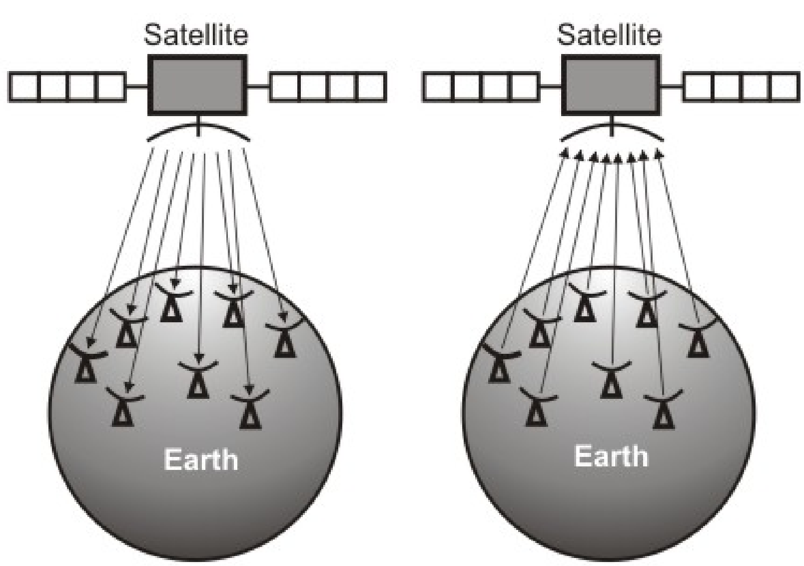


Figure 5.10.16 Uplink frequency is shared and downlink signal is broadcasted

The round robin and contention-based medium access control schemes have been found to be suitable for local area networks. But most of the schemes are unsuitable for communication satellite medium used in wide area networks. Apart from the nature of traffic, unique features of the satellite channels are to be taken into consideration for designing suitable medium access control protocol for them. The most important feature of the satellite channels is their long up-and-down prorogation delay, which is about one fourth of a second. The second most important feature of the satellite channels is that, after about one fourth a second a station has ceased transmission, it knows whether the transmission was successful or suffered a collision. These two features along with the nature of traffic, whether bursty or streamed are the determining factors for the designing of medium access control schemes.

As more than half a second is necessary to get response of a poll, polling scheme is inefficient for satellite channels. The CSMA-based schemes are also impractical because of long propagation delay; whatever a station senses now was actually going on about on quarter of a second ago.

For a satellite system with a limited number of ground stations and all of them having continuous traffic, it makes sense to use FDM or TDM. In FDM, each transponder channel is divided into disjoint subchannels at different frequencies, with guard bands to reduce interference between adjacent channels. In TDM, the channel is divided into slots, which are grouped into frames. Each slot is allocated to each of the ground stations for transmission.

But, in situations where the number of ground stations is large and stations have bursty nature of traffic, both TDM and FDM are inefficient because of poor utilization of the slots and subchannels, respectively. A third category of medium access scheme, known as *reservation* has been invented for efficient utilization of satellite channels. In all the reservation schemes, a fixed frame length is used, which is divided into a number of time slots. For a particular station, slots in the future frames are reserved in some dynamic fashion, using ALOHA or S-ALOHA. The schemes differ primarily in the manner the reservations are made and released using either a distributed or a centralised policy as discussed in the following subsections.

Contention-free protocols:

Fixed assignment protocols using FDMA or TDMA: Allocation of channel assignment is static; suitable when number of stations is small. These provide deterministic delay, which is important in real-time applications.
Demand assignment protocols: Suitable when the traffic pattern is random and unpredictable. Efficiency is improved by using reservation based on demand. The reservation process can be implicit or explicit.

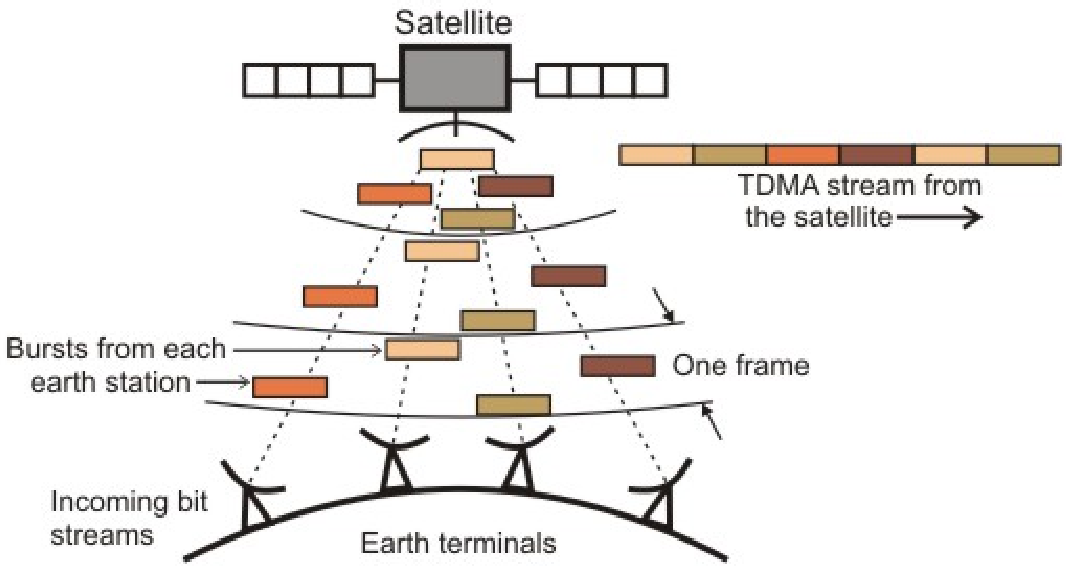


Figure 5.10.17 TDMA MAC technique

Random access protocols:

- Pure ALOHA
- Selective-reject ALOHA
- Slotted ALOHA
- Reservation Protocols
- Reservation ALOHA (R-ALOHA)
- Hybrid of random access and reservation protocols
- Designed to have the advantages of both random access and TDMA

Distributed Protocols

A large number of reservation schemes have been proposed. A few representative schemes are briefly outlined below. It is assumed that there are n stations and m slots per frame.

R-ALOHA: The simplest of the schemes, proposed by Crowther et al (1973) is known as R-ALOHA. As illustrated in Fig 5.10.18, the scheme assumes that the number of stations is larger than the number of slots (n>m) and with time the number of active stations is varying dynamically. A station wishing to transmit one or more packets of data monitors the slots in the current frame. The station contends for a slot in the next frame, which is either free or contains a collision in current frame. Successful transmission in a slot serves as a reservation for the corresponding slot in the next frame and the station can send long stream of data by repeated use of that slot position in the subsequent frames. The scheme behaves like a fixed assignment TDMA when the stations send long streams of data. On the other hand, if most of the traffic is bursty, the scheme behaves like the slotted ALOHA. In fact, the performance can be worse than S-ALOHA.

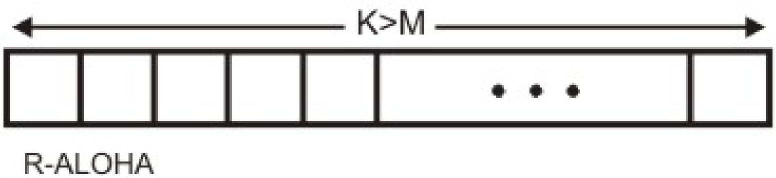


Figure 5.10.18 R-ALOHA based MAC technique

Binder's Scheme: The scheme proposed by Binder works for a fixed number of stations which is less than or equal to the number of slots (n<m). It starts with the basic TDM by giving ownership of one particular slot to each station. If there are extra slots, these are contended for by all stations using S-ALOHA. The owner of a slot can continue to use it as long as it has got data to send. If the owner has no data to send, the slot becomes available to other stations, on a contention basis. The owner of a slot can get it back simply by sending a packet in its slot. If there is no collision, the station acquires it from the current frame. If there is collision, other stations withdraw and the owner reclaims the slot in the next frame. This is illustrated in Fig 5.10.19.

This scheme is superior to R-ALOHA for stream-dominated traffic, because each station is guaranteed at least one slot of bandwidth. However, for large number of stations, this scheme can lead to a very large average delay due to large number of slots per frame.

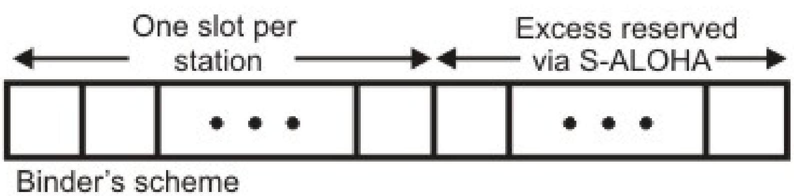


Figure 5.10.19 Binder's scheme

Robert's scheme: Unlike the previous two schemes, where the reservation is implicit, Robert proposed a scheme where explicit reservation is made. As usual, a frame is divided into a number of equal length slots. But, one of the slots is further divided into minislots. As shown in Fig 5.10.20, a station having data to send, sends a request packet in a minislot, specifying the number of slots required. The minislot is acquired using S-ALOHA and acts as a common queue for all the stations. A successful transmission allows reservation. By keeping track of the global queue, the station knows how many slots to skip before it can send.

Although Robert's scheme gives better performance compared to S-ALOHA, for lengthy streams there can be considerable delay, because a station may have to contend repeatedly to reserve slots. If the maximum reservation size is set high to facilitate transmission of lengthy streams in one go, the delay to start a transmission increases.

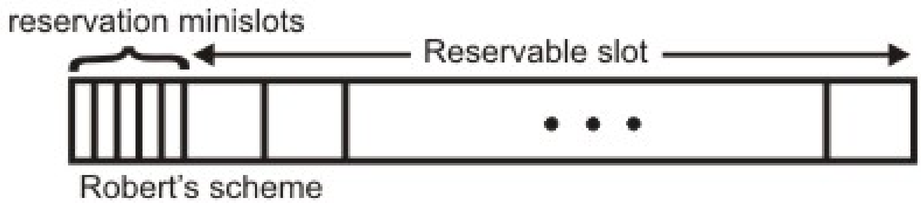


Figure 5.10.20 Robert's scheme

Centralized Protocols

Distributed reservation schemes suffer from the disadvantage of higher processing burden on each station and vulnerable to a loss of synchronization. These problems can be overcome by using centralized schemes. Two such schemes are discussed below.

FPODA: The Fixed-Priority Oriented Demand Assignment (FPODA) technique is an extension of the Robert's scheme that functions in a centralized manner. In this scheme, each frame begins with a number of minislots, each dedicated to one of the stations. In a particular implementation of the scheme, there are six stations as shown in Fig 5.10.21. Minislots are used for sending short data or reservation, which specifies the type of service required- priority, normal or bulk. Priority requests specify the amount of data to be sent with high priority and normal requests indicate an estimation of required future throughput. One of the six stations acts as a central controller and allocates time based on reservation requests. The controller allocates the remaining part of the frame into six variable length slots, one to each of the six stations. The controller station maintains a queue of requests and allocates time based on the requests. On a first-come first-serve basis the priority requests are kept at the front. After allocating to the priority requests, remaining time of the frames are allocated to normal requests. Remaining time after allocating to normal request is divided equally among the bulk requests.

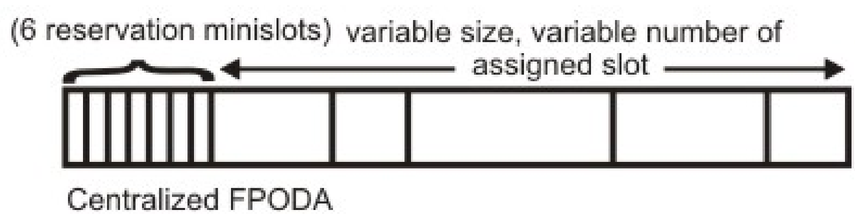


Figure 5.10.21 A Fixed-Priority Oriented Demand Assignment (FPODA) frame

PDAMA: The frame format for PDAMA, as shown in Fig. 5.10.22, has four types of slots, a leader control slots, a guard slot, a reservation minislots and data slots. The leader slot is used by the master station to communicate acknowledgement of received reservations and allocation of slots to other stations. The guard ring helps other stations to hear the leader control slot and prepare for further reservations. It can also be used for the purpose of ranging. The reservation minislots are reservation requests using S-ALOHA.

The data subframe is of variable length and a number of stations having reservation send their packets in this subframe.

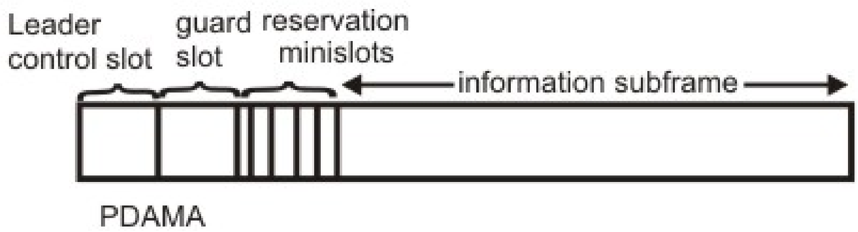


Fig. 5.10.22 Packet Demand Assignment Multiple Access (PDAMA) frame

Review Questions

1.Distinguish between footprint and dwell time.
Ans: Signals from a satellite is normally aimed at a specific area called the footprint. On the other hand the amount of time a beam is pointed to a given area is known as dwell time.

2. Explain the relationship between the Van Allen Belts and the three categories of satellites?
Ans: Van Allen belts are the two layers of high energy charged particles in the sky. Three orbits, LEO, MEO and GEO are chosen such that the satellites are not destroyed by the charged particles of the Van Allen belts.

3. Explain the difference between the Iridium and Teledesic systems in terms of usage.
Ans: Iridium project was started by Motorola in 1990 with the objective of providing worldwide voice and low-rate data communication service using handheld devices. On the other hand Teledesic project started in 1990 by Craig McCaw and Bill Gates with the objective of providing fiber-optic like broadband communication (Internet-in-the-sky).

4. What are the key features that affects the medium access control in satellite communication?
Ans:

- Long round-trip propagation delay
- Inherently broadcast media
- Lower privacy and security
- Cost of communication is independent of distance

5. What are the possible VSAT configurations?
Ans: Possible implementation configurations are:

- One-way:
    - Used in the broadcast satellite service (BSS)
    - Satellite Television distribution system
    - Direct to home (DTH) serviceØSplit two-way:

    - VSAT does not require uplink transmit capability, which significantly reduces cost
- Two-way:
    - All the traffic is routed through the Master control station (hub) or each VSAT has the capability to communicate directly with any other VSATs