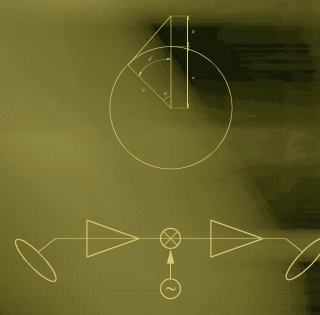




International Telecommunication Union



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Handbook Mobile-satellite service (MSS)

Edition 2002

THE RADIOCOMMUNICATION SECTOR OF ITU

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

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International Telecommunication Union

Handbook
Mobile-satellite service (MSS)

FOREWORD

In today's world, people have become increasingly mobile in both their work and play. This trend has been reflected in an increasing demand for mobile-satellite services (MSS) of all kinds over the past two to three decades; that is, demand for maritime, aeronautical and land mobile-satellite services. These needs have been well documented within the ITU through many studies and proposals, which have recently led to the creation of a number of new allocations of radio frequencies for use by MSS. Outside the ITU, trade press and newspaper articles frequently highlight the benefits of MSS, particularly in applications such as disaster relief and emergency uses in connection with search and rescue operations. The application of MSS within developing countries, making available viable telecommunications services in low telephone-density areas of the world, has also gained world attention.

The present MSS Handbook brings into sharp focus, in one place, the numerous capabilities that MSS systems now in service – and systems currently being built out – can provide in our mobile world.

MSS first began as an outgrowth of the creation and development of Inmarsat, an organization established to operate maritime satellite communications by the International Maritime Organization. This required early input by the Radiocommunication Sector of the ITU in defining the first allocations of frequencies for use by MSS at 1.5/1.6 GHz and for satellite EPIRBs (emergency position-indicating radio beacons) in the 406 MHz band, and in developing the technical standards for these MSS networks.

Today there are numerous MSS frequency allocations below 1 GHz in the ITU Radio Regulations and more MSS allocations between 1 and 3 GHz – many of these allocations having been made at world radiocommunication conferences in 1992 and 1995. Despite the surge in interest in MSS in the last ten years, many in the telecommunications field are not so familiar with the capabilities and design aspects of this type of satellite communications service. The MSS Handbook is intended as a readable manual covering the basic principles of MSS design, typical and potential applications of MSS, frequency bands available to MSS, certain special ITU regulatory provisions pertaining to MSS in the Radio Regulations and a brief overview of the technical aspects of MSS systems. Finally, the Handbook includes thumbnail profiles of the technical and operational characteristics of MSS systems currently in operation or poised for launch.

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CHAPTER 1

INTRODUCTION TO THE MOBILE-SATELLITE SERVICE

1.1 Overview of the Handbook

1.1.1 Purpose of this Handbook

This mobile-satellite service (MSS) Handbook has been written to provide a brief survey and introduction to the field of MSS, intended primarily for those readers who are not so familiar with the capabilities of MSS or the system and design aspects of this type of satellite communications service. However, it may also serve as useful reference document for users of MSS, MSS providers and national regulators, as it contains – in one place – much useful information and cross-references to other source documents of the ITU as well as to the general technical literature and appropriate web sites.

1.1.2 Organization of this Handbook

This Handbook is organized into five main Chapters as follows:

Chapter 1 – Introduction

Chapter 2 – Frequency allocation and frequency sharing/regulatory aspects

Chapter 3 – Typical and potential applications for MSS communications

Chapter 4 – Technical aspects of MSS systems

Chapter 5 – Technical and operational characteristics of some current and planned MSS systems

1.2 Historical perspectives on the evolution of MSS networks

The field of MSS has a history nearly as long as that of satellite communications itself. In 1963-64, SYNCOM II, SYNCOM III, the world's first geosynchronous/geostationary communications satellites were launched by NASA. The SYNCOM I spacecraft launched prior to SYNCOM II/III was lost when its apogee motor was fired; SYNCOM II was launched into an orbit with a 24-h period at 36000 km, but this orbit was in a highly inclined plane. SYNCOM III was truly geostationary, being in a 24-h orbit in a nearly perfect equatorial plane orbit; i.e., with zero degrees inclination.

Technically, these SYNCOM satellites were being used primarily for fixed-satellite service (FSS) experimental communications; that is, they were being used primarily to relay communications from fixed earth stations at several locations around the world. However, one earth station was actually located aboard a mobile platform: the USNS Kingsport, a large transport type vessel, home-ported in Honolulu, Hawaii. The ship had been modified by the US Navy to carry a 30-foot/9.1-m parabolic antenna to track the SYNCOM satellites – the dish was protected from the marine environment by an inflatable dacron radome, requiring access to the 3-axis antenna through an air lock within the ship. The Kingsport ship terminal was thus the world's first truly mobile earth station; and, could be considered the first maritime mobile earth terminal, as well. SYNCOM utilized special frequencies authorized by the ITU for SYNCOM's experimental satellite communications experiments. The frequencies were at around 1.8 GHz for the space-to-Earth link (downlink) and at around 7.3 GHz for the Earth-to-space link (uplink).

Project SYNCOM was an unqualified success; proving the practicality of the geostationary orbit for satellite communications; but, unfortunately perhaps because of the large size of the Kingsport earth station antenna many experts in the 1960s concluded that *mobile-satellite* communications at sea; or, maritime mobile-satellite service (MMSS) would never really be practical. It was not until the mid 1970s that the basis for a truly global MSS system was begun with the launch of the three Marisat satellites in 1976. These satellites were launched by COMSAT/Comsat General Corporation, the first one as a pilot system for a U.S.-based system providing maritime mobile-satellite services; and later formed the basis of the space segment of the International Maritime Satellite System or Inmarsat, based in London, UK.

Marisat was also a geostationary satellite and contained a hybrid payload: one transponder for US NAVY ship terminals operating in a government UHF frequency band and another transponder for civilian merchant ships utilizing the then newly allocated maritime mobile-satellite service (MMSS) frequencies in the 1.5/1.6 GHz bands (the lower 1.5 GHz frequency band being used for space-to-Earth service links).

The 1.5/1.6 GHz transponder for this first commercial MMSS satellite employed a travelling-wave tube amplifier (TWTA) that could operate at two or three different power levels. This feature enabled Marisat to operate at the beginning of life (BOL) with most of the spacecraft's solar panel DC power devoted to running the US Navy payload; but, as traffic increased in the MMSS, and the Navy began deploying its own dedicated satellite system, the TWTA was operated at the higher power level taps – providing higher channel capacity for the MMSS operation. The program was very successful and the three Marisat satellites leased by COMSAT to Inmarsat, together with later leases of capacity from the European Space Agency (ESA) Marecs experimental spacecraft and L-band payloads on Intelsat-V spacecraft formed the world's first truly global MSS system, under aegis of Inmarsat.

As Inmarsat matured, it evolved from utilizing the Marisat and Marecs satellites to employing the MSS payloads that shared spacecraft power and other resources aboard a number of the Intelsat-V satellites (1980s). Subsequently it launched its own, dedicated Inmarsat-II (1990/1992), and Inmarsat-III (1995) spacecraft that provided mobile-satellite services not only for maritime and aeronautical, but also for land mobile-satellite services.

In parallel with the above historical developments, the ITU also re-defined and broadened the spectrum available to MSS in the 1-3 GHz bands, starting with only a 15 MHz allocation: 7.5 MHz for MMSS and 7.5 MHz for aeronautical mobile-satellite service (AMMS) in the 1.5/1.6 GHz band frequency allocations, at WARC-71. The ITU increased these 1.5/1.6 GHz MSS allocations by 1987-1992-1995-1997 to an eventual 34 MHz of spectrum (in both the uplink and downlink bands), including 14 MHz in each direction for maritime mobile-satellite services (MMSS), another 5 MHz for MMSS/LMSS, 10 MHz in each direction for aeronautical mobile-ROUTE satellite services (AMS(R)S) and 4 MHz in each direction for land mobile-satellite services (LMSS), plus 1 MHz in each direction limited to distress and safety communications. More recently, the ITU has favoured the creation of so called *generic* MMS allocations, which can be used for maritime, aeronautical, or land mobile-satellite services.

In recent years the ITU has expanded or made several new MSS allocations in the 1-3 GHz bands. These allocations included expansion of L-band; plus, the addition of the 1.9/2.1 GHz bands, the 1.6/2.4 GHz and the 2.5/2.6 GHz MSS bands.

The MSS allocations have also been exploited by various national MSS systems which have been developed and launched during the last 10 or so years. For example, the 1.5/1.6 GHz band has been extensively used by a number of North American, European, and Asian MSS systems. The North American MSS systems would include those of American Mobile Satellite Corp. (AMSC), an identical space segment operated by TMI (Canada), and Solidaridad (Mexico) which carries a 1.5/1.6 GHz band payload which is capable of addressing portions of the 1.5/1.6 GHz MSS spectrum. AMSC was licensed within the United States of America in 1989, after an FCC multi-year process determined that various competing MSS networks proposed by a number of companies would have to be merged into one single national network, due to the inability of these systems to share 1.5/1.6 GHz band spectrum. AMSC launched its AMSC-1 spacecraft in 1995, while TMI's "sister" satellite (capable of backing up AMSC-1) was launched in 1996. ESA's Marecs spacecraft and Italy's Italsat are examples of European systems; while, Australia's Aussat system and the Russian Federation's Volna are examples of Asian MSS networks. More recently, several so called "Super-GSO" networks; e.g., AceS Garuda and Thuraya have been launched, systems which can deliver very high e.i.r.p.s at 1.5/1.6 GHz in order to operate with low-gain, hand-held terminals, as well as to provide data and other services to higher-gain mobile earth stations.

Other MSS allocations have also been used by several MSS systems in the world; for example, the 1.6/2.4 GHz bands by Globalstar (USA) and 2.5/2.6 GHz bands by N-STAR (JAPAN).

As can be seen from the history above, for many years the largest amount of spectrum – of the three types of MMS – was devoted to MMSS, due to the demand pressures caused by an increasing numbers of MMSS terminals in use, as well as the development of Global Maritime Distress and Safety System (GMDSS) which dictated that certain types of Inmarsat maritime terminals could be used to satisfy Safety of Life at Sea (SOLAS) requirements for sea-going vessels operating beyond the coverage of VHF coast stations, in accordance with the provisions of the SOLAS treaty and the GMDSS.

Thus, in summary, we see that the demand for vital, reliable, satellite communications at sea by mariners, especially for distress or emergency situations, and the ITU's opening up of allocations for MMSS/AMSS really spawned the development of the entire field of MSS; and in particular, was the driving force behind the creation of the Inmarsat system, an MSS system which is still being heavily utilized by the maritime community today.

A chronological summary of some of the key milestones in the development of MSS in general and the evolution of Inmarsat in particular is provided below:

- 1962-1964* First launch of a communications satellite, SYNCOM II/III into geosynchronous/geostationary orbit(s) by NASA. It was clear that the potential to provide a high quality line-of-sight communications path from any ship to the continents via the satellite transponder now existed. But it appeared that the costs would be too high for individual countries and that some sort of International cooperation was necessary to make mobile-satellite services available globally.
- 1964* Intelsat (International Telecommunications Satellite Organization) was formed to provide intercontinental telephony, and this was watched closely by the maritime community as a possible model.
- 1966* The Inter-Governmental Maritime Consultative Committee (IMCO) began to study the use of satellites to improve maritime communications.
- 1971* Frequencies at 1.5/1.6 GHz were allocated by WARC-71 to mobile-satellite services; 7.5 MHz for the maritime mobile-satellite service; 7.5 MHz for the aeronautical mobile-satellite service.
- 1973* IMCO convenes an international conference to consider establishment of an international organization to operate maritime satellite communications.
- 1975-1976* The International Conference on the establishment of an international maritime satellite system met in London, setting up the international structure of Inmarsat. In 1976, the Inmarsat Convention and operating agreements were finalized and opened for signing by States wishing to participate.
- 1976* Three Marisat satellites were launched by the United States of America and stationed over the Atlantic, Pacific, and Indian Oceans, and providing hybrid military (UHF) and commercial (1.5/1.6 GHz band) payloads.
- 1979* The Inmarsat Convention and operating agreements entered into force on 16 July and were signed by 29 countries.
- 1982* Inmarsat began global operations. Comsat General Corporation owns and manages Marisat, with Inmarsat leasing capacity.
- 1982* Additional leased satellite capacity from ESA (Marecs) and Intelsat (1.5/1.6 GHz band payload on Intelsat-V's), all with global beams and forming the "First Generation" satellites of the Inmarsat global system.
- 1983* The bands 406-406.1 MHz were reserved for low-power satellite EPIRBs.
- 1985* Cospas-Sarsat System was declared operational.
- 1987* WARC Mob-87 made land mobile-satellite allocations at 1.5/1.6 GHz.

- 1988 International Cospas-Sarsat Programme Agreement was signed by Canada, France, USA, and USSR.
- 1990-1992 Inmarsat launched its own, dedicated “Second Generation” Inmarsat-II satellites with higher 1.5 GHz downlink e.i.r.p. levels, but still employs global beam.
- 1992 WARC-92 made additional MMSS/LMSS allocations in 1.5/1.6 GHz, 1.6/2.4 GHz, 2.5/2.6 GHz and 1.9/2.1 GHz bands; and, below 1 GHz, for “little LEOs”. Many new non-geostationary MSS constellations were proposed and filed (IRIDIUM, etc.).
- 1995 Inmarsat launched own “third generation” Inmarsat-III satellites with spot beams covering land masses and using LMSS allocations.
- 1998 New non-geostationary systems were planned for service, such as Globalstar, ICO, Iridium, and Orbcomm; IRIDIUM began operational service.
- 2000 WRC-2000 identified 1-3 GHz MSS bands for the satellite component of IMT-2000.

1.3 Tutorial on MSS system engineering aspects

Communication is a very general subject. It is a variety of behaviours, processes and technologies by which meaning is transmitted or derived from information. The term is used to describe diverse activities such as: conversation between two persons; data exchange between computers; courting behaviour of birds; the emotional impact of a work of art; the course of a rumour through a society or the network of nervous and metabolic subsystems that make up the body’s immune system.

In 1928 the English literary critic and author I. A. Richards offered one of the first – and in some ways still the best – definition of communication as a discrete aspect of human enterprise:

“Communication takes place when one mind so acts upon its environment that another mind is influenced, and in that other mind an experience occurs which is like the experience in the first mind, and is caused in part by that experience.”

Interest in communication has been stimulated by advances in science and technology, which, by their nature, have called attention to man as a communicating creature. Among the first and most dramatic examples of the inventions resulting from technological ingenuity were telegraph and telephone, followed by others like wireless radio and telephoto devices. The development of popular newspaper and periodicals, broadcasting, motion pictures, and television led to institutional and cultural innovations that permitted efficient and rapid communication between a few individuals and large populations; these media have been responsible for the rise and social power of the new phenomenon of mass communication.

We then see that communication phenomenon forms a very broad and general universe. Inside this general universe we can highlight a smaller subset that deals with communication which uses optical or electromagnetic means to transport information that is telecommunication, as defined by ITU: “*telecommunication*: Any transmission, *emission* or reception of signs, signals, writings, images and sounds or intelligence of any nature by wire, *radio*, optical or other electromagnetic systems (CS).” (Radio Regulations (RR) No. 1.3)

Within the telecommunication set we can highlight the telecommunication subset, consisting of the telecommunication accomplished by means of radio waves, which forms radiocommunication, defined by the ITU as:

“radiocommunication: Telecommunication by means of radio waves (CS) (CV).” (RR No. 1.6)

When we use radiocommunication for a specific purpose we have a Radiocommunication Service.

“radiocommunication service: A service as defined in this Section involving the transmission, emission and/or reception of radio waves for specific telecommunication purposes.” (RR No. 1.19)

Within the studies that constitute a Radiocommunication Service we can highlight the following:

Fixed Service means a radiocommunication service between two fixed points.

Mobile Service refers to a radiocommunication service between two points, when at least one is mobile or is at an undetermined location.

Broadcasting Service is a radiocommunication service between a fixed point and many other scattered points in a certain area, all of them receiving the same information.

Radio Astronomy Service means a radiocommunication service intended to receive and to analyse the radio signals emitted by the stars or other radiating bodies in outer space.

Among the various existing services, we will centre our attention on the Mobile Service:

“mobile service: A radiocommunication service between mobile and land stations, or between mobile stations (CV).”

So, we see that the characteristic of a Mobile Service is that at least one of the communication stations be mobile, that is, it can communicate while in motion from an uncertain and unknown location.

There are several Mobile Services, such as:

Terrestrial Mobile Service: the case in which stations in mobile communication are located on the Earth's surface.

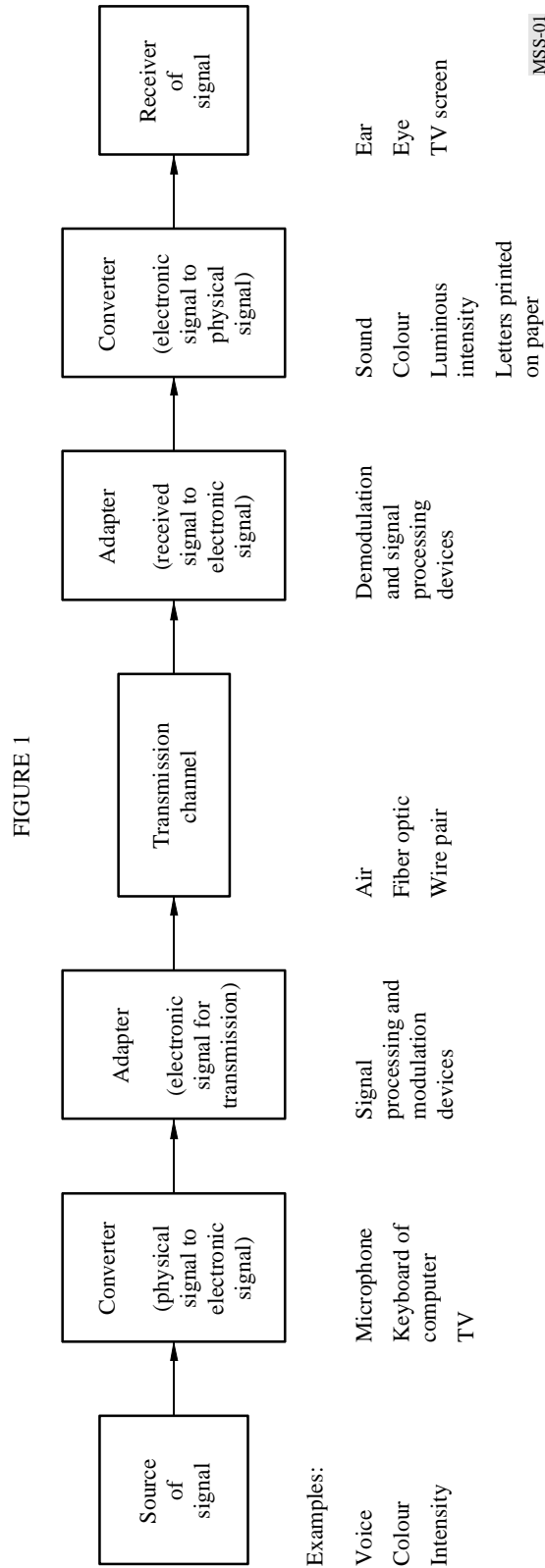
Maritime Mobile Service: the case in which the stations in mobile communication are located on the Earth's surface and at least one of the stations is aboard a ship or a vessel.

Aeronautical Mobile Service: the case in which the stations in mobile communication are located on, or near, the Earth's surface and at least one of the stations is aboard an aircraft.

Mobile-Satellite Service: the case in which a station of a Mobile Service is located on the Earth's surface communicates with one or more satellites or when a station of a Mobile Service on the Earth's surface communicates with another mobile service station, located on the Earth's surface, by means of one or more satellites, or when two satellites communicate with each other.

This Handbook centres only on the mobile-satellite service (MSS).

Any basic telecommunications system comprises 7 parts, as shown in Fig. 1:



- 1 The source of the signal that we want to transmit can be the human voice, a photoelectric cell in a fax machine, the keyboard of a computer, a sensor of a physical measure, such as a wind speed or temperature meter, etc.
- 2 A converter device that transforms the generated physical signal into an electrical signal, because telecommunication systems only transmit electromagnetic signals.
- 3 An intermediate electronic system that modifies the electrical signal obtained in the previous stages in order to adapt it for transmission to the outer medium, which can be a pair of wires, an optical fibre or an antenna that will irradiate the signal produced.
- 4 The transmission channel, which can be the length of the wire pair or of the optical fibre, or the distance between two antennas, a transmitting antenna on one end and a receiving one on the other.
- 5 An intermediate electronic system that converts the received signal into an adequate electrical signal, which will be usable by the following device.
- 6 A device that transforms the electrical signal deriving from the previous stages into a physical signal, such as acoustic pressure, luminous intensity, a colour, or a signal that will be printed on paper.
- 7 An element or device that will receive the information originally transmitted, such as a human being, paper on which the message will be printed, a computer's memory, or a video screen.

Other signals generated by the electronic devices or by the transmission media are incorporated into the information that we wish to transmit, and receive the generic name of noise. Thus, noise is all undesirable information that is mixed with the usable information, impairing the communication.

The stages introduced previously have been thoroughly studied by engineers and scientists with the objective of achieving the best possible transmission, whereby the original information is carried from the source to the intended destination with the least possible distortion and the smallest cost. The aforementioned distortion may be caused by modifications produced in the signal or by the presence of noise.

When the information is transmitted by electromagnetic waves in a medium, as is the case of transmission of signals between two antennas, we have the field of study known as radiocommunication.

Although the radiocommunication field is quite extensive, two fundamental concerns warrant attention: the propagation of electromagnetic waves between the transmitting and receiving antennas, and also how the influence of noise in the transmission process can be minimized.

The physical medium between antennas influences the manner in which information is transmitted between them. When both antennas are located on the Earth's surface, for example, the physical parameters of the soil and of the air, including the meteorological phenomena, produce perceptible effects in electromagnetic wave propagation. Additionally, since the Sun is a bright star, it radiates electromagnetic waves. Hence it is a source of ionized particles that reach the Earth, creating an ionized medium of gaseous layers, which also produces effects in electromagnetic wave propagation. All of these effects are intensively studied.

The simplest situation involving the transmission of information by electromagnetic waves is when the transmitting antenna transmits directly to the receiving antenna, without any obstacles in the path through which the electromagnetic waves will travel. In this case, there is full visibility between both antennas. This situation occurs when both antennas are located on the Earth's surface and the distance between them is relatively short, due to the Earth's spherical shape. As the distance between the two antennas increases, the path is no longer a direct (line-of-sight) path. In order to increase the path length the antenna heights can be made higher, but only to the extent that the costs do not become prohibitive.

In such a case, the problem can be solved by means of communications satellites. Since these satellites are placed at very high altitudes, their reach is far superior to that of the highest towers that can be built on the Earth's surface. When two antennas situated on the Earth's surface are very far apart and there is no visibility between them, communications satellite can be used to relay the signal. Thus, a transmitting antenna transmits the signal to the satellite, which in turn relays the signal to the receiving antenna. In this case, there is visibility between the transmitting antenna and the satellite, and between the satellite and the receiving antenna.

Because telecommunications satellites are located at high altitudes relative to the Earth's surface, they cover a wide area, which is particularly beneficial for rural regions and countries with large dimensions since it allows the accomplishment of the radiocommunication between distant points using few links, thereby reducing the related costs. Table 1 shows the distance between two points on the Earth's surface as a function of the height of a satellite antenna. In fact, the actual reach of an antenna's signal is slightly higher than the values indicated in Table 1, whenever the refraction effect in the Earth's atmosphere and the diffraction along Earth's surface are taken into account, and slightly lower whenever rain precipitation is taken into account, but the indicated values serve as reference. (Figure 2 shows the parameters of Table 1.)

FIGURE 2

$$\begin{aligned} a &= (a + h) \cos \alpha \\ \downarrow \\ \cos \alpha &= a / (a + h) \\ \downarrow \\ \alpha &= \cos^{-1} (a / (a + h)) \\ \downarrow \\ d &= a * \alpha \text{ (rad)} \\ \downarrow \\ d &= a * \cos^{-1} (a / (a + h)) \end{aligned}$$

a : average Earth's radius = 6 371.8 km
 d : distance from antenna to horizon

Note – a and h should be the same units

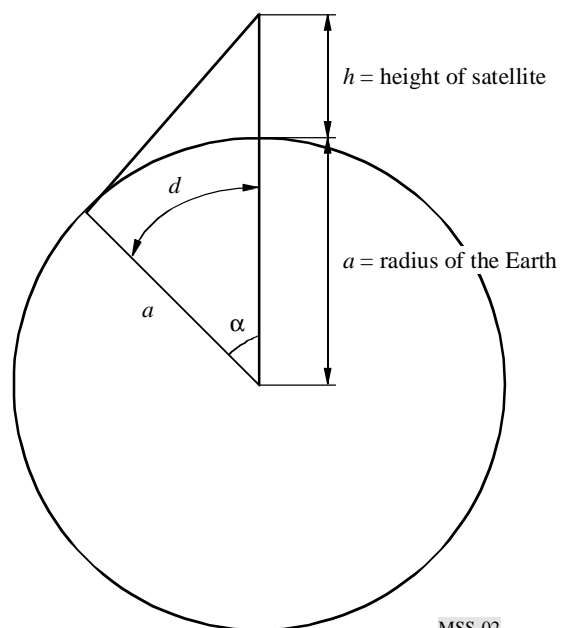


TABLE 1

Relationship between height and distance of an antenna

Height h (km)	Angle (degrees)	Distance d (km)
10 ⁽¹⁾	3.313	368.4
30 ⁽²⁾	5.549	617.1
150 ⁽³⁾	12.312	136.2
780 ⁽⁴⁾	27.008	3 003.6
2 000 ⁽⁴⁾	40.438	4 497.1
10 000 ⁽⁵⁾	67.095	7 461.7
35 600 ⁽⁶⁾	81.268	9 037.8

- (1) Altitude of an international flight.
- (2) Altitude of a stratospheric balloon.
- (3) Altitude of an amateur radio satellite or of a space research satellite.
- (4) Altitude of typical commercial satellite systems – known as LEO satellite systems.
- (5) Altitude of typical commercial satellite systems – known as MEO satellite systems.
- (6) Altitude of a GSO satellite system.

Communications satellites are objects that orbit around the Earth according to Newton’s gravitational laws. The trajectory of an object that orbits around the Earth coincides with an ellipse or a circle, depending on the direction and speed of the satellite when placed in orbit. For each height of an object orbiting around the Earth there is a rotation period whose expression is given below (see Fig. 3):

$$T = 165.87 \times 10^{-6} \times a^{3/2}$$

where:

- T : orbital period (min)
- a : semi-major axis of ellipse (km).

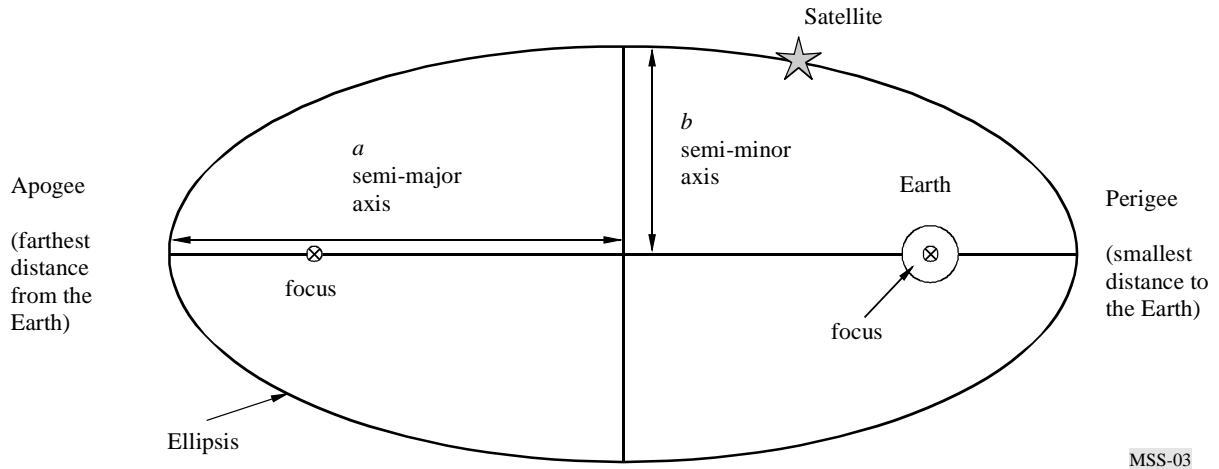
If the orbit is circular, a is the distance from the centre of the Earth to satellite.

We observe that the higher the satellite is positioned, the larger its orbital period around the Earth will be. There is a height such that the satellite’s orbital period around the Earth is equal the rotation period of the Earth. For an observer situated on the Earth’s surface, the satellite may seem to be motionless or stationary in space, thence the denomination => geostationary-satellite orbit (GSO).

According to the orbital period, satellites may be classified as geostationary (GSO) and non-geostationary (non-GSO). Geostationary satellites illuminate the same area of the Earth’s surface, which enable antennas located on the Earth’s surface used in communicating with them to point toward a specific direction, thereby reducing the overall cost of antenna systems and allowing these to be adjusted manually.

FIGURE 3

$$T(\text{minutes}) = 165.87 \times 10^{-6} \times a^{3/2} (\text{km})$$



In the case of (non-GSO) satellites, since they move at velocities different from that of the Earth, the illuminated area moves along with them, so that the associated antenna systems change their direction continuously, thereby increasing the costs of these systems due to the need for automatic tracking systems for azimuth and elevation adjustments.

On the other hand, since GSO satellites are located farther out in space than non-GSO satellites, the propagation attenuation is greater, so that GSO satellite systems require larger antennas and transmitters and, therefore, are more expensive than those antennas and transmitters used by non-GSO satellite systems.

This Handbook contains information regarding various aspects of mobile-satellite systems.

1.4 MSS general system architecture

MSS systems, whether they be designed to address maritime mobile, aeronautical mobile, or land mobile-satellite services all have certain common characteristics. Likewise, the satellites employed in these MSS systems can be found in constellations using the geostationary-satellite orbit (GSO), low Earth orbit (LEO), medium Earth orbit (MEO), elliptical orbit (with widely differing perigees and apogees); or even some combination of these types of orbital configurations (see § 1.5). It is noted here that it is now more common, both globally and regionally, for the majority of MSS allocations to be specified as generic MSS, in the RR Table of Frequency Allocations, Article 5 – rather than specifying the particular type of MSS: maritime, aeronautical, or land mobile.

1.4.1 Function of feeder links in MSS networks

However, irrespective of which orbital configuration is employed, the MSS systems differ from fixed-satellite service (FSS) systems in one key respect. Specifically, the FSS uses one pair of frequency bands; one band for uplink and one for downlink, to connect fixed points via the satellite links. The MSS system employs *two pairs* of links: one set known as MSS *service links* and the other set designated as MSS *feeder links*.

The MSS system works as follows: the mobile earth station or terminal transmits on the (Earth-to-space) *service link* to the satellite and then the satellite repeats that transmission on the (space-to-Earth) *feeder link* to the gateway fixed earth station. The gateway station, in turn, is typically interconnecting the call or data transmission via the public switched telephone network (PSTN) to the party to whom the mobile wishes to connect. The land line party then sends back his/her voice or data to the gateway station, which transmits it via the (Earth-to-space) *feeder link* to the satellite. Finally, the satellite transponder repeats that latter transmission back again to the mobile terminal which originated the call, via the (space-to-Earth) *service link*.

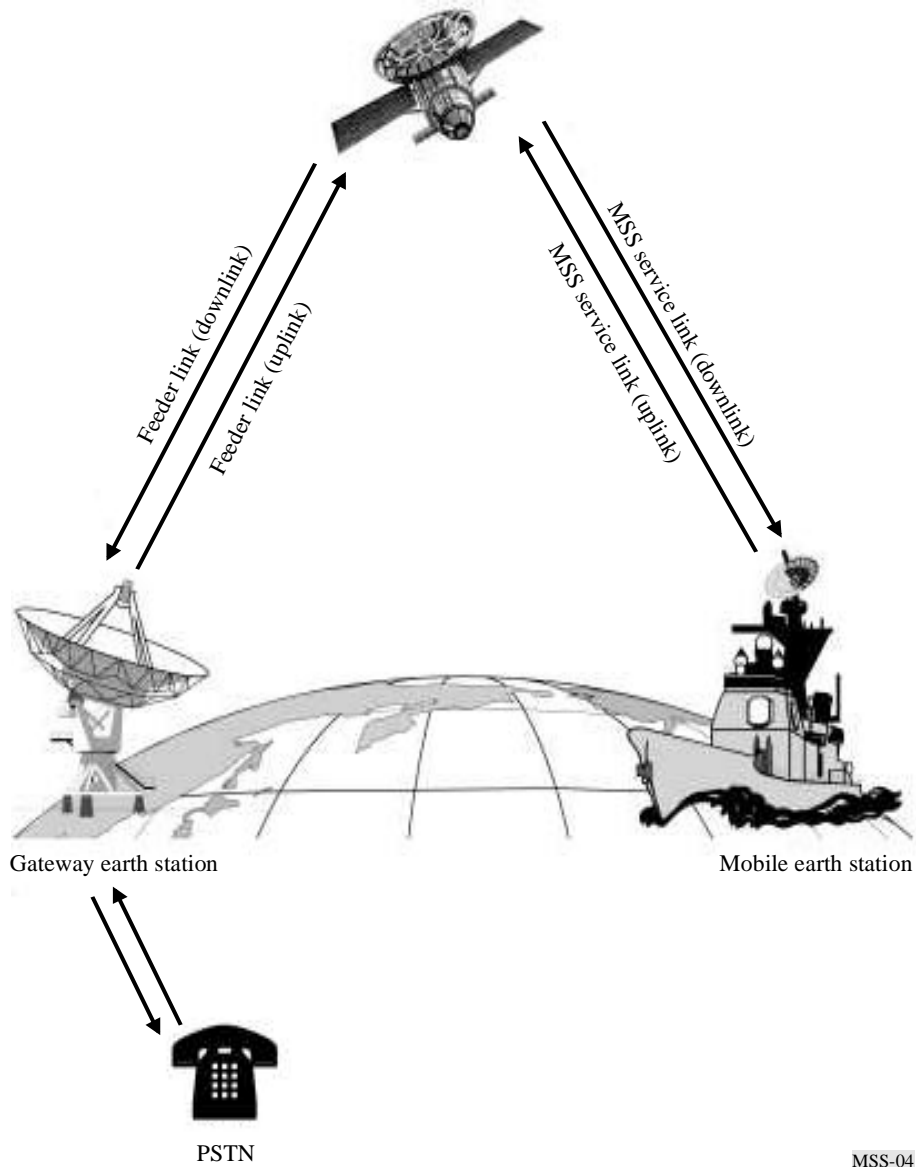
Figure 4 illustrates the tandem use of feeder links plus service links in a MSS satellite link in relation to the gateway station and the mobile earth station.

Thus, in any MSS network, the *service links* connect the mobile earth station or terminal to the satellite; whereas, the *feeder links* are used to connect the land-based gateway or feeder link station to the satellite. It takes *two pairs* of links to complete the full MSS circuit; i.e., the *forward link* (link from gateway out to the mobile) comprises (*one feeder link + one service link*) pair of links and *return link* (link from the mobile back to the gateway) comprises (*one service + one feeder link*) pair of links. Quite often, the MSS networks utilize any of several conventional FSS bands – generally bands higher in frequency than the service link allocations themselves – to operate their feeder links. For example, a particular MSS system could be designed to use segments of any of the FSS allocations at 5/7 GHz, 11/12/14/15 GHz, or 19/29 GHz for feeder link purposes. However, there are also particular FSS bands allocated by the ITU which are specified in the Radio Regulations as being designated exclusively for use by certain MSS feeder link operations.

For example, the FSS band 5 150-5 250 MHz is listed in the Article 5 Table of Frequency Allocations as a primary FSS (Earth-to-space) allocation. However, footnote RR No. 5.447A is attached to this band. The footnote reads as follows: “The allocation to the fixed-satellite service (Earth-to-space) is limited to feeder links of non-geostationary-satellite systems in the mobile-satellite service and is subject to coordination under No. **9.11A**” (Resolution 46A). Thus, this particular band is designated for exclusive use by non-geostationary-satellite (non-GSO) systems providing MSS.

Currently, several non-geostationary MSS systems are employing or planning to employ the above 5 GHz and companion 7 GHz (6700-7075 MHz) FSS bands designated especially for non-GSO MSS, including Globalstar and ICO. Other FSS bands set up specifically for non-GSO/MSS feeder links were allocated at the World Radiocommunication 1995 and 1997 (WRC-95/97) Conferences in the 15 GHz band and the 19/29 GHz bands.

FIGURE 4
Tandem feeder/service links: MSS satellite link



MSS-04

It should be noted that the bandwidth occupancy or level of spectrum uptake in the MSS service links places an equal demand for spectrum within the feeder link band(s) of choice. However, the total spectrum requirements for the feeder links can be reduced by one-half by means of employing the technique of orthogonal polarization (e.g.; *right-hand* versus *left-hand* circular polarization) on the feeder links, a technique which is feasible in most cases, yielding a two-fold frequency re-use. Such an approach is feasible for feeder link operations because of the high directivity and purity of polarization that can be obtained routinely with large-aperture antennas used at gateway stations. The same approach cannot be used on MSS service links because the typical, low-gain mobile earth station antennas cannot maintain adequate polarization purity needed to support good isolation between opposite or orthogonal senses of polarization.

In MSS system design, the gateway or feeder link earth stations “look” like standard FSS earth stations. Generally these stations are large-aperture antennas; and, in the case of non-geostationary networks would employ multiple antennas at a given site, in order to facilitate handing over the feeder links to another satellite as a given satellite sets on the horizon. These stations use large antennas because MSS system design typically result in margins on the service links being generally fairly slim, due to satellite power limitations and/or very modest G/T ratios for the mobile earth stations, as well as propagation anomalies. As a consequence, link designers attempt to provide ample margins on the feeder links that result in “transparent” transmissions (no significant impairments) that could otherwise degrade the performance of the feeder link + service link.

As mentioned above the ITU has recently expanded or made several new MSS allocations in the 1/3 GHz bands. These allocations include expansion of the original 1.5/1.6 GHz bands; plus the addition of the 1.9/2.1 GHz bands, the 1.6/2.4 GHz (so called “Big LEO” bands), and the 2.5/2.6 GHz MSS bands. In addition, there are also the so called “Little LEO” (non-voice, data only) bands allocated in several narrow-band allocations below 1 GHz. Recently, global MSS bands at around 137/138 MHz, 148/150 MHz, 399.9/401 MHz, and at 406 MHz have been allocated.

Today’s mobile terminals are of course much more compact than the Kingsport’s 30-foot (9.1 m) dish. These can range in size from 0.9 m, stabilized dishes used by the Inmarsat-A terminal to hand-held phones not much bigger than standard cellular phones – such as those being utilized by the Globalstar Big LEO MSS system. Generally speaking, the “moving satellites” employed by typical non-GSO MSS networks employ low-gain, nearly omni-directional antennas built into hand-held terminals only slightly larger than typical cellular phones. GSO systems can generally take advantage of the somewhat higher antenna directivity, when the direction to the satellite is known and/or when the mobile platform can employ a tracking antenna system to keep a high-gain antenna pointed at the satellite’s main beam. However, some simpler, less-expensive GSO terminals also employ near omni-directional antennas, such as the Inmarsat-C data-(only) terminal, which can be used by small ships and pleasure water craft, without the need for any antenna pointing system (which increases the cost/weight of the terminal installation, etc.).

1.5 Types of orbits employed by MSS systems: GSO, LEO and MEO

As mentioned above, MSS systems can employ any type of orbital configuration, GSO, LEO, or MEO. The early history of MSS would suggest the GSO was the orbit of choice, since Inmarsat and most of the national or regional MSS systems chose to launch their satellites to the GSO. Up until the 1990s, nearly all MSS systems employed the GSO.

Very briefly, the GSO configuration is undoubtedly the simplest and least expensive type of system to deploy, since from the geostationary altitude (height above the Earth’s surface) of approximately 36 000 km (22 300 st.miles), a satellite can see about one third of the Earth’s surface and is visible from 70° North to 70° South latitude. Therefore, 3 or 4 satellites can provide global coverage, with the exception of the extreme latitudes above 70 N or below 70 S, which minimizes launch costs and the number of feeder link or gateway stations is held to a minimum. In addition, gateway and semi-fixed mobile earth stations have simplified tracking, because a satellite in geostationary orbit (24 h orbital period, plus in the equatorial plane) will appear at a stationary point in the sky, as viewed

from any point of Earth. The disadvantages of the GSO orbit are lack of coverage at high latitudes near the poles and a fairly long propagation delay time: about 240 ms (minimum, depending on the slant range to the satellite) for a round trip (uplink + downlink). On the plus side, no hand-over of feeder links is required, since a given gateway station will generally be tracking the same satellite in the particular regions of the world it is serving.

All non-GSO satellites appear to move with time relative to the location of any user/mobile earth station or feeder link/gateway station. Non-GSO satellites are placed in circular, inclined orbits at altitudes much lower than the GSO spacecraft at 36 000 km – generally at an altitude of from several hundred to several thousand kilometres. The Van Allen belts of earth-trapped intense radiation run from 3 200 to 7 600 km, so LEO orbits are located below the lowest Van Allen belts and the exact altitude depends upon a trade-off between the desired coverage and other factors needed to provide this coverage – generally the orbit selected provides an overlap between cones of visibility (as seen from the Earth) of a given satellite at the desired altitude. LEOs and MEOs have an advantage over GSOs in their ability to provide coverage at higher latitudes – right up/down to the poles. There is a trade-off in complexity versus altitude: at the lower LEO altitudes, more satellites are required for global coverage than at the higher LEO/MEO altitudes. For example, the IRIDIUM LEO/MSS system has an orbital altitude (height) of 780 km (110 min orbital period); the IRIDIUM constellation is comprised of 66 satellites; whereas, Globalstar, another LEO/MSS has an orbital altitude of 1 400 km, but this constellation is comprised of only 48 satellites.

Similarly, MEO satellites use orbits lower in altitude than the GSO, but at higher altitudes than the LEO orbits. MEOs are also established in orbits higher than the highest Van Allen radiation belt (above ~7 600 km). An example of a MEO/MSS system would be ICO, which will be orbited at an altitude of 10 388 km (6 h orbital period). This MEO is designed to operate with only 12 satellites for full global coverage. Figure 5 shows examples of different orbit configurations.

1.6 Concluding introductory remarks

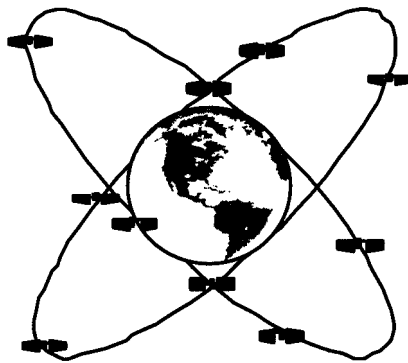
This introductory section has been a very basic, preliminary review of the subject of mobile-satellite communications. In the three chapters of the MSS Handbook that follow, additional, more detailed information is provided that should provide a great deal more insight as to how MSS systems – including ones that are actually operational at this writing – are configured; and, the types of services they are capable of delivering, as well as some of the interference, spectrum management, regulatory, and operational issues that typically may be encountered – for either the users or providers of these MSS systems. Some sections also will delve more deeply into the system architecture, spacecraft transponder designs, available MSS terminal types, and advantages and disadvantages of different orbital configurations, etc.

FIGURE 5
Example: orbit types

GSO
Altitude: 36 000 km



MSO
Altitude: 10 000 km
Example constellation: 10 satellites in 2 orbit planes



LEO
Altitude: 1 400 km
Example constellation: 48 satellites in 8 orbit planes



LEO
Altitude: 780 km
Example constellation: 66 satellites in 6 orbit planes



CHAPTER 2

FREQUENCY ALLOCATION AND REGULATORY ASPECTS (UNDER THE ITU RADIO REGULATIONS)

2.1 General definitions of mobile-satellite services and some terminology

It is important to have a basic grounding in the general definitions and terms of reference commonly used in the field of MSS. Here follows some relevant definitions and explanations of some of the most important terms of reference, drawn from Article 1 of the ITU Radio Regulations:

1.25 Mobile-satellite service: A radiocommunication service:

- between mobile earth stations and one or more space stations, or between space stations used by this service; or
- between mobile earth stations by means of one or more space stations.

This service may also include feeder links necessary for its operation.

1.27 Land mobile-satellite service: A mobile-satellite service in which mobile earth stations are located on land.

1.29 Maritime mobile-satellite service: A mobile-satellite service in which mobile earth stations are located on board ships; survival craft stations and emergency position indicating radiobeacon stations [EPIRBS] may also participate in this service.

1.35 Aeronautical mobile-satellite service: A mobile-satellite service in which mobile earth stations are located on board aircraft; survival craft stations and emergency position-indicating radiobeacon stations [EPIRBS] may also participate in this service.

1.36 Aeronautical mobile-satellite (R = route) service: An aeronautical mobile-satellite service reserved for communications relating to safety and regularity of flights, primarily along national or international civil air routes.

1.37 An aeronautical mobile-satellite service (OR = off-route) intended for communications, including those relating to flight coordination, primarily outside national and international civil air routes.

1.41 Radiodetermination-satellite service: A radiocommunication service for the purpose of radiodetermination involving the use of one or more space stations.

1.59 Safety service: Any radiocommunication service used permanently or temporarily for the safeguarding of human life and property.

- 1.63** Earth station: A station located either on the Earth's surface or within the major portion of the Earth's atmosphere and intended for communication:
- with one or more space stations; or
 - with one or more stations of the same kind by means of one or more reflecting satellites or other objects in space.
- 1.64** Space station: A station located on an object which is beyond, is intended to go beyond, or has been beyond, the major portion of the Earth's atmosphere.
- 1.68** Mobile earth station [MES]: An earth station in the mobile-satellite service intended to be used while in motion or during halts at unspecified points.
- 1.70** Land earth station [LES]: An earth station in the fixed-satellite service or, in some cases, in the mobile-satellite service, located at a specified fixed point or within a specified area on land to provide a feeder link for the mobile-satellite service.
- 1.76** Coast earth station: An earth station in the fixed-satellite service or, in some cases, in the mobile-satellite service, located at a specified fixed point on land to provide a feeder link for the maritime mobile-satellite service.
- 1.78** Ship earth station [SES]: A mobile earth station in the maritime mobile-satellite service located on board ship.
- 1.82** Aeronautical earth station: An earth station in the fixed-satellite service, or, in some cases, in the aeronautical mobile-satellite service, located at a specified fixed point on land to provide a feeder link for the aeronautical mobile-satellite service.
- 1.94** Satellite emergency position-indicating radiobeacon [satellite EPIRB]: An earth station in the mobile-satellite service the emissions of which are intended to facilitate search and rescue operations.
- 1.112** Satellite network: A satellite system or part of a satellite system, consisting of only one satellite and the cooperating earth stations.
- 1.113** Satellite link: A radio link between a transmitting earth station and a receiving earth station through one satellite.

A satellite link comprises one uplink and one downlink.

2.2 Frequency allocations for MSS (RR Article 5)

In this section the most commonly used bands for MSS are listed in two Tables. The first Table, Table 2, lists all the current ITU MSS allocations below 1 GHz, which are used by so called "Little LEO" MSS systems, which are typically non-GSO satellite networks providing non-voice, digital data only – packets at bit rates from about 2.8 to 19.2 kbit/s. The second Table, Table 3 lists all the current ITU MSS allocations between 1 and 3 GHz, which include bands used by geostationary (GSO) national and international MSS systems as well as by so called "Big LEO" non-GSO/MSS networks. These systems are capable of voice plus data transmissions at bit rates, as high as – at the moment – up to ~144 kbit/s. These two Tables are based on the International Table of Frequency Allocations in RR Article 5 (Geneva, 2000).

2.2.1 Frequency bands allocated to the MSS below 1 GHz

TABLE 2
MSS allocations below 1 GHz

Frequency band (MHz)	Region	Relevant provisions ⁽¹⁾	Allocation status
137-137.025 (s-E)	1 2 3	–	Primary
137.025-137.175 (s-E)	1 2 3	–	Secondary
137.175-137.825 (s-E)	1 2 3	–	Primary
137.825-138 (s-E)	1 2 3	–	Secondary
148-149.9 (E-s)	1 2 3	–	Primary
149.9-150.05 (E-s)	1 2 3	RR No. 5.224A	Primary
235-322 (E-s) (s-E)	1 2 3	RR No. 5.254	RR No. 9.21
312-315 (E-s)	1 2 3	RR No. 5.254	Secondary
335.4-399.9 (E-s) (s-E)	1 2 3	RR No. 5.254	RR No. 9.21
387-390 (s-E)	1 2 3	RR No. 5.254	Secondary
399.9-400.05 (E-s)	1 2 3	RR No. 5.224A	Primary
400.15-401 (s-E)	1 2 3	–	Primary
406-406.1 (E-s)	1 2 3	RR No. 5.266	Primary
454-455 (E-s)	Countries listed in RR No. 5.286D and RR No. 5.286E	–	Primary
455-456 (E-s)	2 and countries listed in RR No. 5.286E	–	Primary
459-460 (E-s)	2	–	Primary
608-614 ⁽²⁾ (E-s)	2	–	Secondary
806-890 (E-s) (s-E)	2 (except see RR No. 5.317)	RR No. 5.317	Primary/ RR No. 9.21
806-840 ⁽²⁾ (E-s)	Countries listed in RR No. 5.319	RR No. 5.319	–
856-890 ⁽²⁾ (s-E)	Countries listed in RR No. 5.319	RR No. 5.319	–
806-890 ⁽³⁾ (E-s) (s-E)	3	RR No. 5.320	Primary/ RR No. 9.21
942-960 ⁽³⁾ (E-s) (s-E)	3	RR No. 5.320	Primary/ RR No. 9.21

(1) Provisions listed in Tables 2 and 3 relate to the allocation of frequency bands to the mobile-satellite service only. The provisions do not necessarily take into account the protection of other services operating in accordance with the Table of Frequency Allocations of Article 5 of the Radio Regulations or operational constraints for the mobile-satellite service.

(2) Except AMSS.

(3) Except AMS(R)S.

2.2.2 Frequency bands allocated to the MSS between 1-3 GHz

TABLE 3
MSS allocations between 1-3 GHz

Frequency band (MHz)	Region	Relevant provisions ⁽¹⁾	Allocation status
1 492-1 525 (s-E)	2	–	Primary
1 525-1 530 (s-E)	1 2 3	–	Primary
1 530-1 535 (s-E)	1 2 3	–	Primary
1 535-1 559 (s-E)	1 2 3	RR No. 5.356	Primary
1 610-1 610.6 (E-s)	1 2 3	RR No. 5.367	Primary
1 610.6-1 613.8 (E-s)	1 2 3	RR No. 5.367	Primary
1 613.8-1 626.5 (E-s)	1 2 3	RR No. 5.367	Primary
1 613.8-1 626.5 (s-E)	1 2 3	RR No. 5.367	Secondary
1 626.5-1 660 (E-s)	1 2 3	RR No. 5.375	Primary
1 660-1 660.5 (E-s)	1 2 3	–	Primary
1 675-1 690 (E-s)	2	–	Primary
1 690-1 700 (E-s)	2	–	Primary
1 700-1 710 (E-s)	2	–	Primary
1 930-1 970 (E-s)	2	–	Secondary
1 980-2 010 (E-s)	1 2 3	–	Primary
2 010-2 025 (E-s)	2	RR No. 5.389C, RR No. 5.389D	Primary
2 120-2 160 (s-E)	2	–	Secondary
2 160-2 170 (s-E)	2	RR No. 5.389C, RR No. 5.389D	Primary
2 170-2 200 (s-E)	1 2 3	RR No. 5.389A	Primary
2 483.5-2 500 (s-E)	1 2 3	–	Primary
2 500-2 520 (s-E)	1 2 3	RR No. 5.414	Primary (after 01.01.2005)
2 500-2 535 ⁽²⁾ (s-E)	1 2 3	RR No. 5.403	RR No. 9.21 (until 01.01.2005)
2 520-2 535 ⁽²⁾ (s-E)	1 2 3	RR No. 5.403	RR No. 9.21 (after 01.01.2005)
2 515-2 535 ⁽³⁾ (s-E)	Countries listed in RR No. 5.415A	RR No. 5.415A	RR No. 9.21
2 655-2 690 ⁽²⁾ (E-s)	1 2 3	RR No. 5.420	RR No. 9.21 (until 01.01.2005)
2 655-2 670 ⁽²⁾ (E-s)	1 2 3	RR No. 5.420	RR No. 9.21 (after 01.01.2005)
2 670-2 690 (E-s)	1 2 3	RR No. 5.419	Primary (after 01.01.2005)
2 670-2 690 ⁽³⁾ (E-s)	Countries listed in RR No. 5.420A	RR No. 5.420A	RR No. 9.21

(1) Provisions listed in Tables 2 and 3 relate to the allocation of frequency bands to the mobile-satellite service only. The provisions do not necessarily take into account the protection of other services operating in accordance with the Table of Frequency Allocations of Article 5 of the Radio Regulations or operational constraints for the mobile-satellite service.

(2) Except AMSS.

(3) Including AMSS.

2.3 Regulatory issues of frequency sharing within MSS bands

2.3.1 Frequency sharing between MSS networks

The allocations for MSS (discussed above in § 2.2) are used by a number of different administrations for their national or international MSS networks. One should note, however – as seen by inspection of Tables 2 and 3 above that there are some small differences between the band limits in the ITU Tables of Frequency Allocations for particular MSS bands within certain ITU Regions and/or even those for certain, particular countries (generally indicated by country footnote) as opposed to the general, global MSS frequency allocations, found in RR Article 5.

Nevertheless, it is common practice for many different MSS networks to *share* a give frequency band, in the same or different ITU Regions. For example, the 1.5/1.6 GHz MSS band is presently utilized by about two dozen MSS networks. The band was first opened up by Inmarsat, back in the 1970s. Later, the national networks of Canada and the United States began to use the same band. Today, this band is used by many, many other MSS networks – not only by Inmarsat worldwide and Canada/USA/Mexico in North America, but also by numerous other administrations in South America, Europe, Asia, the middle-East, plus Australia and Japan.

As a result of the simultaneous use of, for example, the 1.5/1.6 GHz MSS band, by multiple networks, there needs to be consideration given to minimizing mutual interference between these networks sharing the same MSS frequency band. The ITU Radiocommunication Sector (ITU-R) has played a central role in working out standards and processes for keeping interference within tolerable limits between MSS networks sharing a common frequency band. For example, RR No. 9.11A contains the procedures for coordination and notification of frequency assignments of satellite networks in certain MSS bands.

Many of these sharing principles set forth in the Radio Regulations were worked out previously for FSS networks – primarily for GSO/FSS networks in the previous two decades of development of global FSS networks. However, when MSS bands became more heavily used, it was necessary to extend and apply similar – but not identical – principles to the MSS operations. The introduction of non-GSO MSS networks also required the ITU to revise and update coordination and notification procedures which had been previously codified for only the GSO type of MSS networks.

One of the key issues that makes sharing between multiple networks in the MSS more difficult than the FSS is that the antenna directivity associated with mobile earth stations (MESs) is much lower than that of traditional FSS earth stations. The MES antenna gain cannot approach that of FSS fixed earth stations simply because the antenna aperture or the size of the MES dish is very limited due to its inherent mobility – being located on a ship, aircraft, or even on a person. Consequently, the antenna beamwidth is also much greater; and, this limits the ability of one MES antenna to distinguish the desired or intended satellite it is working to from the undesired or unwanted satellites in adjacent GSO orbital slots.

Thus, while orbital separations needed to manage inter-system interference on the order of 3° are possible in the lower FSS bands, such as 4/6 GHz, and even down to 2° in the 11/12 GHz FSS bands, similar interference objectives in an MSS band such as 1.5/1.6 GHz typically require orbital separations of around 40° or more! Often times, this factor alone require MSS networks to resort to frequency band segmentation techniques rather than the use of co-channel frequency sharing.

However, the use of narrow-coverage spot beams on the newer generation of MSS systems can allow for a degree of frequency re-use when there is sufficient isolation between the beams of two adjacent (GSO) networks operating in the same portion of an MSS band. MSS networks not operating co-coverage are also, under the right conditions, able to re-use the same frequencies.

In summary, MSS networks can share frequencies; i.e., transmit and receive on the same or overlapping radio frequency channels, only if the mutual interference can be kept below a specified level to achieve the interference objective on both the uplink and downlink.

There are only a limited number of mechanisms whereby one MSS satellite network can discriminate against, or isolate itself from, interfering signals from another MSS satellite network sufficiently in order to meet its interference objective:

- using the angular *directivity* of the receiving and/or transmitting *space station* antennas;
- using the angular *directivity* of the transmitting and/or receiving *earth station* antennas;
- using *opposite polarizations* on the wanted and interfering channels;
- *interleaving* or off-setting channels (in frequency) in order to avoid full co-channel operation.

The extent to which each of these four mechanisms can be used to provide part or all of the necessary inter-system isolation or interference discrimination depends on the size and design of the earth and space station antennas, the orbital positions (in the GSO, or other orbits) and geographical coverage of the antennas of the space stations of the two systems, the extent to which each of the mechanisms may already have been employed to re-use frequencies within the individual systems, the cost and other, practical, operational factors.

The criteria for sharing between MSS service links and/or feeder links are based on the maximum acceptable levels of interference within MSS channels – as developed within appropriate ITU-R Recommendations – as well as agreed between MSS operators when they are engaged in inter-system coordination discussions.

2.3.2 Frequency sharing between MSS networks and other services

In certain MSS bands, other services, such as the fixed service (FS), are allocated on a co-primary basis with MSS. In these bands, sharing criteria have been developed to enable the two services to share without causing unacceptable levels of interference to one another. For example, Section II of RR Article 9 provides the coordination thresholds for sharing between MSS (space-to-Earth) or downlink emissions and terrestrial FS allocated within portions of the 1-3 GHz MSS bands; as well as hard limits (power flux-density limits) between non-GSO feeder link downlinks and terrestrial FS – operating in the same frequency bands (at 7 GHz and 15 GHz).

2.4 Other types of specialized MSS – given special status in the Radio Regulations

2.4.1 Distress and safety applications/special RR provisions

2.4.1.1 GMDSS distress and safety

The Global Maritime Distress and Safety System (GMDSS) is an international system that was developed to save the lives of mariners. It was established by the International Maritime Organization (IMO), a specialist agency of the United Nations responsible for maritime matters. The system requires certain types of ships, whatever their location, to have the ability to transmit a distress alert to shore-based search and rescue authorities with a high probability that the message will be received. Consequently, GMDSS provides for improved means of locating survivors, providing sailors with vital maritime safety information, and alerting other vessels in the immediate vicinity of the distress so they may assist in the rescue.

GMDSS special regulatory provisions in the Radio Regulations

In the 1.5/1.6 GHz band MSS allocations GMDSS is given special status and protection in the Radio Regulations, by virtue of certain footnotes in the former MMSS part of the 1.5/1.6 GHz MSS band. Specifically, footnote RR No. 5.353A applies here:

5.353A *In applying the procedures of Section II of Article 9 to the mobile-satellite service in the bands 1 530-1 544 MHz and 1 626.5-1 645.5 MHz, priority shall be given to accommodating the spectrum requirements for distress, urgency and safety communications of the Global Maritime Distress and Safety System (GMDSS). Maritime mobile-satellite distress, urgency and safety communications shall have priority access and immediate availability over all other mobile-satellite communications operating within a network. Mobile-satellite systems shall not cause unacceptable interference to, or claim protection from, distress, urgency and safety communications of the GMDSS. Account shall be taken of the priority of safety-related communications in the other mobile-satellite services. (The provisions of Resolution 222 (WRC-2000) shall apply.)*

GMDSS represents a significant change in the way maritime safety communications are conducted. It forms an element of the international Safety Of Life At Sea (SOLAS) Convention, which was first adopted in 1914, and is generally regarded as the most important of all International Treaties concerning the safety of merchant ships. The SOLAS Convention requirements are mandatory for all passenger vessels and commercial shipping of 300 gross tons or more which make international voyages. Furthermore, it is recognized that GMDSS can be of help to most vessels regardless of size. It is therefore recommended that all shipping and large pleasure craft carry GMDSS equipment, as applicable to their sea area of operation.

GMDSS is based on the combined use of traditional maritime radio frequencies (MF/HF/VHF) as well as the MSS communications provided by Inmarsat (originally created by the IMO to support GMDSS) and emergency distress alerting and locating services as provided by Cospas-Sarsat. The equipment required by ships varies according to the sea area in which they operate as indicated in the Table below. Ships travelling on the high seas will need to carry more communications equipment than those that remain within the reach of specified shore-based radio facilities.

<p>Area A1 Within range of VHF coast stations with continuous digital selective calling (DSC) alerting available (about 30-50 km)</p>	<ul style="list-style-type: none"> – VHF equipment – satellite (Cospas-Sarsat or Inmarsat) or VHF EPIRB
<p>Area A2 Beyond area A1, but within range of MF coastal stations with continuous DSC alerting available (about 160 km)</p>	<ul style="list-style-type: none"> – VHF and MF equipment – satellite EPIRB (Cospas-Sarsat or Inmarsat)
<p>Area A3 Beyond the first two areas, but within coverage of geostationary maritime communication satellites (in practice this means Inmarsat). This covers the area between roughly 70° N and 70° S</p>	<ul style="list-style-type: none"> – VHF and MF equipment – satellite EPIRB (Cospas-Sarsat or Inmarsat) – HF or satellite equipment
<p>Area A4 The remaining sea areas. The most important of these is the sea around the North Pole (the area around the South Pole is mostly land). Geostationary satellites, which are positioned above the equator, cannot reach this far</p>	<ul style="list-style-type: none"> – VHF, MF and HF equipment – Cospas-Sarsat satellite EPIRB

In areas without any VHF or MF shore safety calling facilities, at latitudes between about $\pm 70^\circ$, Inmarsat-A, B or C terminals can be used for distress alerting and the general communications requirements of GMDSS. A vessel in distress fitted with such ship earth stations (SES) would have a priority channel made available for the transmission of the distress message. Furthermore, Inmarsat-C terminals can be used to receive the International “Maritime Safety Information” broadcasts comprising of distress alerts, search and rescue information, navigational danger warnings, meteorological forecasts, and other urgent information to ships. These terminals are connected to the vessel’s navigation interface and are therefore able to filter out broadcast data which is outside the areas applicable to the vessel.

It should be noted that HF radiocommunications can also be used for GMDSS, particularly in the polar regions where there is no visibility of the geostationary-satellite orbit (GSO), but such links are greatly affected by propagation variations.

Satellite emergency position indicating radio beacons (EPIRBs) provide an alternative method for sending GMDSS distress alerts. These terminals are described in detail in § 4.2.3. In summary, EPIRB are data communications devices that are capable of fulfilling a distress-alerting role in one or more of the following applications:

- manual activation from the position of a ship’s bridge;
- float-free and automatic activation in the case of the sudden foundering of a ship;
- manual activation at the terminal either at the point of installation, or after being carried from the ship onto the survival craft.

An auxiliary homing transmitter can also be included within the EPIRB to aid location by search-and-rescue authorities.

2.4.1.2 Aeronautical MSS safety

Aeronautical satellite communications can play a major role in air-traffic-management systems (ATM) to ensure that a plane gets to its destination both safely and efficiently, and for providing alerting and locating services for aircraft involved in accidents.

In respect of the ATM function, ATM must perform three basic tasks termed communications, navigation and surveillance (CNS):

- communications is the exchange of voice and data information such as routine clearances or instructions between the aircraft pilots and air traffic controllers;
- navigation is the process of providing pilots with information on the position of the aircraft;
- and surveillance is the process of detecting the position of the aircraft by air traffic control.

Until recently, the only means of communicating between pilots and air traffic control was by voice channels on VHF and HF radio frequencies. VHF frequencies are used in “line-of-sight” conditions, for example, when an aircraft is in domestic airspace. While HF frequencies are used for “over-the-horizon” communications capability, for example, when the aircraft is in oceanic airspace or in certain remote continental airspace areas.

To negate the effects of unreliable radiocommunications or unavailability of radar coverage, ATM systems maintained safety by keeping aircraft separated from one another by large distances. Unfortunately, this method of operation was relatively inflexible. Pilots often could not reliably contact air traffic control to deviate around adverse weather systems or take advantage of any new information on meteorological conditions. The procedure thereby resulted in aircraft delays, inefficient operation, and higher fuel costs – all of which were further compounded by a growing air traffic demand along heavily travelled routes.

To overcome the disadvantages associated with HF and VHF radio communications, the International Civil Aviation Organization (ICAO), a specialist agency of the United Nations, encouraged the development of satellite-based communications with aircraft. The process led to the development of the aeronautical mobile-satellite service (AMSS) in which mobile earth stations are located on board aircraft. An important application within AMSS is for “route” communications, designated AMS(R)S, which relate to safety and regularity of flights primarily along national or international civil air routes.

There is a variety of AMS(R)S applications that have been developed to support the communications, navigation and surveillance functions of air traffic management (ATM/CNS). The applications necessitate high level of availability, performance and integrity, as defined internationally in ICAO standards and recommended practices (ICAO – SARPs) and regionally, by standards such as the Radio Telecommunication Association minimum operational performance standards (RTCA – MOPS).

AMS(R)S special regulatory provisions in the Radio Regulations

Specifically, AMS(R)S has special protection in the former AMSS part of the 1.5/1.6 GHz band MSS allocations by virtue of footnote RR No. 5.357A, as follows:

5.357A *In applying the procedures of Section II of Article 9 to mobile-satellite service in the bands 1 545-1 555 MHz and 1 646.5-1 656.5 MHz, priority shall be given to accommodating the spectrum requirements of the aeronautical mobile-satellite (R) service providing transmission of messages with priority 1 to 6 in Article 44. Aeronautical mobile-satellite (R) service communications with priority 1 to 6 in Article 44 shall have priority access and immediate availability, by pre-emption if necessary, over all other mobile-satellite communications operating within a network. Mobile-satellite systems shall not cause unacceptable interference to, or claim protection from, aeronautical mobile-satellite (R) service communications with priority 1 to 6 in Article 44. Account shall be taken of the priority of safety-related communications in the other mobile-satellite services. (The provisions of Resolution 222 (WRC-2000) shall apply.)*

The main types of AMSS applications are related either to air-traffic control and airline administrative communications, or to passenger services. These are summarized as follows:

- for air-traffic control, aeronautical communications are used by pilots to keep in contact with ground staff for routine communications such as the requests, clearances and advisories. Correspondingly, controllers use aeronautical data communications to monitor and direct the position of aircraft, even when outside normal radar range;
- for passenger services, MSS communications are used by customers to make phone calls or send faxes whilst in flight. A range of data services are also available including duty-free shopping, airline, hotel and car hire reservations, and reception of real time world and financial news.

In addition to the ATM function, satellite systems provide important distress alerting and locating services. This is accomplished by equipping aircraft with emergency distress beacons (also referred to as emergency locator transmitters or ELTs) which can be detected and located by the Cospas-Sarsat System.

2.4.1.3 Integral and integrated radiodetermination functions

One method of locating the position of MSS earth-station equipment is to employ direction-finding techniques at the satellite. Although this method can estimate the position of a terminal to an accuracy within as little as a few kilometres, which is sufficient for example in billing purposes and rudimentary tracking of terminals, the technique is only available for non-GSO systems.

For increased accuracy position determination (typically to within two hundred metres), or for systems having other types of satellite system architecture (i.e., GSO systems), a radio-determination unit must be linked to the earth station terminal in order to automatically report the terminal's position. This is accomplished through reception of GPS, GLONASS or LORAN-C radio navigation signals.

There are two basic kinds of applications where it is useful to determine the position of the mobile earth station terminal: those designed primarily for safety purposes, and those for commercial purposes. Both applications, however, have similar functionality in that the terminal must automatically identify itself, report its position, and transmit the required messaging information.

– *Safety applications*

Integral radiodetermination capability is available in some advanced types of EPIRBs for use with MSS satellites. An important application of EPIRBs is on ships where they are one of the prime means of distress alerting and positioning in GMDSS. EPIRBs either operate in the 121.5 MHz, 406 MHz, or 1.6 GHz band. The differences between the various types of EPIRB are described in detail in § 4.2.3.

Another safety application requiring integrated MSS radiodetermination capability is for aeronautical services as a part of ICAO's communications navigation and surveillance/air traffic management (CNS/ATM) system. Many aeronautical earth-station terminals support automatic dependent surveillance (ADS) which allow air traffic controllers to poll the aircraft for positioning and other information.

2.5 MSS feeder link earth stations

2.5.1 Feeder link earth stations – GSO/MSS networks

Feeder link earth stations are used to connect mobile-satellite communications with terrestrial networks such as the public switched telephone network (PSTN). Feeder link earth stations that operate to GSO satellites have a simpler antenna tracking structure than those that operate to non-GSO networks because the relative movement of GSO satellites is much smaller. Consequently, large earth station antennas (10-15 m diameter) can be economically used thereby improving link margins.

Furthermore, only one feeder link earth station antenna (and one spare for backup purposes) is required to handle all calls from the coverage area of a GSO satellite. Having said this, other feeder link earth stations are normally added within the system to provide for resilience and to allow for national presence of operations within different regions. These are typically operated by "service providers" who inter-connect traffic to the local terrestrial networks and who also market the mobile services within the region.

2.5.2 Feeder link earth stations – non-GSO/MSS networks

Feeder link earth station antennas for non-GSO systems are generally smaller than those used for GSO operation because of the lower path losses to the satellites and to allow for easier tracking ability. Feeder link frequencies normally used by "Big LEO" systems are in the 5/7 GHz bands or 20/30 GHz bands. Frequencies in the 15 GHz band are also available.

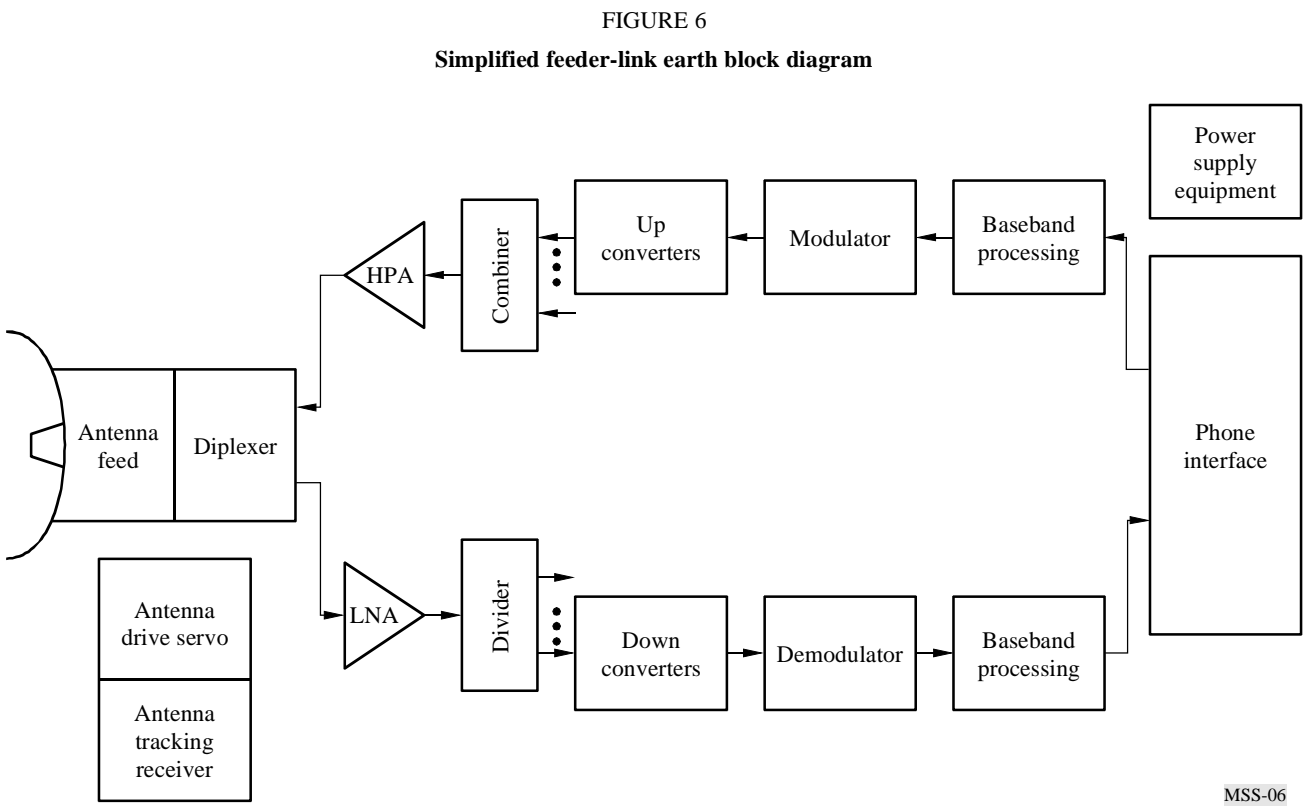
The design and location of feeder link earth stations is related to the satellite constellation characteristics. For example, system having inter-satellite links to route traffic between satellites would need fewer earth stations than otherwise required; while systems using lower Earth orbits will need more earth stations than those using medium Earth orbits. Furthermore, the location of feeder link sites must take into consideration the existing national or regional telecommunications infrastructure available.

By way of illustration, in the ICO satellite system there are 12 land earth stations sites connected together via a global fibre optic network. Traffic is internally routed to the closest gateway to the call destination before being routed through the public terrestrial networks. In the Globalstar system, there are between 30 and 40 gateways sites planned worldwide with traffic routed directly through the public terrestrial networks at the gateways.

The number of tracking earth station antenna installed at individual sites will vary depending on the number of satellites being tracked, the number of antennas lining up for the next satellites to become visible, and the number being used as spare. Typically, the number of antennas installed at an individual non-GSO feeder link site can vary from about 2 to 6.

In addition to feeder link earth stations, satellite operations require telecommand, telemetry and control (TT&C) centres in order to track and control the satellite constellation. There are at least two such sites in a given satellite system serving as primary and backup facilities. They are used to provide command functions to satellites such as to perform orbit manoeuvres, as well as monitor the status of the satellite and subsystems.

Figure 6 shows a simplified block diagram of a typical gateway or feeder link earth station, with its receive and transmit chains.



MSS-06

2.6 Role of MSS in IMT-2000

2.6.1 Satellite component of IMT-2000

IMT-2000 are third generation mobile systems which will provide access, by means of terrestrial and/or satellite radio links, to a wide range of telecommunications services supported by the fixed telecommunication networks (e.g. PSTN/ISDN/Internet protocol (IP)) and to other services which are specific to mobile users. A range of mobile terminal types is encompassed, linking to terrestrial and/or satellite-based networks, and the terminals may be designed for mobile or fixed use.

The *satellite component* of IMT-2000 will complement the terrestrial component by providing service for international roaming, by serving sparsely populated areas where terrestrial infrastructures are uneconomic due either to sparse population or to timing of terrestrial roll-out, and to introduce IMT-2000 globally. The ubiquitous coverage of IMT-2000 can only therefore be realized using a combination of satellite and terrestrial radio interfaces.

Recommendation ITU-R M.1455 lists the key characteristics of the radio interfaces for the satellite component of IMT-2000. As highlighted in that Recommendation, due to the constraints on satellite system design and deployment, several satellite radio interfaces will be required for IMT-2000 (see Recommendation ITU-R M.1167 for further considerations). The detailed specifications of the satellite radio interfaces of IMT-2000 are fully defined by information supplied in Recommendation ITU-R M.1457.

Recommendation ITU-R M.818 also considers the satellite component of IMT-2000 noting that satellite operation within IMT-2000 could facilitate the development of telecommunication services in developing countries.

The IMT-2000 satellite user terminals will offer one or more modes of operation: one satellite mode and possibly one or more terrestrial modes. If a terrestrial mode is implemented, terminals should be able to select either satellite or terrestrial modes of operation automatically or under user control.

The satellite/terrestrial (dual-mode) terminal interface performs the following functions:

- provide the bearer service negotiation capabilities in both terrestrial and satellite networks;
- support roaming between terrestrial and satellite networks;
- align the service management and provisioning with IMT-2000 Recommendations.

Handover between terrestrial and satellite components is not a requirement of IMT-2000. It is up to the network operator to determine whether to implement handover between the terrestrial and satellite component. If handover is not implemented, roaming between terrestrial and satellite component may be just a switching function; i.e., if a user terminal loses its connection to a terrestrial network, it could “look” for a satellite network.

Although satellites and satellite systems will continue to achieve higher performance (e.g. quality and higher bit rates) and accommodate smaller antennas on terminals, the satellite market will favour small terminals and mobility rather than high bit rates. With the constraints imposed by link budget and bandwidth limitations for satellite systems it may be uneconomic to support wideband services to a hand-held terminal from a satellite. This means that the service capabilities of the satellite component of IMT-2000 may not be identical to the terrestrial component.

The satellite component of IMT-2000 may be “stand-alone”, with intelligence to be able to originate, terminate, and charge for services, to re-register and locate users as they roam onto other networks or service areas, and to maintain user databases. Alternatively, the satellite component may share intelligence with other networks.

The ITU Radio Regulations identify the following frequency bands in the MSS for use, on a world-wide basis, by administrations wishing to implement the satellite component of IMT-2000 (see RR No. 5.351A): 1 525-1 544 MHz; 1 545-1 559 MHz; 1 610-1 626.5 MHz; 1 626.5-1 645.5 MHz; 1 646.5-1 660.5 MHz; 1 980-2 010 MHz; 2 170-2 200 MHz; 2 483.5-2 500 MHz; 2 500-2 520 MHz and 2 670-2 690 MHz.

Resolution 225 (WRC-2000) provides flexibility for the longer-term use of the bands 2 500-2 520 MHz/2 670-2 690 MHz.

Note that, in addition to the use of the MSS bands identified for the satellite component of IMT-2000, the FSS bands may be used for feeder links and other network connections in support of IMT-2000.

2.7 Global mobile personal communications by satellite systems

A global mobile personal communications by satellite (GMPCS) system is defined as “any satellite system (i.e. fixed, mobile, broadband or narrow-band, global or regional, geostationary or non-geostationary, existing or planned) providing telecommunication services directly to end users from a constellation of satellites”. This definition can cover a broad range of satellite configurations and related services.

GMPCS was the topic of the 1996 World Telecommunication Policy Forum (WTPF-96) which developed five Opinions that have been key to the development of a Memorandum of Understanding (MoU), associated Arrangements, and a regulatory framework for the implementation of services.

Briefly the five Opinions are:

Opinion 1 – The role of GMPCS in the globalization of telecommunications

Opinion 2 – The shared vision and principles of GMPCS

Opinion 3 – Essential studies by ITU to facilitate the introduction of GMPCS

Opinion 4 – Establishment of an MoU to facilitate the free circulation of GMPCS

Opinion 5 – Implementation of GMPCS in developing countries

Signatories to the MoU, (Administrations, system operators, terminal manufacturers, and others) agree to cooperate on issues concerning type approval, licensing, and marking of terminals as well as customs arrangements, and access to traffic data. The MoU indicates that “Signatories will periodically review the results and consequences of their cooperation under this *Memorandum of Understanding*. When appropriate, the Signatories will consider the need for improvements in their cooperation and make suitable proposals for modifying and updating the *arrangements*, and the scope of this GMPCS-MoU.” Yearly meetings are scheduled to accomplish this goal.

The essential studies by the ITU to facilitate the introduction of GMPCS breakdown as follows:

ITU-R

Compatibility

ITU-T

Standards

ITU-D

Assist developing countries in taking measures to introduce GMPCS.

Also, in Opinion 5 of the World Telecommunication Policy Forum, the Director of the BDT was invited to establish a group of experts:

- 1 To prepare a checklist of factors that developing countries may take into account in introducing GMPCS.
- 2 To advise and assist developing countries on technical and regulatory issues associated with the introduction of GMPCS on a global or regional basis (particularly tariffs and inter-connection).
- 3 To study the policy and socio-economic impacts of GMPCS services in developing countries.
- 4 To prepare a Report to the next WTDC based on studies carried out by the group of experts and urges developing countries to communicate their concerns and needs to the BDT.

The Arrangements are intended to aid in the authorization/licensing of services by specific system operators, allow for the marking of system specific type-accepted terminals with an “ITU GMPCS-MoU Mark”, and to encourage Administrations to allow unrestricted movement of “marked” terminals across their national borders. The ITU Secretary-General is the conduit for information, developed within the context of the Arrangements, that flows between Administrations, system operators, terminal manufacturers, and the ITU. The ITU Council in May 1998, via Council Resolution 1116, endorsed and provided the formal authorization for the ITU to carry out this role and become the depository for the GMPCS Arrangements on a full cost-recovery basis.

In its role as depository, the ITU established a web page in December 1998 that contains a listing of GMPCS-MoU signatories. In addition it contains information on specific system implementations of the arrangements, terminals associated with each system that has been type accepted and authorized to bear the “ITU GMPCS-MoU Mark”, and responses from administrations regarding the unrestricted movement of specific terminals across their national borders. Further details regarding the GMPCS-MoU depository function and associated data can be obtained by visiting the ITU home page, selecting “Highlights” and then selecting the GMPCS-MoU database. Alternatively, the web site can be found by going to <http://dmsprod.itu/gmpcs>.

CHAPTER 3

TYPICAL AND POTENTIAL APPLICATIONS FOR MSS COMMUNICATIONS

3.1 General applications for maritime, aeronautical and land MSS

There are a wide variety of applications supported by the mobile-satellite service for the general provision of voice and data communications to users of the maritime, aeronautical and communities. The applications include: emergency distress alerting and locating services, direct-dial telephone, data transfer, facsimile, telex, electronic mail (email), high-quality audio transmission and compressed (digital) video, still pictures, and videoconferencing. Digital data rates currently available from the different MSS providers vary from tens of bits-per-second – which is suitable for short messaging services to 64 kbit/s – which is suitable for many high-speed data applications. Even higher bit rates are planned.

The MSS equipment terminals come in a wide variety of shapes and sizes. They may be designed to be carried by the person, transported to a site; or, fixed to a vehicle, ship (or small craft) or an aircraft. They can vary from small paging terminals or hand-held phones that fit on a trouser belt to very large terminals with directional antennas, requiring a stable platform for operation to compensate for ship movement in rough seas.

Typical users of MSS applications are:

- Land users, such as journalists, travelling executives, disaster relief agencies, government officials, operators of trucks or trains, mineral exploration companies, and workers at remote sites (for example, in the building of hydropower projects or roads).
- Maritime users, such as operators of fishing boats, yachts, cargo ships, container vessels, drilling rigs, oil tankers, liquid natural gas carriers, and passenger cruise ships.
- Aeronautical users, such as operators of airlines, corporate aircraft, general aviation, and helicopters.

3.2 Applications within developing countries

A principal aim of MSS applications within developing countries is to make available viable telecommunications services to the low telephone density areas of the world. There are a variety of MSS applications that can be of benefit to developing countries ranging from communication services for their rural communities to specialist applications for their industries.

Many of these applications could be provided by the public switched telephone network (PSTN) or terrestrial wireless networks (wireless local loop or cellular mobile), if they were available. However, extending these terrestrial networks out to under-served areas, sometimes over difficult terrain, is likely to be expensive in terms of the high forward capital requirements and poor investment returns. Furthermore, such networks will also require a considerable amount of time to roll-out.

Mobile-satellites communications have the ability to overcome the practical and logistical difficulties associated with land-line or terrestrial wireless installation. They have the advantage of being available now, require substantially less forward investment for the user and have quicker implementation times. In many instances, they are the only realistic method of providing a telecommunication service out to remote and rural areas.

Situations in which MSS applications are suitable for use within developing countries are examined below:

Use in rural communities

These are villages or small towns that are widely dispersed and distant from the urban centres (and, thereby, from the nearest terrestrial telecommunications facilities). MSS communications can have a significant positive impact on the rural communities. As well as satisfying universal access objectives, availability of telecommunications invariably leads to increased social and economic development within those rural communities.

Examples of terminals suitable for use in rural communities are portable or semi-fixed equipment powered by batteries which can be recharged through solar power or electric generators.

Use in remote sites

These are loosely classified as industrial sites in isolated locations. They consist of places like mines, construction sites, tourist resorts, or industries such as forestry, agriculture, oil, gas, or mineral extraction plants. The availability of communications is essential for the site's administrative, security and health care facilities.

Examples of terminals suitable for use in remote sites vary from low data rate remote monitoring equipment to high-speed data and voice equipment.

Government use

These involve communications to remote governmental services such as the police, schools, public health-and-safety offices, road maintenance, and border guards.

Disaster relief and emergency use

These include the likes of relief agencies and aid workers who use MSS communications for purposes such as ordering essential supplies and maintaining contact with their headquarters. Also, MSS communications are increasingly being used for contingency planning and disaster preparations, for example in the coordination of police and fire brigade units, or for remote monitoring of potential disaster areas such as earthquake and flood zones.

Telemedicine use

This allows medical practitioners to diagnose an illness or examine a patient a long distance away without the cost or risk of transporting the patient.

Other professional users

These are individuals such as business travellers, journalists, geologists, and the like, who use MSS applications to meet a variety of their communication requirements. Their usage can range from filing of reports and fieldwork to the communications necessary for “mobile office” operation.

Examples of the terminals suitable for professional users vary from the recently available dual mode hand-held mobile phones (allowing both terrestrial cellular and MSS access), to computer notebook size terminals having integrated voice, fax and data communications capability.

3.3 Applications within highly developed telecommunications infrastructures

It is not only in developing countries where remote areas are currently without public telecommunication connections. Wherever great distance and difficult terrain separate rural communities (with their small potential user base) from the key urban centres, cost can prohibit the implementation and operation of conventional terrestrial services.

In this sense, there is little distinction in the applications outlined above for developing countries with the types of applications suitable for developed countries. The typical user profiles and utilization are common in both situations.

3.4 Typical “Little LEO” (MSS) operating in bands below 1 GHz

Frequency allocations to the mobile-satellite service are both general (to the MSS) and sometimes restricted (e.g. to the LMSS). This discussion of communications applications is written broadly and applies to the MSS. For systems that might operate with frequency allocations that are restricted to the LMSS, the applications identified would need to be restricted to only land-based applications.

The communications applications within the MSS that are most economical are functions of the data rate required, terminal size and cost, overall system cost, real-time or delayed communications, and several other factors. Consequently, different implementations of the MSS can better provide different communications applications. The following sections identify the typical and potential communications applications for the non-GSO MSS below 1 GHz.

3.4.1 Typical and potential communications applications provided by the non-GSO, non-voice MSS below 1 GHz

Systems in the non-GSO MSS below 1 GHz are capable of transmitting digital packets of data at low data rates (2.8 to 19.2 kbit/s). The low frequencies (below 1 GHz) and the low Earth orbit result in small, low power earth stations and satellites and consequently, low system implementation costs. Networks are designed to be capable of providing coverage to all or most of the world (some systems do not include full coverage of the polar areas). Generally, the MSS below 1 GHz systems operate in a near real-time mode when the same satellite covers both the user station and the feeder link station. However, the systems can also operate in the store and forward mode when the user and the feeder link stations are not in the same satellite footprint, such as a user located in an open ocean area. In this mode, the systems operate with some time delay that can range from seconds to hours, depending on the next satellite pass over a feeder link station.

Applications that have been identified for the non-GSO MSS below 1 GHz are listed in Table 4. Several types of communications applications are listed and explained in the Table. The non-GSO MSS below 1 GHz systems are suitable for applications which require intermittent transmissions of small data packets. While technically all applications would be available throughout the coverage area of the network, the market demand for the different applications will vary with the demographic characteristics of the local area (urban or rural, developing or highly developed telecommunications infrastructure, and other factors). Urban and rural areas have different needs for data communications and have different existing alternatives for providing data communications. Countries with highly developed telecommunications infrastructures may have existing networks to carry a variety of data communications. These countries may also have a greater need for person-machine and machine-machine data interactions, resulting in a high demand for applications that may be needed to a lesser degree in developing countries. Table 4 also lists market demand projections for applications in developing and highly developed countries and in urban and rural areas.

TABLE 4

Communications applications and market demand projections for the non-GSO MSS below 1 GHz used in urban and rural areas of countries with developing and developed communications infrastructure⁽¹⁾

Communications applications		Market demand projections⁽¹⁾ H = high, M = medium, L = low			
Type	Specific applications	Developing communications infrastructure		Developed communications infrastructure	
		Urban	Rural	Urban	Rural
Asset tracking and fleet management	Trucks, trailers, containers, heavy equipment, railroad cars, ships, aircraft	H	H	H	H
Monitoring and remote control	Meter reading, oil and gas wells, pipelines, irrigation systems, vending machines	L	M	M	H
Two-way messaging and location	Email, paging, vehicle monitoring and messaging, personal messaging, business messages.	L	M	L	M
Emergency services	Monitoring, security systems, location, dispatch	M	M	L	M
Business transactions	Credit card validations, point of sale data processing, inventory control, direct-to-home interactive services	L	L	M	H

⁽¹⁾ All communications applications are technically possible in all areas. This Table shows market demand projections in each area.

3.5 Types of service (voice, fax, data and email)

MSS systems are able to provide wide and seamless coverage for maritime, aeronautical and land mobile services. A wide variety of services are available for voice, facsimile and data communications. Portable and hand-held terminals have been realized for personal communications applications as well. There also is a trend to increase transmission speed (bit rate) to introduce so-called multi-media services – mainly by using high-speed data or packet data transmission. Some user applications have also been developed to make better use of MSS.

3.5.1 Basic services

Inmarsat started its operation first for maritime services. Inmarsat-A ship earth stations were implemented mainly for large, sea-going vessels to provide telephony, facsimile, telex and data services – by narrow-band FM analog transmission. A digital transmission system was first realized by Inmarsat-B terminals where similar services were available, at very high quality (low BER). For smaller size ships and boats such as pleasure craft, Inmarsat-C terminals were developed to provide a means for store-and-forward type data and message transmission. Inmarsat-M terminals have also been developed for digital transmission by a small, suitcase-size mobile earth station, again providing voice, facsimile and data services. Later, a much smaller portable terminal called “mini-M,” a terminal the size of a laptop computer, was developed for the Inmarsat system. The antenna for the mini-M is usually contained in the lid of the instrument (like a laptop PC lid), representing the area of an “A4” document.

3.5.2 User applications

3.5.2.1 Email

Email transmission has high compatibility with message transmission services of MSS. For example, Inmarsat-C is capable of interconnecting store-and-forward type message transmission via satellite link to terrestrial Internet at the coast earth station. At the CES, Inmarsat-C messages are generally transferred to gateway equipment which provides interface functionality with terrestrial Internet services. Special attention is necessary here for billing information management and security control. Another example is email transmission over little LEO systems. Applications transmitting email to or from a little LEO subscriber provide the communications link between remote hand-held or mobile subscriber units and the Internet. Typically these would be straightforward text messages as opposed to messages with lengthy attachments because of the limited bandwidth available for MSS below 1 GHz.

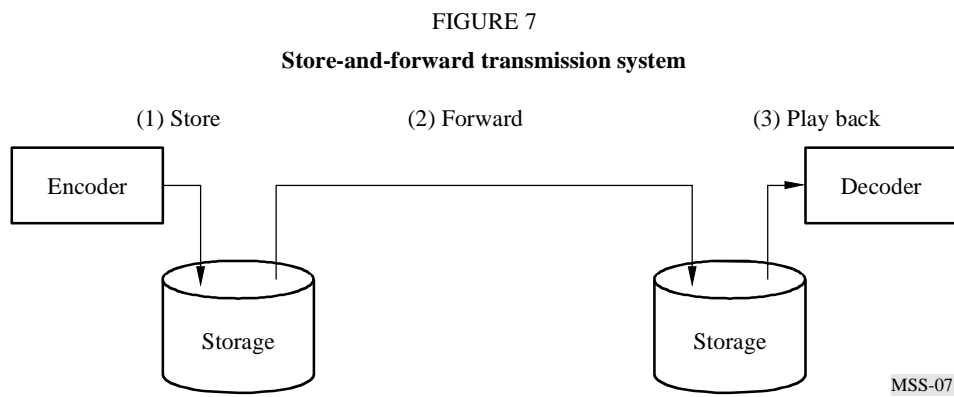
If the satellite is in sight of a gateway earth station (GES) at the time the message is sent, the message is relayed down to the GES immediately. If not, the satellite enters the store-and-forward mode and the message is held on the satellite until it is in view of an appropriate GES.

3.5.2.2 Video transmission

a) *Store-and-forward video transmission systems*

Real time video transmission requires a QoS (quality of service)-guaranteed digital link at higher bit rates, and unfortunately, such a channel is not always available. Video compression or coding is one solution, but a coding rate of several tens of Mbit/s is still necessary for transmission of high-quality TV material that needs post-processing.

Store-and-forward video transmission is another solution. In this approach, the encoded video data is first stored in a local storage media. Then, the stored data is transmitted to a remote storage media. Finally, video data is decoded and played-back at a remote end terminal (see Fig. 7).



Thus, in the store-and-forward video transmission, coded video quality is independent from the transmission bit rate, therefore high quality video transmission is realized, for example through Inmarsat satellite system. The only thing to be noted in store-and-forward is that there is a trade-off between transmission time and coding rate (i.e. video quality). Therefore, the balance of coding rate and available communication link is important.

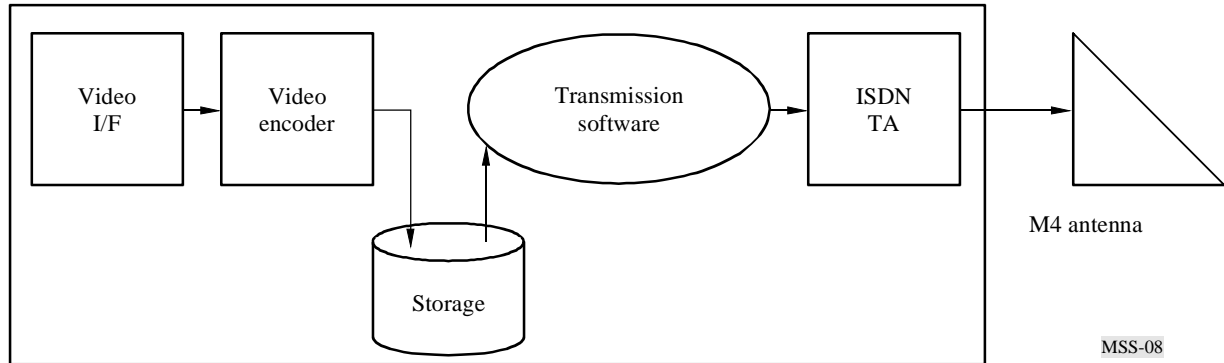
b) *For the Inmarsat Global Area Network (formerly M4)*

The Inmarsat GAN (Global Area Network) is the latest service for applications requiring higher bandwidth. It offers 64 kbit/s to data terminal equipment with an ISDN interface. Therefore, the store-and-forward (S&F) video transmission system needs to have an ISDN TA device. The size of the Inmarsat GAN antenna is small and transportable ($5 \times 20 \times 20$ cm), so it can be used for quick news coverage from accident sites or case locations combining S&F systems.

Since the transmission bit rate is 64 kbit/s, an appropriate video-coding method is MPEG-4 (about 10 kbit/s to 1 Mbit/s) or MPEG-1 (1.5 Mbit/s). In the case of MPEG-1 encoding, the transmission time of a 1 minute video scene is 24 min.

Figure 8 shows a typical configuration of the store-and-forward video transmitter.

FIGURE 8
Transmitter configuration



First, a video signal is captured, encoded and stored. Then the stored data is transmitted using transmission software through a satellite channel. The devices will have the following specifications:

Video I/F: analog composite and/or IEE 1394 (VD) I/F

Video encoder: MPEG-1 or MPEG-4

Transmission software: Shall be reliable (i.e., error free) and it should be able to resume an interrupted transmission.

A receiver has almost the same configuration as the transmitter except the antenna. The receiver may be located at a broadcaster's station when the incoming network is (wired) ISDN.

CHAPTER 4

TECHNICAL ASPECTS OF MSS SYSTEMS

4.1 System architecture and network control

4.1.1 Overview of system architecture and network control

In GSO and non-GSO MSS systems, different system architectures have been developed to meet various user requirements for optimal design and specific services.

4.1.1.1 GSO MSS

GSO MSS systems have been used to provide global, regional and domestic (national) MSS services. The Inmarsat system is a typical example of a global GSO MSS system. There are today a number of other systems which have already been in operation for both regional and domestic services. Examples include *Motient* (formerly American Mobile Satellite Corporation – AMSC), TMI (Canada), *Thuraya*, *Optus* (formerly Aussat), etc. Several GSO MSS systems are planned or about to be launched which will be capable of providing MSS voice and slow-speed data directly to hand-held terminals.

A global GSO MSS system

Inmarsat typifies a global MSS system configuration and presently uses four GSO satellites to provide worldwide coverage. Each satellite is dedicated to service of a specific ocean region, for which an ocean region code is given for identification of the satellite network – in an equivalent fashion to a country code in the public-switched telephone network.

In each ocean region, there are several coast earth stations (CESs) to establish as access to a satellite from ground telephone and other communications networks. Billing information is also managed at each CES. In addition, a network coordination station (NCS) is responsible for channel assignment control of the satellite.

The satellite links connecting a CES and the satellite are, as explained earlier in this Handbook, called “feeder links;” and, in the case of Inmarsat, the 6 GHz and 4 GHz bands are used. Of course, Inmarsat provides the connections between the satellite and the mobile terminals; i.e., its “service links” in the 1.6 GHz and 1.5 GHz MSS bands.

The earlier generation of Inmarsat satellites employed so called “global beams” where each satellite illuminated about one-quarter to one-third of the world. The latest generation of Inmarsat satellites, Inmarsat-3, also provides up to seven (7) spot beams to provide higher power (e.i.r.p.) to specific oceanic and land mass coverage zones. Banks of surface acoustic wave (SAW) filters are contained in the Inmarsat-3 payload to channellize portions of the 1.6/1.5 GHz spectrum into smaller segments addressed to specific spot beams or the global beam.

Non-GSO MSS (“Big LEO”) systems

The system architecture of non-GSO MSS systems is basically dependent on their constellation design: LEO (low Earth orbit) or MEO (medium Earth orbit); i.e., type of non-geostationary orbit altitude and inclination selected. LEO MSS systems, because of their low altitude, will require many more satellites to provide complete global coverage, due to the limited field of view (FOV) of each individual satellite. For example, IRIDIUM requires 66 satellites and Globalstar maintains 48 satellites. MEO systems, which operated at altitudes between LEO and GEO require fewer satellites; ICO can provide global coverage with about 10-12 satellites. All systems to date employ the 1-3 GHz MSS bands.

Non-GSO MSS (“Little LEO”)

Non-geostationary MSS systems operating below 1 GHz, usually referred to as non-GSO – non-voice (NV) are also known as “little LEO” systems. Typically, a little LEO system is a wide area, packet-switched, two-way data communication system. Communications to and from mobile earth stations (MESs) and gateway earth stations are accomplished through a constellation of LEO satellites. Gateways connected to them implement dial-up circuits, private dedicated lines or the Internet.

4.1.2 Traffic planning

4.1.2.1 Long-term planning

Long-term traffic forecasting is indispensable for design of new MSS systems and for system deployment planning. It is generally sufficient in long-term traffic planning to estimate the total traffic volume and its growth rate. It is also useful if geographical distribution is available for the estimated traffic demands and if the traffic demands are estimated for each of the different services.

For long-term traffic forecasting, statistical time-series analysis methods have been used for PSTN for years. There are ITU-T Recommendations for reliable methods of such statistical time-series analysis methods (ITU-T Recommendation E.506).

Another effective means of long-term traffic forecasting is econometric analysis which takes advantage of mutual relationship between traffic demands and various metrics of economical activities.

Though these methods are not developed for the purpose of applications to MSS systems, they are reliable enough for long-term traffic planning of MSS systems.

4.1.2.2 Short-term planning

a) *Geographical distribution of traffic demands*

Estimation of traffic demands distributed all over the world is indispensable for system design and operation planning of global mobile satellite networks, in particular for non-GSO MSS systems.

Though ship terminals and airborne terminals are widely distributed over the major ocean regions, it is generally considered that traffic demands for portable mobile-satellite services are concentrated around areas which are populated but are not well-served by existing telecommunication infrastructure. From this point of view, one way to estimate the traffic demands is to use the indices including population size and the number of exchange access lines (which implies the development of telecommunication infrastructure).

b) *Traffic profile depending on local time*

Another important factor to be taken into consideration for short-term traffic planning is a 24 h traffic profile for international traffic streams that the global networks have to carry. For traffic modelling, 24 h standard traffic profiles for the international traffic streams provide the hourly traffic volume as percentage of the busy hour traffic. It should be noted that the profiles generally vary depending on both origin and destination countries for various cases of time difference between them. For the sake of simplicity, an approximate approach would be to take account of only the local time of the originating country and to assume a single 24 h traffic to all the traffic streams regardless of time difference between two countries. A percentage of hourly traffic volume on a local time basis is calculated from both the traffic profile and the time lag from a given Universal Coordinated Time (UTC).

c) *Short-term traffic estimate for satellite resource planning*

As the result of geographical traffic distribution and a daily traffic profile at each local time, the amount of traffic demand is not uniform over the Earth surface and the traffic intensity at each area is time variant. It is then possible to represent the amount of traffic demand by $D(X, Y, t)$ where X and Y are coordinates such as longitude and latitude, and t shows UTC. The traffic demand may be given in terms of Erlang, the number of channels, transmission rate, etc. A database indicating $D(X, Y, t)$ is indispensable for operation planning of non-GSO MSS systems as shown in § 4.1.2.3.

4.1.2.3 Non-GSO MSS example

A non-GSO MSS satellite generally covers its service area by a number of spot beams. The total traffic demand, $T(t)$, in the coverage of each spot beam at time t is estimated by:

$$T(t) = \sum D(X, Y, t)$$

$$C \ni X, C \ni Y$$

where C shows the coverage of the spot beam.

The coverage of each spot beam is always moving due to the movement of the satellite and the traffic intensity at each area of the Earth is time variant. It is therefore essential to evaluate exactly the total traffic demand for each spot beam at all instant of time based on the information of the location of spot beam coverage at each instant of time. The total traffic demand is consequently time variant. This information is indispensable for transmission capacity allocation control for each spot beam for operation planning.

4.1.3 Channel assignment methods

4.1.3.1 Demand assigned multiple access

Mobile-satellite service systems are operated by demand assigned multiple access (DAMA) to share the limited satellite capacity by a number of mobile terminals. Random access control is the essential function so as to make the most efficient use of the system capacity. General methods for random access control include ALOHA and Slotted ALOHA.

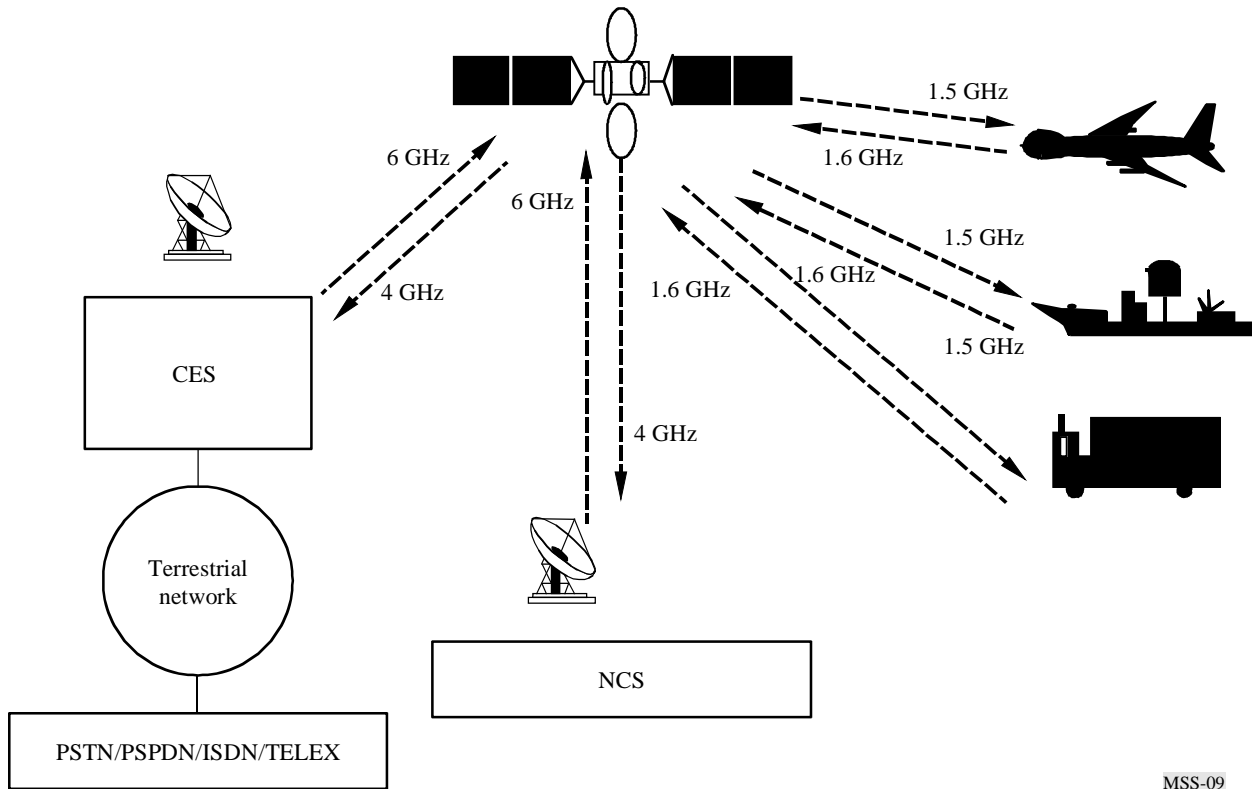
For instance, a ship terminal in the Inmarsat system sends a request for a satellite circuit to a coast earth station by a *request* channel which is operated with Slotted ALOHA. Transmission of the request message is successful when there is no contention during its transmission. When the request message is successfully received, the coast earth station sends a request message for channel assignment to the network coordination station, and a channel assignment message is then returned through an *assignment* channel from the network coordination station.

In a similar way as in GSM, a mobile terminal of a GSM-based mobile satellite network sends a channel request message by using so-called “RACH” based on Slotted ALOHA. RACH transmission is successful if collision of message transmission does not occur during its transmission. When RACH is successfully received, a channel allocation message is then returned through “AGCH”.

4.1.3.2 GSO MSS (Inmarsat Network Coordination Station)

The Inmarsat system employs a dedicated demand assignment control station called the network coordination station (NCS) for a satellite in each ocean region. The NCS is responsible for control and management of satellite capacity and for channel assignment control based on DAMA. It should be noted that coast earth station (CES) has the capability of interconnection between satellite links and terrestrial networks but relies on the NCS for channel assignment control. Figure 9 illustrates the typical configuration of the Inmarsat network.

FIGURE 9
Configuration of the Inmarsat network



MSS-09

In this network configuration, the following procedure is applied for channel assignment control.

a) *Mobile originated call*

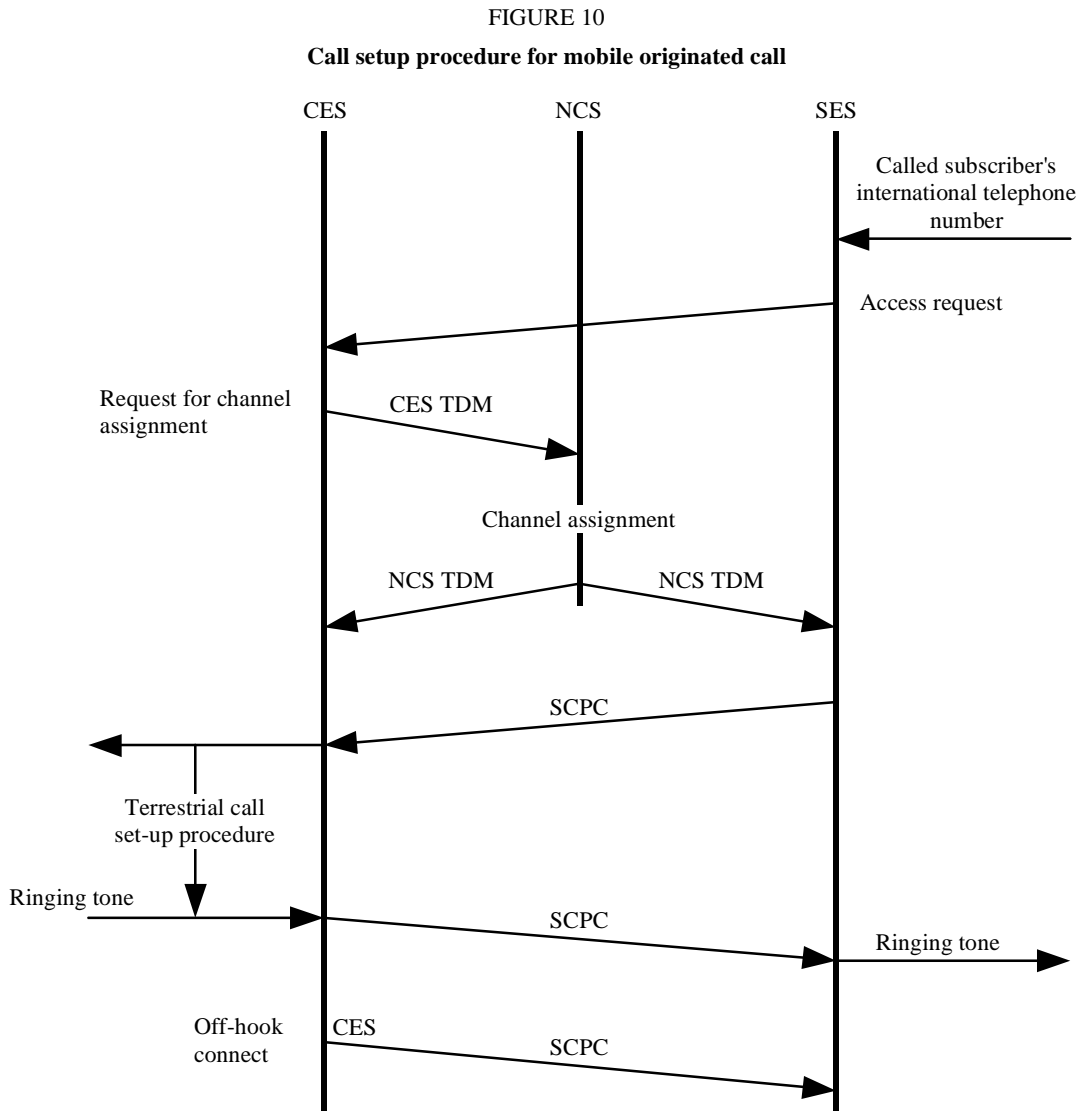
Step 1: A ship earth station (SES) sends a request message through the *request* channel on a random access basis. If the message transmission is unsuccessful, the transmission of the *request* message is repeated.

Step 2: If the *request* message is successfully received by the CES without any contention, then the CES sends a request message for channel assignment to the NCS. The NCS seeks an available satellite channel between the requesting SES and a destination CES. When an available satellite channel is successfully found, the NCS transmits an *assignment* message to both the SES and the destination CES.

Step 3: When the assignment message is received by the SES and the CES, a satellite link is established between them.

Step 4: When the call is terminated, the CES notifies the NCS which releases the satellite link allocation.

Figure 10 presents this channel assignment sequence.



Note:

- CES: coast earth station
- NCS: network coordination station
- SES: ship earth station
- TDM: TDM carrier
- SCPC: SCPC carrier

MSS-10

b) *Mobile terminated call*

Step 1: When a CES has an incoming call from terrestrial networks, it requests the NCS to send a call announcement message to the called SES.

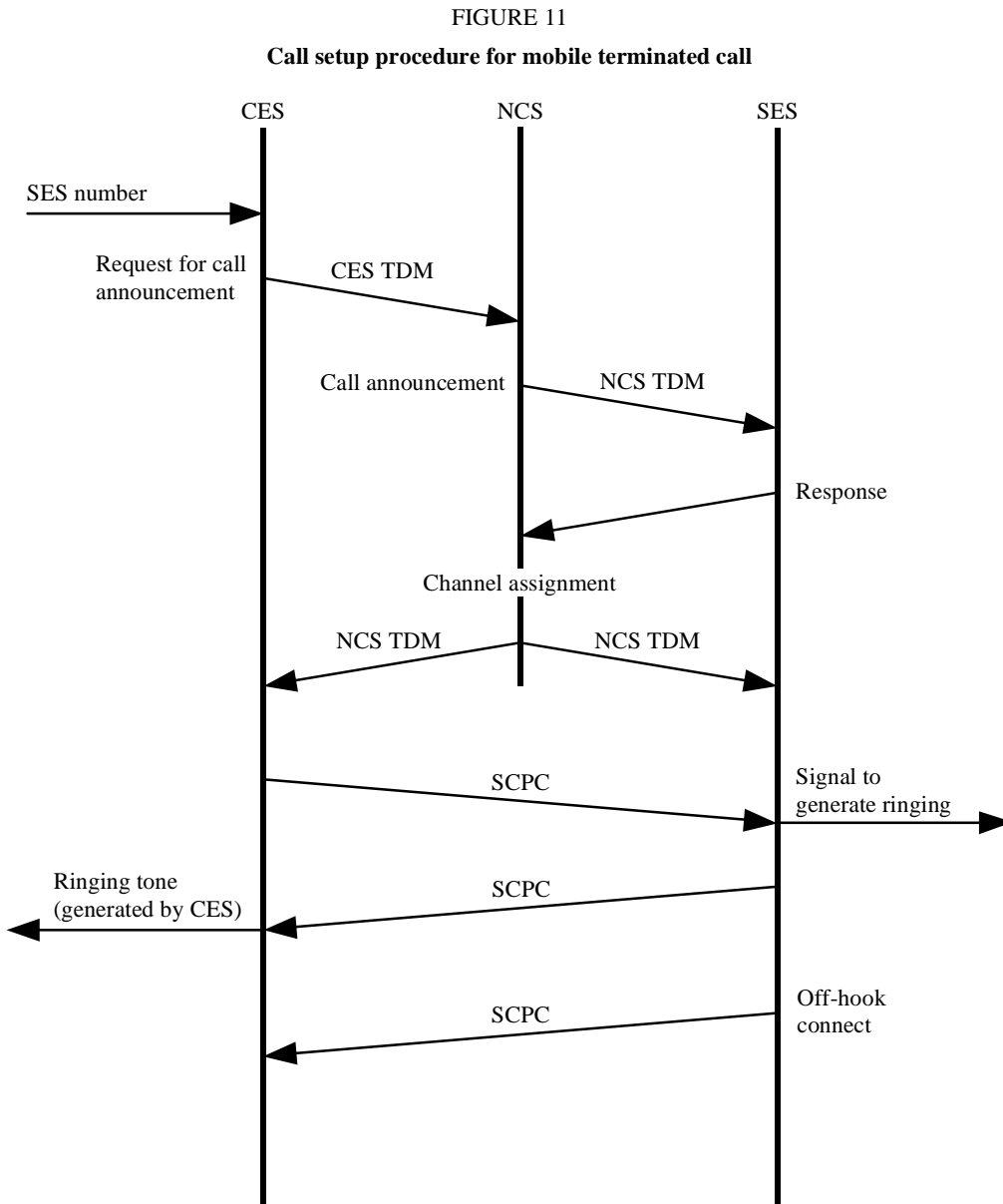
Step 2: The NCS sends a *call announcement* message to all the SES in the ocean region, and waits for the response from the called SES.

Step 3: After receiving the response from the called SES, the NCS then sends an *assignment* message to both the CES and a destination SES.

Step 4: When the *assignment* message is received by the SES and the CES, a satellite link is established between them.

Step 5: When the call is terminated, the CES notifies the NCS which releases the satellite link allocation.

This channel assignment sequence is illustrated in Fig. 11.



Note:

- CES: coast earth station
- NCS: network coordination station
- SES: ship earth station
- TDM: TDM carrier
- SCPC: SCPC carrier

4.1.3.3 Satellite resource management in non-GSO MSS

As presented in § 4.1.2.3, the amount of traffic demands that each spot beam has to accommodate dynamically varies in accordance with a location of satellite beam coverage and local time. The satellite has to provide sufficient capacity for each spot beam to route the traffic demands at every instant. For this purpose, a management function is indispensable for non-GSO MSS systems to allocate dynamically required bandwidth for each spot beam so that the traffic demands may be properly routed. The satellite resource management function needs to meet the following requirements:

- Each spot beam is given a sufficient bandwidth to route the requested traffic demands.
- A carrier frequency is assigned to each spot beam so that frequency reuse conditions may be satisfied, to guarantee the required criteria to avoid unnecessary co-channel interference.
- Satellite transponder power needs to be made available for each spot beam to support transmission within the allocated bandwidth.
- Sufficient capacity can be reserved for a number of spot beams to support hand-over traffic, preferably without any unnecessary change of frequency and/or time slot allocation.

Based on these requirements, satellite transponder capacity needs to be appropriately reserved for each spot beam. The reserved satellite transponder capacity is a channel pool in which gateway earth stations can make channel assignment for incoming and hand-over calls.

4.1.3.4 Channel assignment control for non-GSO MSS

A gateway earth station of non-GSO MSS system plays a role of channel assignment control for a given channel pool capacity of the satellite transponder for each spot beam. Within this channel pool capacity, the gateway earth station is responsible for channel assignment control for call requests. In the case that there exist multiple gateway stations within the satellite coverage, a mechanism is needed to share the available satellite channel pool among the gateway earth stations.

A non-GSO MSS system based on extension of GSM technology generally employs the following channel assignment control procedure.

a) *Mobile originated call*

Step 1: The gateway earth station transmits a BCCH (broadcast channel) message to a responsible spot beam.

Step 2: A mobile terminal receives the BCCH message and establishes synchronization and control in the network.

Step 3: A mobile terminal transmits a channel request message through RACH (the random access channel) based on slotted-ALOHA.

Step 4: If the request message is successfully received by the gateway earth station without any contention, the gateway earth station allocates a satellite link channel through the AGCH (access grant channel) in so far as a satellite channel is available. Otherwise, the mobile terminal retries Step 3.

Step 5: Based on the AGCH message, a satellite link is established between the mobile terminal and the gateway earth station.

b) *Mobile terminated call*

Step 1: The gateway earth station transmits a BCCH message to a responsible spot beam.

Step 2: A mobile terminal receives the BCCH message and establishes synchronization and control in the network.

Step 3: When there is an incoming call from a terrestrial network, the gateway earth station transmits a channel assignment message to a destination mobile terminal through an AGCH in so far as a satellite channel is available.

Step 4: Based on the AGCH message, a satellite link is established between the mobile terminal and the gateway earth station.

4.1.3.5 Satellite diversity and hand-over

Non-GSO MSS satellites are operated in a very dynamic condition where both satellites and mobile terminals are moving continuously. Due to the movement of satellites, it is not always easy to ensure direct satellite visibility from a mobile terminal even when the mobile does not move. In particular, blocking and shadowing often occur in urban areas mainly because of high-rise buildings. In such a situation, satellite diversity is a reliable countermeasure to improve availability by maintaining a satellite link out of two visible satellites. The channel assignment control has to provide a function to support establishment of satellite links to the two visible satellites for satellite diversity operation.

Another important control function is hand-over so that a satellite link can be allocated when a mobile terminal coverage is changed from a spot beam to another or from a satellite to another. This control is generally supported by the following procedure.

Step 1: A mobile terminal always monitors signal reception strength from the satellite. In the case that the signal strength falls below the threshold level, the mobile terminal notifies the gateway station of hand-over request through a dedicated signalling channel.

Step 2: When the gateway earth station receives the hand-over request, the gateway station seeks a new available satellite channel in an adjacent spot beam which can accommodate the hand-over traffic. The gateway station then assigns the new channel to the mobile terminal requesting the hand-over.

4.1.3.6 Channel assignment and interference avoidance

Dynamic channel activity assignment system

For little LEOs, the channel assignment process is similar to that described in the previous section for the big LEOs, except that the channel assignment process takes place on the satellite itself, rather than in the gateway earth station. This is possible because of the relatively short nature of the data messages carried by the little LEOs and is necessary because of the required close interaction between the channels assignment system and the MES, which operate in a highly congested band.

The 148-149.9 MHz band used by little LEO systems is also heavily used by terrestrial systems. In order to find usable channels, a little LEO system must scan and identify channels within this band that are not being actively used at that particular time. ORBCOMM has developed a dynamic channel activity assignment system (DCAAS) to identify usable channels and assign them for MES transmissions. This is an implementation of perhaps the oldest technique for avoiding interference in radiocommunications. That is, to “listen” before “transmit” to make sure that the channel is clear. The difference here is that it is the satellite that listens before it permits an MES to transmit.

There is no known way for an FDMA system to operate in the 148-149.9 MHz band without some interference avoidance scheme, such as DCAAS. Any attempt to receive on a channel being actively used by a terrestrial transmitter would result in interference to the satellite and the loss of MSS data.

The DCAAS consists of a receiver and processing unit on each of the satellites. DCAAS scans the MES uplink band for terrestrial transmissions in 2.5 kHz intervals, identifies channels which are not in use and assigns these channels for uplink use by the MESs. The objective is to avoid interfering with terrestrial receivers preventing MES transmissions on active mobile channels. For the details of DCAAS, refer to Recommendation ITU-R M.1039.

Signalling

In MSS systems (GSO or non-GSO/big LEO or MEO), a satellite link is generally established on a random access basis. The signalling message transmission (e.g., a request to set up a call to a particular land-based telephone number – sent from the mobile terminal to the gateway, or the assignment of the frequency for the terminal to conduct a call – sent from the gateway station to the mobile terminal) is made only after the satellite link is established. In general, signalling information is exchanged between a mobile earth station and a gateway earth station through an in-band signalling channel in the established satellite link.

Signalling between a little LEO subscriber and the satellite is equally essential in order to permit the effective and efficient exchange of communications (data) between the two. The subscriber unit must also receive timing information and available channel information from the satellite to ensure that when its data message is transmitted, it will be received at the satellite at the correct time and frequency, avoiding interference with other signals in the system. In the case of little LEO systems, the signalling is particularly important, because the frequencies of the uplink messaging and signalling channels are changing constantly as a result of the operation of the DCAAS system.

4.2 General characteristics of mobile earth stations

The physical appearance of mobile earth stations can vary considerably depending on the nature of subsystem components used. The appearance is associated with factors such as whether the terminal is designed for land, maritime, or aeronautical use, the type of communications required, the frequency band of operation, the satellite system architecture available and the desired antenna characteristics. It is the combination of these factors that leads to the great diversity in the appearance of the mobile earth stations.

The general characteristics of mobile earth stations are, however, similar. The main subsystem components of mobile earth stations and their unique functions can be separated into:

– *The antenna subsystem*

This includes the type of antenna employed, its associated mount and antenna pointing unit. The choice of antenna that is most suitable for a given application can vary from the use of an electrically large antenna such as a parabolic reflector or phased array, through the use of a medium gain antenna such as an helix, to the use of a small antenna such as a half-wave dipole.

The choice of antenna is a trade-off between the system requirements for efficient usage of space segment capacity and user requirements for small compact equipment. A high gain antenna is desirable in that it increases the e.i.r.p., receive sensitivity and interference rejection of the terminal. However, on the down side, it also increases the cost and reduces the portability of the terminal. A low gain antenna will cost less, have a simpler structure and will not require beam pointing. But, correspondingly, it will require more satellite downlink e.i.r.p. (which is one of the most cost sensitive parameters of an MSS system) to support a given data rate and, because of its omni-directional coverage area, it will also receive more external interference.

The selection of antenna type is further influenced by whether there is a need to track MSS satellites. This not only depends on whether the terminal is in motion at the time of use but also whether the satellite(s) being tracked are moving relative to the terminal. The interplay between both sets of movements can lead to complex tracking requirements. Because of this, non-GSO MSS terminals generally only use omni-directional antenna.

Typical antenna gains used in the MSS vary between 0 dBi to 21 dBi (85 cm diameter reflectors). While, the receiver gain-to-noise-temperature (G/T) ratios typically range between $-26 \text{ dB(K}^{-1})$ to $-4 \text{ dB(K}^{-1})$.

In two-way communications, the antenna is normally common for both transmission and reception functions. These functions are usually assigned different frequencies (termed frequency division duplex), with a diplexer used to combine the two chains into the same feed of the antenna. Alternatively, a time division duplex scheme can be employed where the two directions of communication are allocated different time slots. Also, because of the high depolarization effects encountered in MSS communications, use of polarization discrimination is not normally employed in the communications link between the satellite and mobile terminal.

– *The transmit chain*

This encompasses the transmit signal path and includes the high power amplifiers, band-pass filters, combiners for any multi-channel operation, up-converters, baseband modulators and source encoders. Other features such as dynamic power control and voice activation circuitry also form part of the transmission chain.

– *The receive chain*

This encompasses the receive signal path and includes the low noise amplifiers, band-pass filters, multi-channel dividers, down-converters, demodulators and source decoders.

– *The power subsystem*

Power delivery is normally by a battery or uninterrupted power supply which is recharged through the likes of the mains supply, a vehicle cigarette lighter, an electric generator or solar cells. The characteristics and requirements of the power system will vary depending on the application. For example, in portable applications the terminal manufacturer would design for low power consumption and light weight. In safety applications, immunity to power interruption or restoration of primary power would be more essential.

– *The control subsystem*

This includes the miscellaneous control, data-handling, protocol, and signal processing functions required for the effective operation of the terminal.

4.2.1 Vehicular mobile earth stations

General description of functional characteristics

MSS terminals can be located onboard vehicles, ships, and aeroplanes. As these vehicles can be in motion when the communications is in progress, there are some extra considerations that need to be taken into account in the design and installation of the terminals.

The antenna should be mounted clear of any obstructions on the vehicle so as not to reduce the signal strength. If the antenna is directional (typically having a gain greater than 6 dBi) then it will also need to include a mechanism to automatically track the MSS satellite. This may be accomplished by either mechanically rotating a fixed beam antenna, or by the use of electronic steerable or switchable beams in the case of phased array antennas.

The MSS terminal itself may be physically separated into two parts: an external sealed unit comprising the radome which houses the antenna, RF front end, and possible antenna tracking unit; and an internal unit normally located near the operator which houses the other radio components. The low-noise amplifiers are usually placed as close as possible to the diplexer so as to minimize the noise resulting from losses in the feed guides.

Maritime ship earth stations (SES)

These are MSS terminals that have been designed for installation and operation onboard vessels. An example of such terminals are those forming a part of the international global maritime distress and safety system (GMDSS), which are designed for high availability and other safety requirements.

Satellite communications in a marine environment has distinctive propagation characteristics and operating requirements. Maritime communications are particularly susceptible to multipath effects due to signal reflections from the structure of the ship or sea. Methods employed to counter this effect include the use of modulation schemes that are tolerant to signal fading and intersymbol dispersion, and the incorporation of a significant fade margin – through the use of dynamic power control – in the satellite link design. The required fade margin can be minimized by use of data interleaving and forward error correction coding schemes.

Maritime terminals can be classified into three main types:

- Those having low gain antennas (approximately ≤ 6 dBi) as typified by the Inmarsat Maritime-C terminals. These terminal types are characterized by very compact ship earth stations having an unstabilized and unsteered antenna subsystem.
- Those having high gain antennas (approximately ≥ 15 dBi) as typified by the Inmarsat Maritime-A & B terminals. These terminal types would need to track MSS satellites in order to counter the roll, pitch and yaw motion of the vessels on which they are mounted. They must still be capable of correctly pointing to a satellite even when operating under heavy sea conditions.
- Those having medium gain antennas (approximately 6-15 dBi) as typified by the Inmarsat Maritime-M terminals. These are scaled down versions of the high gain antenna. A sub-set of these terminals are designed to operate only within the spot-beam coverage areas of GSO satellites. These terminals typically use antennas that have wide beamwidths in the elevation (vertical) plane so that they need only track the satellite in the azimuth (horizontal) plane. Such terminals would be suitable for installation on pleasure craft because they are smaller, cheaper and simpler than their fully stabilized counterparts.

Aircraft earth stations (AES)

Aircraft terminals, like the maritime terminals, also have high system requirements in the performance, availability and integrity of communications. Aspects specific to aeronautical terminals include: the need to cater for large Doppler shifts and temperature variations, the need for ergonomic design of the external antenna subsystem components so as to minimize atmospheric drag, and the need for compact internal radio units that fit into assigned spaces within the aircraft.

The terminals are likely to be much more integrated with other electronic equipment present on the aircraft than is the case with land or maritime terminals. Additionally, a category of aeronautical terminals has recently become available that is designed for public correspondence calls only and they are not certified for aeronautical safety applications or for use with air traffic management systems. Such terminals, typified by the Inmarsat Aero Mini-M service, are attractive for use in light aircraft as they are compact, the purchase price is lower, and the installation and certification process is much reduced compared against safety compliant terminals.

AMSS terminals normally employ one of three types of antenna:

- Those having high gain antennas (minimum gain of 12 dBi) as typified by the Inmarsat Aero-H/H+ service. The antenna, being directional, needs to track the satellite.
- Those having medium-gain antennas as typified by the Inmarsat Aero-I service. These are designed to exploit the higher power of Inmarsat-3 satellite spot beams to receive Aero-H levels of service through smaller, cheaper terminals.
- Or, those having low gain as typified by the Inmarsat Aero-L service. Typically, these antennas are unsteered dipole or helix antenna having near omni-directional gain.

Land mobile earth stations

In a land mobile environment, the communications link between the satellite and mobile terminal is subject to impairments in the form of multipath effects arising from signal scattering and reflections, and shadowing effects arising from signal blockage. This results in signal fading and phase variations in the carrier – the magnitude of which depends on whether the terminal is stationary or moving, the speed at which it is moving, and the environment between the terminal and the satellite. It is possible to provide sufficient link margin to compensate for fading, or to allow for some in-building penetration of the signal. However, it is not practical in MSS communications to provide sufficient margin to still allow communications when the direct line-of-sight of the link is blocked by buildings or heavy vegetation.

In vehicular applications, the antenna is normally placed on the roof and is typically of low or medium gain (less than 15 dBi). The latter is normally either a low-profile motorized tracking antenna, or a non-tracking rod antenna about a metre in height which has an omni-directional coverage in azimuth and fixed coverage in elevation (coverage suitable for use in temperate regions).

4.2.2 Personal earth stations

Personal earth stations can be divided into two categories: hand-held earth stations and portable earth stations.

Hand-held earth stations

Hand-held MSS terminals are similar in size and appearance to normal terrestrial cellular phones. In fact, the terminals are commonly dual-mode phones that have the capability of operating to either the satellite or terrestrial mobile networks. When a call is placed, it is first connected through the local terrestrial mobile network. If, however, the terminal is outside the terrestrial coverage area, the call is then routed through the mobile-satellite network. This method of operation allows MSS phones to complement the existing terrestrial mobile infrastructure by providing a regional or global extension to its coverage area. An important feature of these terminals is that they are assigned a single telephone number which is used for both satellite and terrestrial cellular call reception. The terminals will generally require a direct line-of-sight to the satellite (which can either be to a GSO or non-GSO satellite). Other than this, their usage will be similar to terrestrial cellular operation.

Portable earth stations

Portable terminals are self-contained in a unit about the size of a laptop computer. The antenna is usually incorporated within the lid of the case and must be manually pointed to a GSO satellite (a quick and simple procedure). Typically, there is a signal meter built into the terminal to aid positioning. Such terminals are ideal for “mobile office” applications due to the wide range of services available ranging from voice to 64 kbit/s data transfer.

4.2.3 Satellite EPIRBs

Satellite emergency position indicating radio beacons (EPIRBs) are used to notify rescue authorities of distress alerts in the case of emergencies. They must be capable of supporting two functions: the initial distress alerting to the relevant authorities, and the geographical positioning of the distress to

within sufficient accuracy to enable assistance to be provided. EPIRBs can be installed on vehicles such as airplanes and ships or carried on the person. Furthermore, “float free” EPIRBs are required under law to be installed on all ships to which the Safety Of Life At Sea (SOLAS) Convention applies.

There are two satellite-based EPIRB systems that have been developed for use. The first is operated by COSPAS-SARSAT, who support a range of beacons for distress alerting and position location purposes including that for the GMDSS. The other is operated by Inmarsat, who concentrate on providing GMDSS capability for use on board vessels only. Both services are provided free of charge by the operators. The two systems are described as follows:

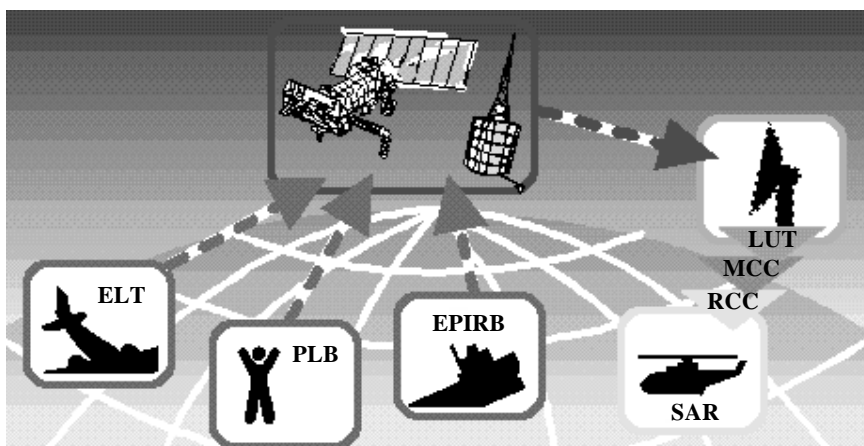
4.2.3.1 COSPAS-SARSAT

Cospas-Sarsat is a satellite system for search and rescue (SAR) which uses satellite-based sensors and ground processing facilities to detect and locate emergency distress beacons. The system is comprised of:

- a) SAR payloads on board satellites in low Earth orbit (LEOSAR) and geostationary orbit (GEOSAR);
- b) distress beacons which transmit at 121.5, 243 or 406 MHz;
- c) satellite ground receiving stations (referred to as local users terminals (LUTs)) located throughout the world; and
- d) an extensive command, control and communications network for distributing distress alert information and data required to operate the system.

The diagram below (Fig. 12) provides a high level overview of the Cospas-Sarsat system. A more detailed description is provided in the Cospas-Sarsat document “Introduction to the Cospas-Sarsat System C/S G.003” which can be obtained free of charge from the Cospas-Sarsat web site at the following Internet address: <http://www.cospas-sarsat.org/>.

FIGURE 12
Overview of the Cospas-Sarsat system



ELT: Emergency locator transmitter
PLB: Personal locator beacon
EPIRB: Emergency position indicating radio beacon
RCC: Rescue coordination centre

Satellites

The space-based components of the Cospas-Sarsat system is comprised of SAR instruments on board satellites in polar low-altitude orbit (LEOSAR) and geostationary orbit (GEOSAR). The combination of low-altitude and geostationary orbit satellites provide a comprehensive distress alerting and locating capability. The polar orbiting satellites provide a global, but non-continuous coverage for the detection and positioning of distress beacons using Doppler location techniques. However, the non-continuous coverage introduces delays in the alerting since the user must “wait” for a satellite pass to view the beacon. On the other-hand the geostationary satellites provide for rapid detection, but do not provide coverage of the polar regions. Furthermore, since the geostationary satellites are stationary with respect to the beacon, Doppler location techniques cannot be used, and therefore, location information is only available if the beacon knows and transmits its location.

The nominal LEOSAR constellation is for 2 Sarsat and 2 Cospas satellites, however, the space segment usually includes a greater number of satellites. The Cospas satellites provide instruments capable of detecting and locating emergency distress beacons which transmit at 121.5 and 406 MHz, and the Sarsat payloads provide instruments for detecting and locating 121.5, 243 and 406 MHz beacons. Beacons operating at 121.5 MHz and 243 MHz require the satellite to have simultaneous visibility of the beacon and the satellite receiving station for the system to generate a distress alert. Consequently the geographical coverage of these frequency bands are dictated by the number and location of satellite receiving stations. All the LEOSAR payloads include on board search and rescue processors and memory modules to handle 406 MHz beacon transmissions. This provides global coverage by storing data derived from on-board processing of 406 MHz beacon signals in the memory module. The content of the memory module is continuously broadcast on the satellite downlink. Therefore, each 406 MHz beacon can be detected by all satellite earth stations which track the satellite.

The Cospas-Sarsat GEOSAR payloads are installed on meteorological and multi-purpose communication satellites. These payloads provide for quasi-instantaneous alerting of 406 MHz distress beacons but they are not equipped with instruments to detect 121.5 or 243 MHz beacons. Since GEOSAR satellites remain fixed relative to the Earth, there is no Doppler effect on the received frequency, consequently, Doppler radio location techniques cannot be used. The GEOSAR System is able to provide beacon position information when such information is acquired by the beacon through an internal or external navigation device and encoded in the beacon transmission.

Distress beacons

Cospas-Sarsat space-based instruments are compatible with distress beacons which transmit at the frequencies described above. The beacons which operate at 406 MHz were designed specifically to be detected and located by the Cospas-Sarsat system. When activated, they transmit a digital message unique to that beacon. There are two main categories of 406 MHz beacons: those which allow for the transmission of encoded position data acquired from global satellite navigation systems along with their unique identification (these beacons are referred to as location protocol beacons), and those which only transmit the unique beacon identification (referred to as user

protocol beacons). With respect to user protocol beacons, the Cospas-Sarsat LEOSAR system is able to determine their location using Doppler radiolocation techniques whereas the GEOSAR system is able to provide a warning that the beacon was activated, but without location information. With respect to location protocol beacons, both the LEOSAR and GEOSAR systems provide location information. The electrical specifications for 406 MHz distress beacons are detailed in Recommendation ITU-R M.633 entitled “Transmission characteristics of a satellite emergency position-indicating radio beacon (satellite EPIRB) system operating through a low polar-orbiting satellite system in the 406 MHz band”.

121.5 and 243 MHz beacons are older generation beacons which were not designed for satellite detection. Consequently, although they are detected and processed by the Cospas-Sarsat system, they do not support all the features typical of 406 MHz beacons. For example, they do not transmit a unique identifier and their transmit power is significantly lower.

Satellite receiving stations

The Cospas-Sarsat system includes two generic types of satellite receiving stations, those which interface with the satellites in low Earth orbit (referred to as LEOSAR local users terminals or LEOLUTs) and those which receive and process signals from GEOSAR satellites (referred to as GEOLUTs). The role of LUTs is to generate distress alert messages from processing the satellite downlink signals. The local coverage area, time responsiveness, and level of redundancy provided by the Cospas-Sarsat system is enhanced by having LEOLUTs at many different locations throughout the world.

Mission control centres

Cospas-Sarsat includes a network of mission control centres (MCCs) which are interconnected via redundant communications systems. The main functions of this network are to:

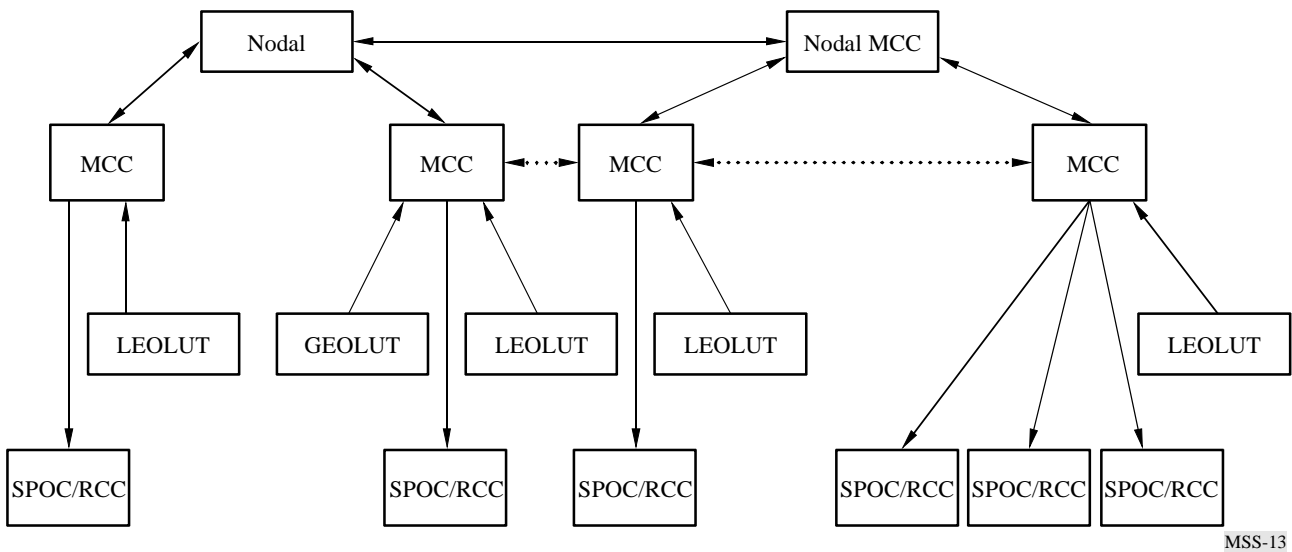
- receive distress alert messages from LUTs and other MCCs and distribute them to the responsible SAR authorities (referred to as search and rescue points of contact or SPOCs); and
- promulgate system status information necessary for the efficient operation of the system.

To ensure timely and reliable distribution of alert and location information to the appropriate search and rescue authorities, Cospas-Sarsat has adopted a command, control, and communications infrastructure based upon a hierarchy of Nodal MCCs, MCCs, LUTs and SPOCs. This structure, depicted in the diagram below (Fig. 13), also permits administrations to establish bilateral agreements for direct MCC to MCC exchange of alert information (as indicated by the dotted lines).

Additional information

Additional information on the Cospas-Sarsat system, including the technical specifications and descriptions of system components, is available from the Cospas-Sarsat web site at the following internet address: www.cospas-sarsat.org. Also, questions can be directed to the Cospas-Sarsat Secretariat at the following email address: cospas_sarsat@imso.org.

FIGURE 13
Cospas-Sarsat infrastructure



4.2.3.2 Inmarsat-E

Inmarsat-E EPIRB Earth-to-space transmissions operates at frequencies around 1.6 GHz, in a portion of the band specifically limited to distress and safety applications. The units incorporate an integral radionavigation receiver which uses the Global Positioning System (GPS) to determine the position of the EPIRB to within an accuracy of 200 m. When an EPIRB is activated, the information is transmitted via one or more Inmarsat satellites to two Inmarsat land earth stations (providing for redundancy) where it triggers an alarm that is automatically relayed to the rescue authorities.

Inmarsat-E EPIRBs are available either as float-free terminals (similar to buoys) or as hand-portable terminals. The float free terminals are suitable for use onboard larger vessels. For added security, many of these EPIRBs are installed with on-bridge displays indicating the status and position reading from the EPIRB. The hand portable EPIRBs are suitable for use on yachts, life-boats and other small craft. The EPIRBs can be either triggered manually by the user, or, in the case of float-free terminals, also triggered automatically when submerged. As a minimum, the message will contain the identity of the terminal and its position at the time of the alert. Crew members can have the option of including, by pressing the relevant button, additional information on the nature of the emergency.

The primary advantage of EPIRBs operating to GSO satellites is the alert is detected nearly instantly (normally within 2 min from transmission). Once triggered, Inmarsat-E terminals will continue transmitting in a predetermined intermittent manner for at least 48 h unless de-activated manually. Alerts can be detected by Inmarsat satellites from ships that are positioned approximately

between 70 North to 70 South latitude. Other features of Inmarsat-E EPIRBs include a high intensity, low duty-cycle flashing light, together with an internal self-test function. Some models also have the option of including a search-and-rescue radar transponder beacon, or 121.5 MHz homing beacons, to enable rescuers to locate the vessel once they have reached the area of the transmitted position.

4.2.4 Special-purpose mobile earth stations

There are two applications not specifically covered above. The first is for paging and messaging terminals, and the second for semi-fixed applications:

Paging and messaging terminals are designed to receive infrequent packets of short data messages. Ideally, the terminals also acknowledge by means of a return channel that the data has been successfully received. The terminals are small, light weight units that are relatively inexpensive and have omni-directional antenna. A few mobile system operators have incorporated very large margins (10 to 15 dB plus) into their system link design to allow for some in-building and other non line-of-sight reception capability.

A variation of paging terminals are those designed to allow for two-way messaging facilities. These are particularly useful when incorporated with positioning information. This category of mobile terminals includes systems operating in the 12/14 GHz bands that use spread spectrum techniques (used principally in order not to cause interference to other services sharing the band) and have directional satellite tracking antenna.

Another class of special purpose mobile terminals are semi-fixed terminals that are designed for use in remote areas. These terminals come in a variety of forms including: traditional pay phone booths, equipment suitable for home installation, or local area trunked networks.

4.3 General characteristics of MSS space segments

The space segment consists of the satellites and communications payload necessary to connect mobile users to the feeder link earth stations or directly to other mobile users. The satellites can be placed either in geostationary orbits (GSO) or non-geostationary orbits (non-GSO). The later are usually placed in circular orbits at altitudes much lower than the GSO. The choice of orbital characteristics is an important factor in the design of the satellite link as it impacts a wide range of other considerations such as the number of satellites in the constellation, the path loss between the satellite and user terminals, and the type of feeder link earth stations required.

Other characteristics of the space segment relate to the design of the communication system. Examples include whether the satellites demodulate the signal before retransmission, whether they employ inter-satellite links, the number and size of satellite beams, and size of the solar cells deployed (affecting the amount of electrical power available). Also, unlike antennas employed in the ground segment, separate antennas are normally used in the space segment for transmission and reception functions so as not to increase the reception of intermodulation products generated at the satellite.

4.3.1 GSO MSS satellite systems (international and domestic)

There are many GSO MSS systems that are either in operation, or being planned. This includes the satellite networks of ASC (AMSC), AUSSAT (OPTUS), CELSAT, EMARSAT (THURAYA), GARUDA (ACeS), INMARSAT, ITALSAT, MARAFON, MARECS/ARTEMIS (ESA), MEASAT, MORE, MSAT (TMI), MTSAT, N-STAR, SOLIDARIDAD, COSPAS-SARSAT GEOSAR and VOLNA.

Most GSO MSS systems operate their radio links used for communicating between the satellites and mobile terminals (service links) in the 1.5/1.6 GHz MSS bands, and the links used in communicating between the satellites and gateway earth stations (feeder links) in the 4/6 GHz FSS bands or 10-12/13-14 GHz and 20/30 GHz FSS bands. For example, signals from feeder link earth stations transmitting (Earth-to-space) in the 6 or 14 GHz band are received at the satellite and retransmitted (space-to-Earth) in the 1.5 GHz band for reception by mobile terminals. In the return direction, mobile terminals uplink signals in the 1.6 GHz band which are received at the satellite and down-linked in the 4 GHz or 10-12 GHz band for reception by feeder link earth stations. A few GSO MSS systems also operate service links at 2.5/2.6 GHz, with others planned in the 2 GHz MSS bands.

Also, satellite systems can have feeder cross-link transponders which allows for signals received on feeder uplink frequencies (e.g. 6 or 14 GHz) to be retransmitted directly on the feeder link downlink frequencies (e.g., 4 or 10-12 GHz). This facility allows for the internal administrative inter-connection within the system without having to use valuable service link spectrum. Similarly, systems can have service cross-link transponders to enable single-hop mobile-to-mobile communications, and for use in special applications such as search-and-rescue operations.

GSO MSS satellite antennas can be deployed as a single “Global” beam that covers the whole of the visible surface of the Earth from the satellite, or as narrower, multiple spot beam transmissions that concentrate energy to particular regions. For global beam coverage, antennas with a maximum gain ranging between 0 dBi to around 20 dBi are normally used. For spot beam coverage, the maximum gain attainable relates somewhat to the developments in technology available at the time of design, together with economic considerations. The gains vary from around 27 dBi for systems having 5 or 6 spot beams each covering an area the size of a continent, to around 44 dBi for the latest MSS systems being designed which can have hundreds of spot beams. Spot beam systems generally have advanced features such as the ability to divert satellite power between different spot beams or spot beam/global beam combinations. Furthermore, some of the newer spot beam systems are also being designed to have the ability to shape their coverage once in orbit. This allows, for example, the ability to counter the effect on the spot beam coverage area resulting from the movement of GSO satellites operating with high inclination angles, or to tailor coverage depending on traffic developments.

It should be noted that current GSO MSS networks all tend to have transparent or so called “bent-pipe” transponders that simply amplify and retransmit signals without baseband demodulation and regeneration. This provides for maximum flexibility in the type of traffic that can be carried within the constraints of the channelization filters and available coordinated spectrum.

4.3.1.1 Selection of orbit locations

GSO satellites are located approximately 36000 km above the equator where they remain essentially stationary when viewed from the Earth. The benefit of the GSO orbit is that no, or very little, hand-over is required between satellite beams or between different satellites. Furthermore, use of directional antennas at the mobile terminal is easier for GSO systems than for non-GSO systems, thereby improving link margins and facilitating higher bit rate services.

Some other advantages of GSO satellites are that the operating procedures, system design, frequency coordination, and regulatory environment are well established. Moreover, only a limited number of GSO satellites are required to achieve a given coverage area, thereby reducing launch and ground segment costs. For example, a single satellite can provide regional coverage and 3 to 4 satellites are enough to provide global coverage. Furthermore, coverage can be shaped to cover particular regions of the Earth such as land masses only.

GSO satellites are traditionally very large (mass greater than 2000 kg) and can have long design life times (15 years or more). At the end of life, they are normally kicked into a higher orbit to free-up the valuable and scarce GSO space (orbital longitude locations registered with the ITU) on the equatorial plane.

4.3.2 Non-GSO satellites

Non-GSO MSS systems that are either in operation, or about to become operational include: ICO, IRIDIUM, GLOBALSTAR, COSPAS-SARSAT LEOSAR and ORBCOMM. Other systems are also in the process of being designed and financed.

These systems can be categorized into what are termed “big LEO” systems which are designed to provide voice and data services, and “little LEO” systems which are designed to provide messaging only services. The “big LEO” systems normally operate their service links in the 1.6, 2.5 GHz or 2 GHz bands and feeder links in the 5/7 GHz or 20/30 GHz bands. “Little LEO” systems normally use the bands 137/138 MHz, 148/150 MHz, and 400 MHz for both service and feeder links. Data rates currently offered by non-GSO systems vary from 2.4 kbit/s to 9.6 kit/s.

The satellite system architectures adopted by the various non-GSO system networks are all different. They relate to the applications being offered, the feeder and service link frequencies available, traffic capacity requirements, and engineering design decisions undertaken by the system operator.

For example, the design philosophy of the Iridium satellite network is based on use of on-board processing to demodulate and regenerate signals at the satellites, and the ability to switch and route calls between different satellites through inter-satellite links. This capability requires advanced satellite technologies and development. In comparison, the Globalstar satellite network is based on simple, frequency changing transponders and use of code division multiple access (CDMA). This results in a simpler satellite architecture with comparatively little satellite on-board processing. However, it requires increased ground structure architecture and other new design techniques such as the need for accurate power control by handsets to reduce the amount of self-interference, and techniques to facilitate beam switching and satellite handover.

An inherent advantage in use of non-GSO satellites is that because they are moving relative to the user, they can have an inherent position determination capability built-in, using pseudo-ranging techniques – without the need to incorporate radionavigation receivers such as GPS into their terminals. However, in employing such an inherent approach, the accuracy of GPS may not be obtained.

4.3.2.1 Selection of constellation parameters

Non-GSO satellites are normally placed in circular orbits at altitudes much lower than GSO satellites. This provides the advantage of a reduced path loss to the mobile terminal (ranging from 11 dB to 30+ dB lower than that for GSO systems), as well as a significantly reduced propagation time delay.

Non-GSO satellites are generally located at altitudes above 200 km to avoid atmospheric drag, and avoid being located in the Van Allen belts which are areas of high natural radiation centred around approximately 3200 km and 7600 km above the Earth's surface. The choice of orbit is then dependent on the coverage area of the satellite. The higher the altitude the larger the coverage area. Consequentially, fewer satellites are required in a constellation to provide for uninterrupted global coverage, together with less frequent handover required between beams due to the slower velocities. However, location of satellites at higher altitudes increases the path loss and time delay to mobile terminals over use of lower altitudes.

The choice in the number of satellites within a constellation additionally depends on how much overlap is required between the satellite footprints. A larger overlap results in more satellites likely to be visible to mobile terminals (which can be used to provide for path diversity and satellite redundancy), and a higher average elevation angle to a satellite. However, a larger overlap requires more satellites to be placed in orbit resulting in higher system cost and greater network complexity. Another factor that influences the coverage is the satellite inclination angle (the angle between the Earth's equatorial plane and the actual plane(s) of the orbit(s) of the satellite(s)). The larger the inclination, the more the coverage, with high elevation angles, is concentrated to higher latitudes.

Low Earth orbit MSS systems such as Iridium, Globalstar and Orbcomm have orbital altitudes between approximately 700 km and 1400 km, and have design lives of about 7 years. Other non-GSO MSS systems such as ICO have opted for medium Earth orbits, basing the constellation on an altitude of around 10400 km and have obtained a design life of about 12 years.

4.4 Interworking with terrestrial networks

To connect the MSS satellite network with the terrestrial network a certain level of interworking or interface components installed at the feeder link or gateway earth station (and the terrestrial network) will be required – depending upon which particular terrestrial network the MSS system needs to be connected with.

4.4.1 Gateway earth station and its operation and management

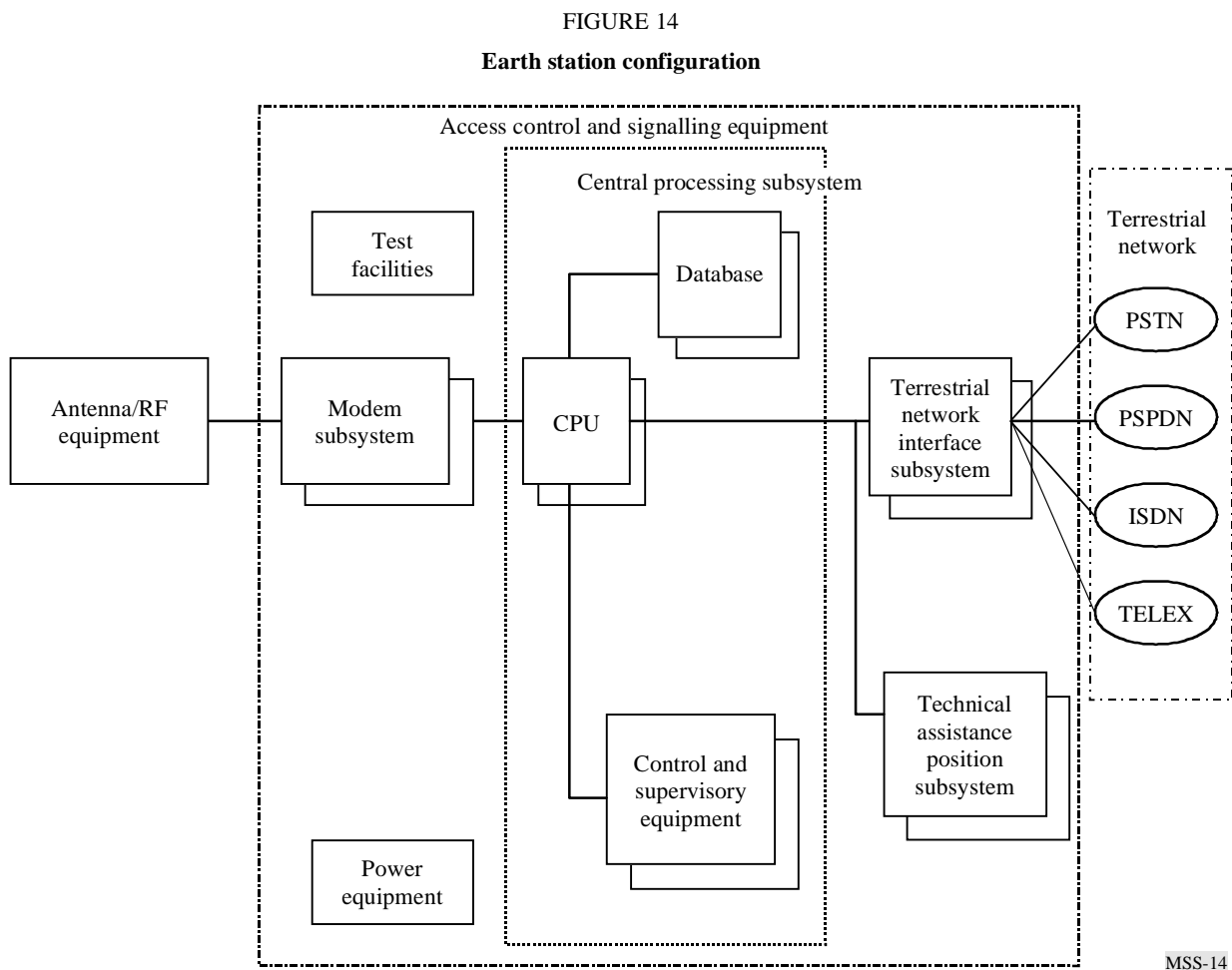
4.4.1.1 General

Gateway earth station equipment generally consists of seven categories of specific functions, as follows:

- the antenna system (including tracking and servo systems);
- RF wideband equipment (including the transmitters and low noise receivers);
- IF equipment (including the modulators, demodulators and frequency conversion);

- access control and signalling equipment (including host computer and database);
- terminal equipment (including baseband, multiplexing and microwave link equipment);
- power equipment and facilities;
- control and supervisory equipment and test facilities.

Figure 14 shows a typical configuration of a gateway earth station.



Operations and maintenance at the earth station requires the specialized knowledge and skill which are dedicated to MSS.

4.4.1.2 Maintenance arrangements

4.4.1.2.1 Maintenance philosophy and spares provision

The main responsibility of maintenance staff at an MSS earth station is the following:

- repair of faulty units;
- management of the database;
- verification and update of software;
- periodic maintenance.

a) *Repair of faulty units*

The following steps are expected for the repair of a faulty unit:

Step 1: On-site diagnostic testing and specify the faulty components.

Step 2: Replacement of the faulty components.

Step 3: Repair of faulty unit.

At each step of the above, the repair philosophies can be selected between the work by manufacturer and by earth station staff. The appropriate repair philosophies may be different depending on the expertise necessary and the test equipment requirements.

The factors which will influence the choice of repair philosophy for a particular item equipment are:

- reliability;
- technical complexity and the possibility to affect the service;
- availability of staff with the required skills to undertake repair;
- type, number and cost of spares;
- necessary test equipment and documentation.

b) *Management of the database*

The earth station staff is required to manage several database tables as a part of maintenance work. The maintenance staff is required to manage these databases. An example of the tables is the following:

- The list of mobile terminals.
- The list of special access codes.
- Country code tables.
- The list of registered users.
- Journal and billing data.

The list of mobile terminals includes several status indications of each mobile terminal such as busy/idle, commissioning status and so on. If the new terminal is registered to the network, an earth station staff would be required to input the information to the database.

In some networks, the list of special access codes is used to call for support desk, rescue coordination centres and so on. The special access code is not used only for routing to special numbers but for routing to value-added services by the earth station.

Earth station has a country code table for the routing of international calls. The list of registered users for the special services would be maintained by the earth station. The earth station often produces journal/billing data.

c) *Verification and update of software*

An earth station for MSS includes the software program in the access control and signalling equipment (ACSE) and/or channel unit, for the assignment and signalling. When such software is updated, earth station staff are expected to work on the testing and update of the software.

If the new software does not work appropriately, the service may suffer critical damage. A small debugging system can avoid such problems.

d) *Periodic maintenance*

Earth station operators are required to perform periodic maintenance and calibration of equipment in order to keep service performance at a good level. The host computer for the ACSE would be maintained by manufacturer staff while earth station staff would be able to maintain radio equipment, terrestrial interface, test equipment and so on.

4.4.1.2.2 Test equipment

Several types of test equipment are required at a satellite earth station for the maintenance work. The network provider of the satellite telecommunication (e.g., Inmarsat, Iridium and ICO) normally issues an operation handbook for satellite earth stations. The range and type of test equipment required at a satellite earth station will be set out in the handbook.

When considering the provision of test equipment different from that recommended, the need for compatibility is important. Other significant factors are ease of operation and the ease with which repair and calibration can be undertaken.

It is strongly recommended that test equipment for particular purposes be standardized throughout an administration's earth stations.

Facilities for the repair and calibration of test equipment are essential. These may be provided through local or regional workshops/laboratories or by arrangement with the test equipment manufacturer or his agents.

4.4.1.2.3 Performance factors

Earth-station operators require constant surveillance if the overall performance is to be maintained at an appropriate level.

Given that appropriate data is recorded on a routine basis, the adequacy of plant capacity and maintenance arrangements are constantly monitored; this permits timely management decisions in order to guarantee the appropriate station efficiency.

4.4.1.3 Operation philosophy and arrangements

4.4.1.3.1 Operation philosophy

The main responsibility of operations staff at an MSS earth station is the following:

– *Handling GMDSS communication*

Many MSS earth stations handle distress/urgent/safety communications and they will be connected to a rescue coordination centre. In some administrations, operations staff would be required to monitor such communication and re-connect if the automatic routing fails.

– *Commissioning test*

In some systems (e.g. Inmarsat-A system), operations staff are required to support commissioning tests of the mobile terminal. In such a case, they will arrange a test schedule and perform the test with the mobile terminal user.

– *Technical assistance*

Operations staff of MSS earth stations are required to provide technical assistance for the end user at the mobile terminal. Connection by special access code is very convenient.

– *Barring and unbarring*

In case the customer did not pay for the communications, operations staff would need to proceed to a barring function if required. Operations staff would be required to unbar the communications once this abnormal situation is corrected.

4.4.2 Connections with the telephone and data network

Typically, since the satellite transmission protocols are unique to the MSS network or even to the particular terminal type requiring interconnection, a particular device for mediating between the satellite protocol and the terrestrial protocol is required as one of the suite of earth station equipment.

a) *Connection with the public switched telephone network*

In MSS systems such as Inmarsat, a unique satellite protocol and a voice codec module are adopted for each system (Inmarsat-A, -B, -M, -Mini-M, -Aero, etc.). In this respect, Inmarsat coast earth stations usually have the interface devices for the satellite network and for the appropriate terrestrial network(s). A subsystem known as the “satellite interface component” will then have several kinds of satellite interfaces for voice, fax, and data, etc. The corresponding subsystem known as the “terrestrial interface component” will convert data into the appropriate terrestrial signalling protocol; e.g., Signalling System No. 5 or No. 7.

b) *Connection with ISDN*

Recently, some services of MSS systems have been upgraded to meet the customer's needs for high-speed data transmission; for example, for information rates as high as 64 kbit/s or even higher. When these high-speed data services are going to be provided by the satellite link, an ISDN interface for the terrestrial is often required at the earth station of the MSS system involved. A typical connection model for connecting with ISDN as the terrestrial network would be similar to the subsystems described above. However, in this case, the terrestrial interface component would have the function of handling the ISDN signalling protocol. Alternatively, if the terrestrial interface component is not so equipped, an inter-working unit (IWU) could be inserted between the terrestrial interface component which is PSTN-equipped and the ISDN network – to convert PSTN protocol into ISDN protocol and vice versa.

c) *Connection with PSPDN*

If PSPDN is adopted for the terrestrial link, an earth station of the MSS system often reassembles the packet data received from mobile terminals. As such it then delivers the messages through PSPDN with the required format, and vice versa. A typical earth station configuration would be similar to that required for connection with the PSTN, but in this case, the processing at the earth station between the satellite interface component and the terrestrial interface component (a so called “central processing component”) may be required to have a function to reassemble the data; and, the terrestrial interface component may need to have a protocol conversion unit for X.25 or X.75.

d) *Connection with Internet*

IP packet transmission has become one of the major applications in recent communication networks. In some MSS systems, IP packet transmission is already in service or under development. Making use of relatively high speed digital mobile satellite links, such MSS systems provide capability of IP packet transmission, where some adaptation is generally needed to accommodate IP packets in the digital frame format of the mobile satellite link. It is also possible to share a mobile satellite link by several connection of IP packet stream to different destinations. The baseband interface unit at a gateway earth station should have such adaptation functions. This interface function enables interconnection of mobile satellite links to terrestrial internet via a router at the gateway earth station.

4.4.3 Connections with terrestrial mobile systems (e.g. IMT-2000)

The design of IMT-2000 recognizes that, while achieving compatibility, commonality, and inter-working, the terrestrial and satellite components may be considered to be independent of each other for operational resources; and, similarly, is independent of the fixed networks. Additionally, IMT-2000 satellite systems may be designed to create satellite extensions to terrestrial networks, thus extending the area over which a network with IMT-2000 functionality can directly provide service. There are probably three different deployment scenarios envisaged for the satellite component of IMT-2000 at this time. The reader is referred to more detailed explanations of this in the ITU-R Recommendations, such as Recommendation ITU-R M.817 and working documents of WP 8F.

4.5 MSS system engineering principles

4.5.1 Satellite antenna coverage and beam patterns

Satellite antenna design is one of the most specialized areas of spacecraft technology and is a highly important aspect of the payload subsystems of both FSS and MSS satellites, mainly due to limitations of available spectrum, the increase in capacity needs of users of satellites and, of course, the current congestion situation associated with use of the geostationary orbit. Advanced antenna technology can enable increased frequency re-use by means of orthogonal polarization or spatial beam-to-beam discrimination. While it is beyond the scope of this Handbook to delve into satellite antenna design theory, it is sufficient to point out certain key characteristics of satellite antennas which may affect performance within a given MSS network as well as the ability to reduce a MSS network's vulnerability to interference from other MSS systems.

The most important characteristics of a satellite antenna are:

- coverage contour (beam configuration);
- pattern shape and side-lobe levels;
- polarization purity;
- power-handling ability;
- RF sensing capability (if any).

Coverage

The coverage area, as seen from the satellite, is usually defined by iso-gain or iso-e.i.r.p. contours. On the early MSS satellites, as well as FSS satellites, the satellite antennas were formed by a reflector fed by circular feed horns – usually “global horns,” feed horns which are cut such that they would illuminate the Earth in a conical beam approximating the angle subtended by the Earth at the satellite (in GSO), $\sim 17.3^\circ$, thus generating a so called global-beam.

However, it is clearly inefficient to illuminate areas of the Earth that are outside the customers to be served, therefore, recent satellites have employed shaped beam antennas which radiate within the service area contours and minimize spilling RF energy into areas outside the service area. When shaped beams are employed on the receive side of the satellite (uplink) it is possible to reduce the earth station uplink power requirement and hence the cost of the earth stations.

Pattern shape and side-lobe level

While not specified in the RR, except for the case of direct broadcast satellites, in Appendix 30, the use of “fast” roll-off of side-lobe levels reduces the levels of interference on satellite downlinks to adjacent satellite systems and lowers the vulnerability of a given system to interference from the earth stations of adjacent satellite networks.

Polarization purity and frequency re-use

The limitations on available spectrum for MSS, as well as for FSS bands used by MSS feeder links and the congestion of the geostationary orbit result in an increasing need for frequency re-use by means of polarization discrimination. Such re-use can normally only be obtained within the feeder link portions of MSS systems, due to inadequate polarization purity on mobile-satellite earth station antennas. Either orthogonal circular polarization or linear (vertical vs horizontal) polarization can be used. Polarization isolations of around 27 dB or more can be obtained with carefully designed feeder link satellite antennas.

Beam (spatial) discrimination

When the service areas can be covered by well isolated beams like the different spot beams of the Inmarsat-III satellites, two well-separated beams can use the same frequency bands. Two networks coordinating their use of the same MSS frequency band may also be able to operate co-channel over a portion of their tuning range, if their respective spot beams do not overlap and if they cover regions of the Earth which are well separated.

Power-handling ability

Successive generations of the MSS networks radiate higher and higher e.i.r.p.s. This evolution places increasing demands on the designs of the feed systems in the areas of thermal control and suppression of intermodulation products.

RF sensing capability

Although more pertinent to FSS national systems, it is possible, for cases where the satellite antenna beamwidth is small, for an MSS satellite to employ an RF sensing system that tracks a ground-based beacon, which is then used to correct automatically any deviation in beam direction. This system is analogous to mono-pulse tracking systems sometimes used on earth station antennas, which employ four feed horns to generate the sum and difference patterns to steer the antenna main beam towards a satellite radiated beacon signal.

Direct radiating antennas and/or phased-arrays

Recent advances in technology have made it possible to construct a phased-array antenna which is composed of a group of individual radiators or feed-horns which are distributed in such a way (generally in a two-dimensional polygon) so as to illuminate a single reflector system; or, they can be used in a direct radiating mode, a so called direct radiating antenna (DRA). The latter design is employed in the ICO MSS spacecraft to generate 163 spot beams (with 127 feed elements). The amplitude and phase excitation of each radiator of the DRA can be individually controlled to form a radiated beam of practically any desired shape; or, the position of the beam in space may be controlled electronically by adjusting the phase of the excitation at individual radiators. Hence, beam scanning is accomplished with the antenna reflector/feed system remaining physically fixed. Beam reconfiguration is also a possibility with a DRA. In this case, the beam shape may be modified via commanding a new set of amplitude and phase excitations. That set of excitations may be fixed for a period of time and then reset at a later time – for example, over different periods of an orbit.

Importance of satellite antenna in inter-system sharing and frequency usage

There are only a limited number of ways by which one MSS satellite network can discriminate against, or isolate itself from, co-channel or adjacent channel interfering signals from another satellite network sufficiently in order to achieve its interference objective:

- using the directivity of the receiving/transmitting *satellite* antennas;
- using the directivity of the transmitting/receiving earth station antennas;
- using opposite polarization on the wanted and interfering channels;
- interleaving channels to avoid full, co-channel operation.

The extent to which each of these four mechanisms can be used to provide part or all of the necessary inter-system isolation depends on the size and the design of the earth and space station antennas, the orbital positions (i.e., in the GSO) and the geographical coverage of the satellites in the two systems, the extent to which each of the mechanisms might already be employed to re-use frequencies within the individual MSS networks, and on cost and operational factors.

4.5.2 Carrier modulation and multiple access techniques

4.5.2.1 Carrier modulation

Operational conditions of mobile satellite links include various limitations and impairment factors which are inherent to mobile satellite systems. Analog modulation was first employed for voice transmission by mobile satellite systems of early generations. Digital transmission systems were then developed for better transmission performance. Digital modulation was newly introduced in combination with error correction schemes. This section provides an overview of carrier modulation and coding techniques with special attention to operational characteristics of mobile-satellite systems.

4.5.2.1.1 Characteristics of mobile satellite links

Transmission over a mobile satellite link involves various factors inherent to mobile satellite systems. Typical characteristics of mobile satellite links include the following factors that shall be taken into consideration for selection of modulation and coding schemes and link design.

a) *Propagation conditions*

Mobile earth stations shall be operated in various conditions of propagation in mobile satellite systems. In particular, in maritime and aeronautical mobile satellite systems, multi-path fading due to sea surface reflection is a typical factor in transmission conditions. The combination of a direct propagation path and multiple reflection paths is generally modelled as “Nakagami-Rice fading” which is different from “Raleigh fading” in land mobile systems.

Pointing error should also be taken into consideration when a directional antenna is employed for a mobile earth station, in particular for ship-borne or air-borne terminals. There may also exist pointing error in operation of a portable mobile earth station.

The effect of shadowing is another factor to be considered for the land mobile earth station. In the environment of the land mobile earth station, there is no guarantee of direct visibility toward a geostationary or non-geostationary satellite due to blocking by buildings or shadowing by foliage. Blocking by buildings will cause short disruption of a link, while light shadowing by foliage may give rise to fading of considerable attenuation.

Taking account of these impairment factors in propagation, the system design should employ modulation and coding schemes which are robust enough and the link design has to reserve a sufficient margin to attain the required availability.

b) *Power limitation and non-linearity*

Mobile earth stations have to operate under many limitations. Antenna size is generally small to guarantee operation in mobile conditions. This results in low G/T giving a severe impact on link design. Transmit power of mobile earth stations is limited, in particular for hand-held terminals to protect users from RF radiation and due to limitation of battery power supply.

It is desirable to increase satellite transmit power so as to overcome the low G/T of mobile earth stations. Use of spot beam satellite antennas or large deployable antennas will contribute to increase the satellite e.i.r.p. Within a limited satellite power supply, a high power amplifier is expected to have higher output power. Non-linearity then becomes a problem when such high power amplifiers are operated with a small back-off, close to saturation. Intermodulation due to non-linearity is one of the dominant impairment factors for common amplification of single channel per carrier (SCPC) carriers under constraints of power limitation.

Due to the aforementioned conditions, link design of mobile satellite systems is often power-limited. Use of error correction techniques is very useful in such circumstances. Adjustment of carrier frequency assignment is also effective to mitigate the effect of non-linearity in such a way that intermodulation products fall in unused frequency slots.

c) *Doppler shift*

Doppler shift is another typical factor in mobile satellite systems. In aeronautical mobile satellite systems, movement of air-borne earth stations at high velocity gives rise to doppler shifts even in a geostationary satellite system. In the case of non-geostationary systems, doppler shift is inevitable due to movement of the satellites. The effect of doppler shift is generally not negligible for stable operation of demodulators. In these cases, the effect of doppler shift is so large that AFC (automatic frequency control) to cover a wider range of frequency offset is needed.

4.5.2.1.2 Analog modulation

Analog modulation was first employed for voice transmission in early generation mobile satellite systems. Frequency modulation (FM) was a commonly used modulation scheme. For transmission of a voice channel, narrow-band FM was suitable for modulation of a single carrier. For example, Standard-A of INMARSAT employs SCPC/FM for telephony services. In combination with narrow-band FM transmission, syllabic companding was sometimes employed to enhance the S/N ratio of the baseband voice circuit.

Table 5 shows typical parameters of SCPC/FM carrier in an example of Inmarsat-A.

TABLE 5
Example parameters of SCPC/FM

Baseband frequency	0.3-3.0 kHz
Maximum frequency deviation	12 kHz
Carrier spacing	25 kHz
Syllabic compandor	2:1 (ITU-T Rec. G.162)
Baseband <i>S/N</i>	46 dB

NOTE – Parameters of Inmarsat-A.

4.5.2.1.3 Digital modulation

Current generation mobile satellite systems generally employ digital modulation which has better performance in efficient frequency band usage and transmission power saving. Despite the aforementioned various transmission impairment factors, it is possible to use digital modulation schemes in mobile satellite systems. Phase shift keying is the most commonly used modulation scheme in mobile satellite systems. Binary phase shift keying (BPSK) is used when a mobile satellite link has a severe power-limited condition. QPSK is more frequently used and it is considered to be more effective in the transmission environment involving non-linearity and bandwidth limitation. Types of QPSK often employed in mobile satellite systems include $\pi/4$ shifted QPSK and offset QPSK. Offset QPSK has different keying timing in the *I* and *Q* channels, in such a way that the keying timing is half a symbol delayed from each other. In $\pi/4$ shifted QPSK, 2 bits of information are mapped on phase shifts of $\pm\pi/4$ or $\pm3\pi/4$. These modulation schemes are able to avoid a phase shift as large as π at any keying timing. It is then possible to reduce envelope fluctuation, which is preferable in the above-mentioned transmission environment.

Table 6 shows typical examples of digital modulation with essential parameters.

TABLE 6
Examples of digital carriers

	Bit rate	Example system
BPSK	1 200 bit/s	Inmarsat-A, TDM carrier
	4 800 bit/s	Inmarsat-A, TDMA carrier
	1 200 bit/s	Inmarsat-C
QPSK	56/64 kbit/s	Inmarsat-A-HSD
	50 kbit/s	System A, Rec. ITU-R M.1184-1, Table 4a
	36 kbit/s	System F, Rec. ITU-R M.1184-1, Table 4a
Offset QPSK	24 kbit/s	Inmarsat-B
	21 kbit/s	Inmarsat aeronautical
	8 kbit/s	Inmarsat-M
$\pi/4$ shifted QPSK	14 kbit/s	N-Star

4.5.2.1.4 Coding for error correction

It is generally not easy in mobile satellite systems to ensure a sufficiently high carrier-to-noise power ratio (C/N) in link design due to the various factors as described above. In such a situation, application of error correcting codes is a very powerful means to improve bit error performance in digital transmission.

The most commonly used error correcting codes include convolutional codes of rate 1/2 and 3/4. Since redundant bits are added, transmission rate increases in error correction coding. Rate 1/2 coding requires doubled transmission rate because the same number of redundant bits are added to the original information bit sequence. Rate 1/2 convolutional code provides better improvement of bit error performance than rate 3/4 code, though rate 1/2 code needs a larger increase in transmission rate. Punctured convolutional codes which are derived from conventional convolutional codes are more efficient. A punctured convolutional code derived from a rate 1/2 convolutional code is capable of attaining equally powerful error correction with a smaller increase in transmission rate than the rate 1/2 code.

Viterbi decoding is the means of decoding convolutional codes. The performance of Viterbi decoding can be further improved by “soft decision”, which makes use of multiple level detection output rather than binary (0 or 1) detection output.

These error-correcting codes are less powerful for burst errors. To mitigate degradation by burst errors, bit interleaving is a powerful means. A bit interleaver re-orders the bit sequence to distribute a series of burst errors to make them look like random errors.

Typical examples of error correction coding in mobile satellite systems are summarized in Table 7.

TABLE 7

Examples of error-correcting codes

Rate 1/2 convolutional code	Inmarsat-B, signalling channel Inmarsat-C Inmarsat aeronautical
Rate 3/4 punctured convolutional code	Inmarsat-B, voice channel

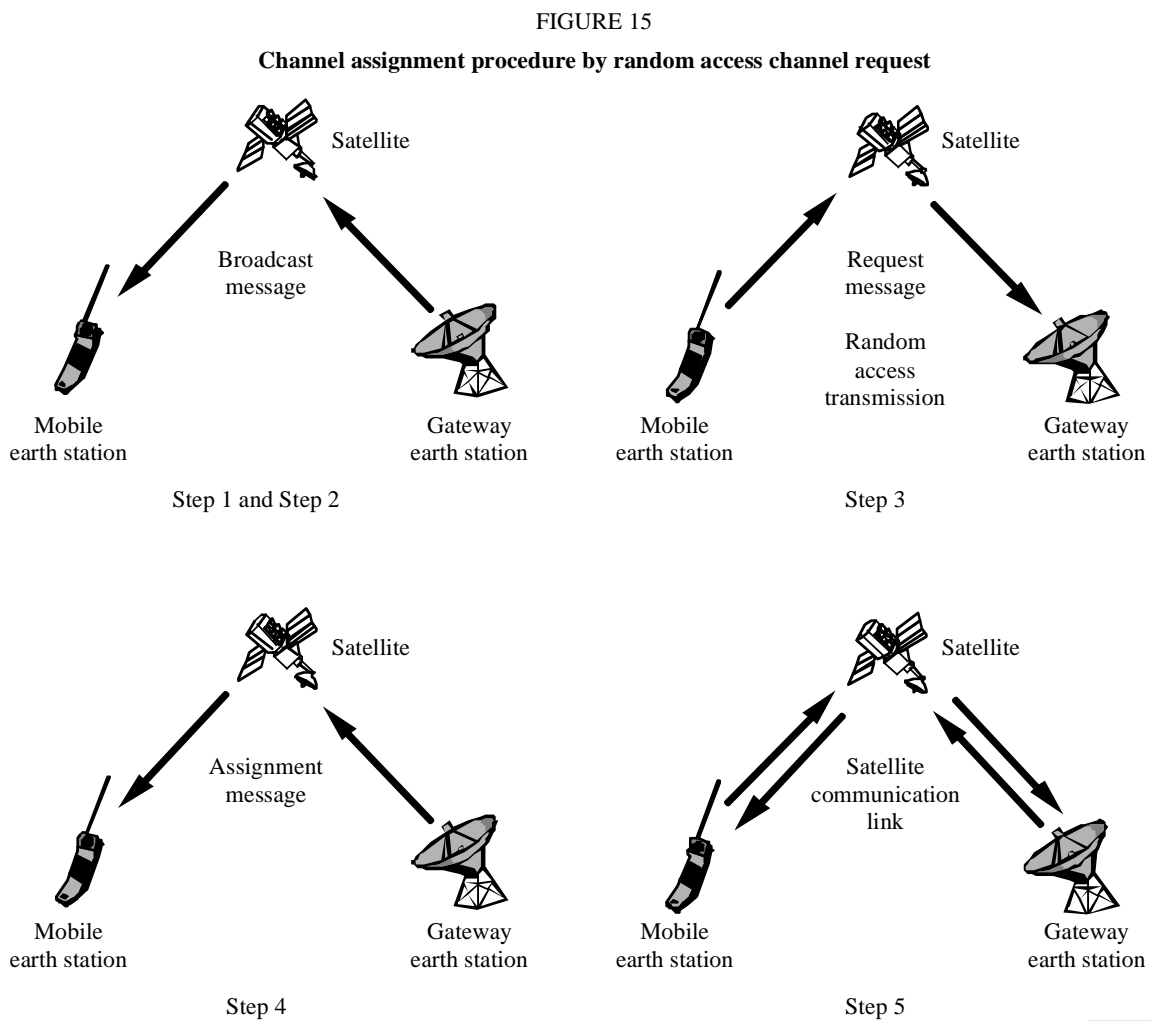
4.5.2.2 Multiple access schemes

Mobile satellite systems are generally operated on a demand-assignment basis to provide services to a large number of mobile earth stations with limited capacity of satellite transponders. Various multiple access techniques are used to share the satellite transponder by a number of mobile earth stations. The multiple access methods used in mobile satellite systems include frequency division multiple access (FDMA), time division multiple access (TDMA) and code division multiple access (CDMA) to accommodate multiple satellite links toward a number of mobile terminals.

Demand-assignment multiple access (DAMA) requires a mechanism for requesting a satellite channel and informing the requesting mobile earth station of the channel assignment. For channel request, mobile earth stations send a request message on a random access basis. Random access control such as ALOHA is therefore employed for request message transmission.

4.5.2.2.1 Random access channels for demand assignment multiple access

Mobile satellite systems generally accommodate a large number of mobile earth stations which establish a satellite link on a request basis. The procedure described in § 4.1.3.4 shows a basic concept of on-demand channel assignment control which involves random access request channel operation. Figure 15 illustrates the concept of this procedure.

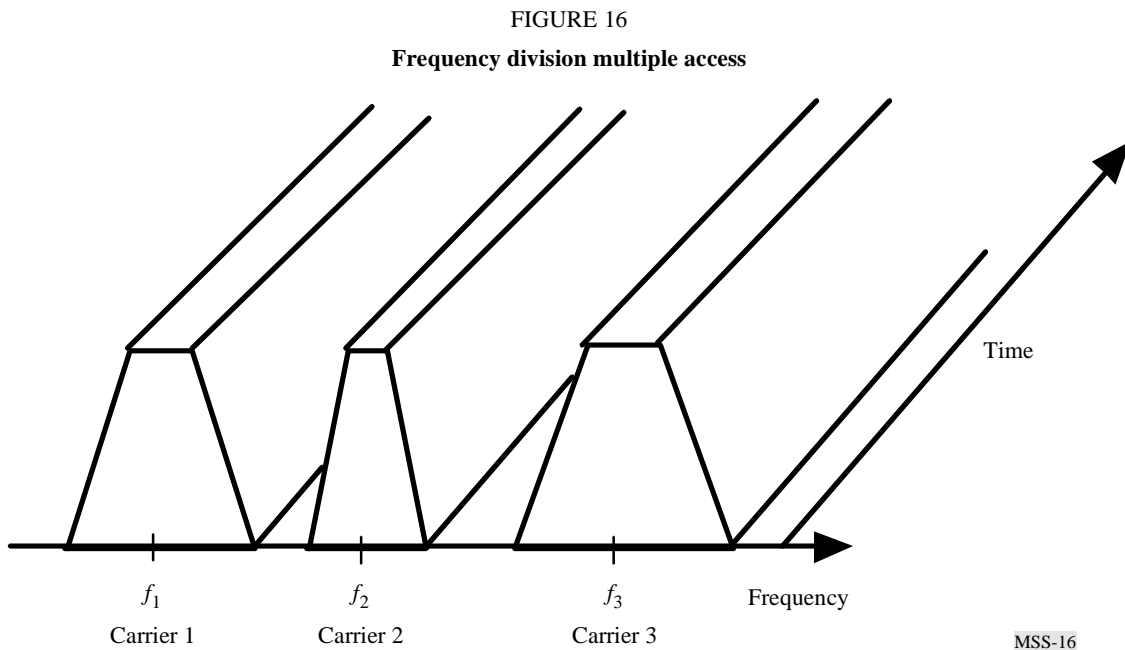


MSS-15

In Step 3, the request message is sent by a random access scheme like pure ALOHA or slotted ALOHA. The random access transmission is successful if the message is received without any contention. If collision occurs, the mobile earth station retransmits the same message again after an appropriate interval. Since transmission of a request message is generally not frequent, collision does not occur so often – even by random access from a number of mobile terminals.

4.5.2.2.2 Frequency division multiple access

Frequency division multiple access (FDMA) is one of the most commonly used multiple access schemes in satellite communication systems. As shown in Fig. 16, the frequency band of a satellite transponder is divided into a number of frequency slots, each of which is used to assign a transmission carrier for a satellite link between a gateway earth station and a mobile earth station. SCPC is an example of FDMA when each carrier accommodates a single satellite channel.



FDMA allows small carriers of a low transmission rate, which are beneficial to mobile earth stations with small transmit power. On the other hand, common amplification of multiple carriers may give rise to intermodulation due to non-linearity when the satellite transponder is operated near saturation. Careful carrier frequency assignment is necessary in such a case to avoid intermodulation products falling into operating carriers.

In the case of FDMA, it is possible to introduce an interference avoidance scheme like DCAAS (dynamic channel activity assignment system). When a mobile satellite system is operating in a frequency band shared with another system like a terrestrial mobile network, it is necessary for the mobile satellite system to avoid the use of a frequency channel used by the other network. Monitoring the frequency spectrum, the mobile satellite system investigates a number of frequency slots and assigns a frequency channel which is not currently used by the other network.

Example systems of FDMA are given in Table 8.

TABLE 8

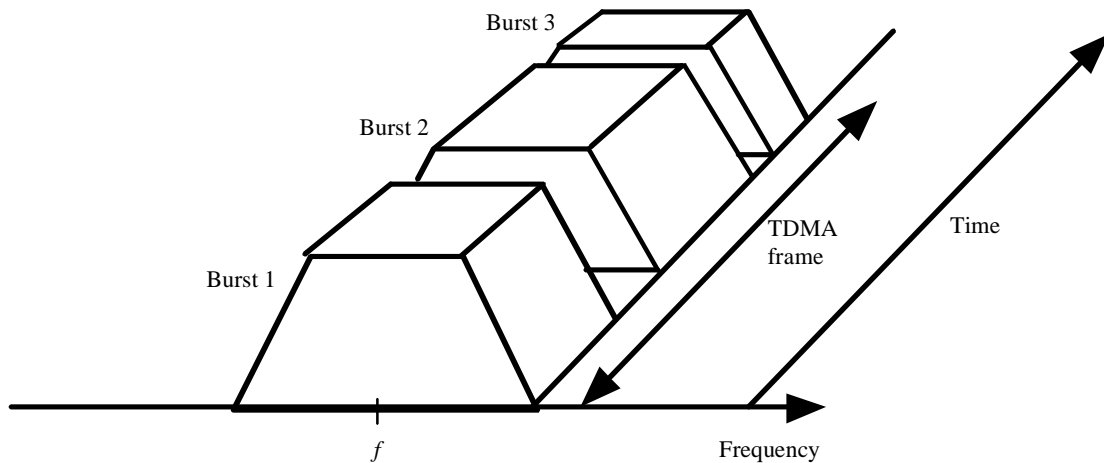
Example systems of FDMA – Inmarsat GSO systems – (Rec. ITU-R M.1184)

Standard	A	B	M	Aeronautical
Channel data rate	N.A. (Analog)	24 kbit/s	8 kbit/s	21 kbit/s
Modulation	FM	OQPSK	OQPSK	OQPSK
Channel spacing	50 kHz (25 kHz actual)	20 kHz	10 kHz	17.5 kHz

4.5.2.2.3 Time division multiple access

Time division multiple access (TDMA) is another common multiple access method in digital transmission systems. As shown in Fig. 17, a frame of given period is divided into multiple time slots for a carrier that has sufficient capacity to accommodate multiple satellite channels. Each time slot is used to provide a satellite channel between a gateway earth station and a mobile earth station.

FIGURE 17
Time division multiple access



MSS-17

It is possible in TDMA to reduce the number of carriers per satellite transponder. A flexible operation is another advantage of TDMA because the transmission channel capacity, for example, can be easily doubled when using two time slots per frame. On the other hand, carrier transmission rate in TDMA becomes higher even for a mobile earth station requiring small capacity.

TDMA is suitable for regenerative type satellite transponder operation and inter-satellite link operation.

Example systems of TDMA are given in Table 9.

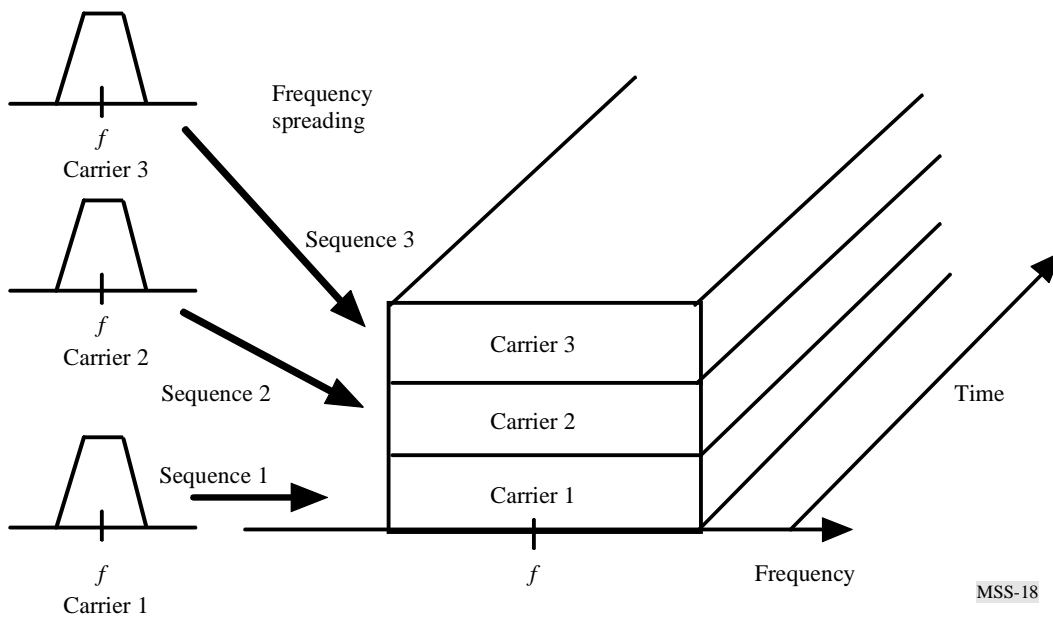
TABLE 9
Example systems of TDMA – (Rec. ITU-R M.1184-1, Table 4a)

Example system	System A	System F
Modulation	QPSK	QPSK
Duplex scheme	TDD	FDD
Bit rate	50 kbit/s	36 kbit/s
Bandwidth	31.5 kHz	25 kHz
Frame length	90 ms	40 ms

4.5.2.2.4 Code division multiple access

Code division multiple access (CDMA) is a new multiple access scheme in mobile satellite systems. As shown in Fig. 18, a different spreading sequence is applied for each digital carrier to generate a carrier of wider bandwidth and the generated wide carriers share the same frequency band in a transmission link. The spreading sequence is designed in such a way that each carrier can be separated by de-spreading, even after mixed transmission with other carriers. All the CDMA carriers are generated by spreading sequence which is different from each other by orthogonal property. Owing to the orthogonal property, each spreading code has correlation with itself only. A desired signal can therefore be separated from other carriers by using its original spreading sequence for de-spreading.

FIGURE 18
Code division multiple access



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Spread spectrum transmission lowers power spectral density per carrier. CDMA is also robust against narrow-band interference. Security is also considered to be better in CDMA.

Example systems of CDMA are given in Table 10.

TABLE 10
Example system of CDMA – (Rec. ITU-R M.1184-1, Table 4a)

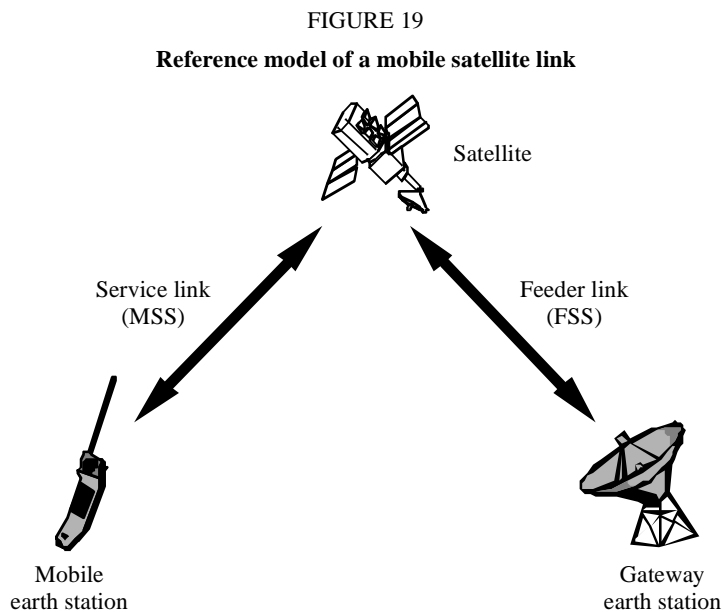
Example system	System D
Modulation	QPSK
Duplex scheme	FDD
Chip rate	1.2288 Mchip/s
RF bandwidth	1.2 MHz

4.5.3 Link design

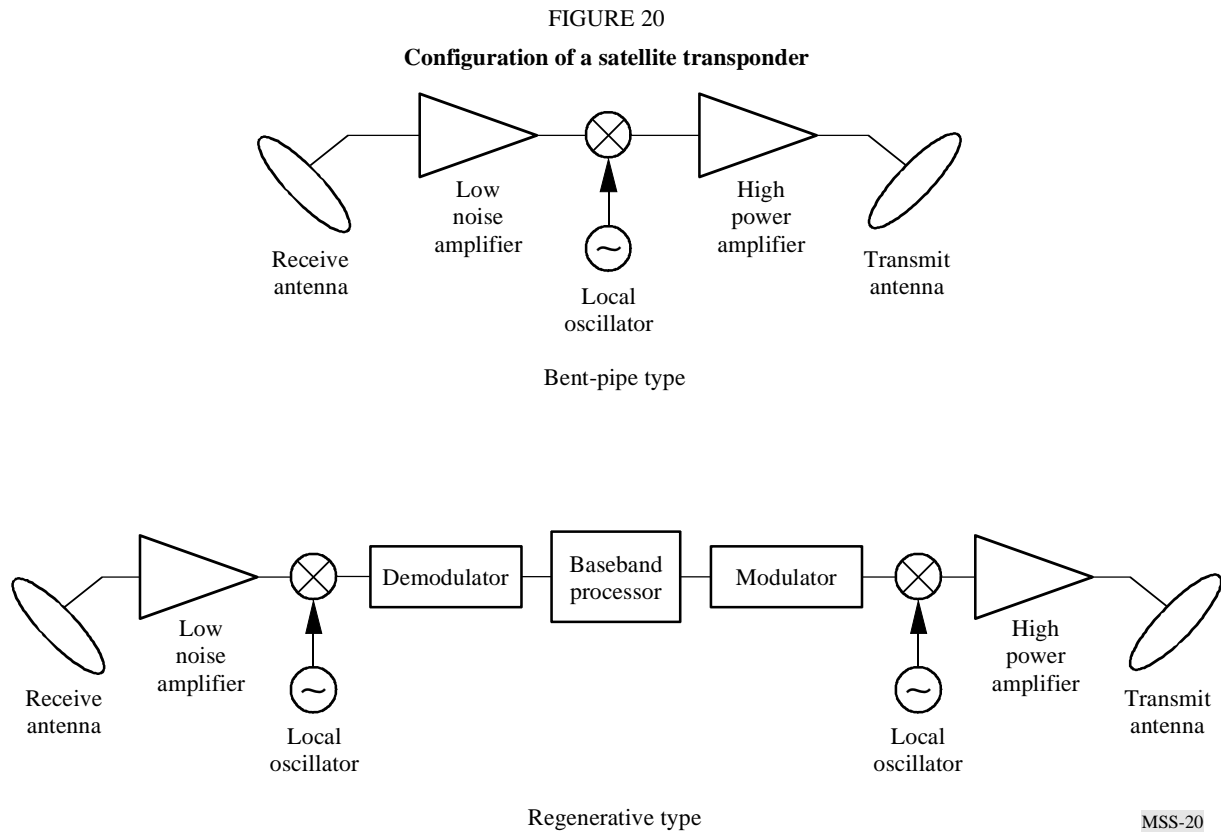
Link design of mobile satellite systems has to be carefully conducted under various limitations as mentioned before. This section is intended to describe the basic engineering concept of the link design approach with particular attention paid to configuration and operational conditions of mobile satellite systems.

4.5.3.1 Configuration of a mobile satellite link

A mobile satellite link is a connection between a gateway earth station and a mobile earth station via satellite. Recommendations ITU-R M.546 and ITU-R M.827 provide a hypothetical reference circuit model for mobile satellite links. As shown in Fig. 19, the part of the mobile-satellite link between the gateway earth station and the satellite is called a feeder link. For both geostationary and non-geostationary satellites, the feeder link is categorized as part of the fixed-satellite service (FSS) because the gateway earth station is a fixed radio station. The other part of the mobile satellite link between the satellite and the mobile earth station is referred to as a service link. The service link falls under the category of mobile satellite service (MSS) because the mobile earth station is a mobile radio station.



There are two types of mobile-satellite link; a bent-pipe link and a regenerative type. Figure 20 shows the configuration of these two types. A bent-pipe link is a commonly used satellite link where a satellite transponder simply converts the uplink radio frequency into a downlink radio frequency with power amplification for the downlink. On the other hand, the regenerative type provides demodulation/modulation capability onboard the satellite transponder. The uplink signal received at the satellite is demodulated and baseband signal processing is available at the satellite, providing flexible functions such as switching and routing. The downlink signal is generated by an onboard modulator after baseband signal processing.



For regenerative type systems, link design can be separately conducted for the uplink and downlink because link degradation factors are decoupled between the uplink and downlink by onboard demodulation/modulation. Bent-pipe systems require a link design for the entire link involving both uplink and downlink. C/N for the bent-pipe mobile satellite link is derived from uplink C/N and downlink C/N as follows.

$$(C/N)^{-1} = (C/N_{\uparrow})^{-1} + (C/N_{\downarrow})^{-1}$$

Advanced mobile satellite systems include inter-satellite links to establish a direct connection between satellites. For instance, inter-satellite links can provide a connection from a satellite to neighbouring satellites in a constellation of non-geostationary satellites. Inter-satellite links are beneficial to reduce the number of satellite hops when Earth coverage of each satellite is limited. Inter-satellite links are implemented usually with regenerative satellite systems mainly due to the flexible connection to inter-satellite links at the satellite.

4.5.3.2 Link design for mobile satellite systems

a) *Constraints in MSS link design*

Link design for mobile satellite systems has various constraints which are inherent in MSS. The following conditions are major limitations in MSS link design.

- e.i.r.p. of the mobile earth station is limited.
- G/T of the mobile earth station is low.
- A large margin is needed to overcome various degradation factors such as antenna pointing error of the mobile terminal, multi-path fading, fading due to light shadowing and so on.

Satellite e.i.r.p. and G/T have been improved in recent satellites but they still provide some constraints in link design. Intermodulation products may have an impact on link design of some MSS systems employing common amplification of multiple carriers by a non-linear satellite transponder.

In general, co-channel frequency sharing with other services is not so common in the frequency bands for MSS operation. Co-channel interference does not affect MSS link design in many cases. On the other hand, the receive level of mobile earth stations is so low that sufficient protection is required from out-band emissions of high power transmitters of other services in the adjacent bands.

b) *Criteria for MSS link design*

Link design has to satisfy various performance criteria to attain the required transmission quality under various constraints. In general, threshold transmission quality is first given. In digital transmission, the threshold bit error rate (BER) is determined, for example, to be 10^{-2} . The performance objective is then given in such a way that the BER of the link shall be better than the threshold at least for a given percentage of time, say 99% of the time.

Given a threshold BER, the threshold C/N is first derived by referring to the BER vs. C/N curve of the modulation technique employed. It should be noted here that improvement by error correction has to be taken into consideration. In order to meet the performance objective, it is necessary to reserve a sufficiently large margin against various degradation factors such as antenna pointing error and fading. Some statistical data is needed here, such as the cumulative distribution of fading. Referring to such statistical data, a link designer can derive information such that the amount of fading is not larger than M dB for 99% of time. Then, the required C/N at a nominal operational condition is easily determined as follows:

$$(C/N)_{nominal} = (C/N)_{threshold} + M \quad \text{dB}$$

Thus the derived C/N at a nominal operational condition can guarantee a BER better than the threshold for a given percentage of time. Performance objectives and the methodology to derive performance objectives are detailed in many Recommendations such as ITU-R M.1181, ITU-R M.1037, ITU-R M.1229 and ITU-R M.1228.

Availability is another criterion in the link design. Mobile satellite links should be designed in such a way that those links are in an available condition for a given percentage of time. The definition of availability is given in Recommendations ITU-R M.828 and ITU-R M.1180.

In the case of bent-pipe systems, the service link places more severe conditions on the link design than the feeder link. In general, a larger margin has to be reserved for the service link in the overall link design. A larger percentage of time should also be allowed for unavailability on the service link.

4.5.3.3 Forward link design example

The forward link is a satellite link from the gateway earth station to the mobile earth station via the satellite.

Equipped with a large high power amplifier and a large antenna, the gateway earth station generally has a sufficiently large e.i.r.p. Therefore, the feeder link is generally stable except for 20/30 GHz feeder links which require a large margin for rain fade. The uplink C/N at a nominal condition, $(C/N)_{\uparrow}$ is determined as follows:

$$\begin{aligned}(C/N)_{\uparrow} &= (C/N_{th})_{\uparrow} + M_{\uparrow} && \text{dB} \\ &= e.i.r.p.gateway - L_{\uparrow} + G/T_{sat} - 10 \log k - 10 \log B\end{aligned}$$

where:

$(C/N_{th})_{\uparrow}$: threshold value of the uplink C/N of the feeder link

M_{\uparrow} : uplink margin for the feeder link

$e.i.r.p.gateway$: e.i.r.p. of the gateway earth station

L_{\uparrow} : propagation loss of the uplink at the feeder link frequency

G/T_{sat} : G/T of the satellite for the feeder link

k : Boltzman's constant

B : bandwidth of a carrier.

When we use the noise power spectrum density, N_0 , the carrier-to-noise power density ratio for the threshold value is obtained as follows:

$$\begin{aligned}(C/N_{0th})_{\uparrow} &= (C/N_0)_{\uparrow} - M_{\uparrow} && \text{dB} \\ &= e.i.r.p.gateway - L_{\uparrow} + G/T_{sat} - 10 \log k - M_{\uparrow}\end{aligned}$$

The downlink (\downarrow) is generally more critical due to the low G/T of mobile earth station. A larger margin is generally required for the service link to overcome various degradation factors as mentioned above. The C/N for the downlink is determined as follows:

$$\begin{aligned}(C/N)_{\downarrow} &= (C/N_{th})_{\downarrow} + M_{\downarrow} && \text{dB} \\ &= e.i.r.p.sat - L_{\downarrow} + G/T_{MES} - 10 \log k - 10 \log B\end{aligned}$$

where:

$(C/N_{th})_{\downarrow}$: threshold value of the downlink C/N of the service link

M_{\downarrow} : downlink margin for the service link

$e.i.r.p.sat$: e.i.r.p. of the satellite

L_{\downarrow} : propagation loss of the downlink at the service link frequency

G/T_{MES} : G/T of the mobile earth station.

When we use the noise power spectrum density, N_0 the carrier-to-noise power density ratio for the threshold value is obtained as follows:

$$\begin{aligned} (C/N_{0th})_{\downarrow} &= (C/N_0)_{\downarrow} - M_{\downarrow} \quad \text{dB} \\ &= e.i.r.p.sat - L_{\downarrow} + G/T_{MES} - 10 \log k - M_{\downarrow} \end{aligned}$$

C/N_0 for the entire forward link at the threshold level is now obtained as follows:

$$(C/N_{0th})^{-1} = (C/N_{0th})_{\uparrow}^{-1} + (C/N_{0th})_{\downarrow}^{-1}$$

In the case of the common amplification of multiple carriers by a non-linear satellite transponder, C/N_0 calculation at the threshold level has to take account of intermodulation noise as follows:

$$(C/N_{0th})^{-1} = (C/N_{0th})_{\uparrow}^{-1} + (C/IM_0)^{-1} + (C/N_{0th})_{\downarrow}^{-1}$$

where:

(C/IM_0) : carrier to intermodulation noise power density ratio.

A numerical example is given in Table 11.

TABLE 11

Example link design for forward link

Uplink frequency	6 GHz
<i>e.i.r.p.gateway</i>	52.0 dBW
L_{\uparrow}	201.3 dB
G/T_{sat}	-17.0 dB/K
M_{\uparrow}	1.0 dB
$C/N_{0\uparrow}$	61.3 dB(Hz)
C/IM_0	60.0 dB(Hz)
Downlink frequency	1.5 GHz
<i>e.i.r.p.sat</i>	17.5 dBW
L_{\downarrow}	188.6 dB
G/T_{MES}	-4.0 dB/K
M_{\downarrow}	5.0 dB
$C/N_{0\downarrow}$	48.5 dB(Hz)
C/N_0	48.0 dB(Hz)

4.5.3.4 Return link design example

The return link is a satellite link from the mobile earth station to the gateway earth station via the satellite.

A critical constraint of the uplink design is the limited e.i.r.p. of the mobile earth station. The downlink design is relatively easy owing to the high G/T of the feeder link gateway earth station. In a similar way, the carrier-to-noise power density ratio at a threshold level is derived for uplink and downlink as follows:

$$\begin{aligned} (C/N_{0th})_{\uparrow} &= (C/N_0)_{\uparrow} - M_{\uparrow} && \text{dB} \\ &= e.i.r.p.MES - L_{\uparrow} + G/T_{sat} - 10 \log k - M_{\uparrow} \\ (C/N_{0th})_{\downarrow} &= (C/N_0)_{\downarrow} - M_{\downarrow} && \text{dB} \\ &= e.i.r.p.sat - L_{\downarrow} + G/T_{gateway} - 10 \log k - M_{\downarrow} \end{aligned}$$

The overall C/N_0 for the return link including intermodulation noise is given as follows:

$$(C/N_{0th})^{-1} = (C/N_{0th})_{\uparrow}^{-1} + (C/IM_0)^{-1} + (C/N_{0th})_{\downarrow}^{-1}$$

A numerical example is given in Table 12.

TABLE 12

Example link design for return link

Uplink frequency	1.6 GHz
$e.i.r.p.MES$	30.0 dBW
L_{\uparrow}	190.3 dB
G/T_{sat}	-14.0 dB/K
M_{\uparrow}	5.0 dB
$C/N_{0\uparrow}$	49.3 dB(Hz)
C/IM_0	67.0 dB(Hz)
Downlink frequency	4 GHz
$e.i.r.p.sat$	-4.5 dBW
L_{\downarrow}	197.6 dB
$G/T_{gateway}$	29.0 dB/K
M_{\downarrow}	1.0 dB
$C/N_{0\downarrow}$	54.5 dB(Hz)
C/N_0	48.1 dB(Hz)

Bibliography

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List of acronyms commonly used in connection with MSS

ADS	Automatic dependent surveillance
AES	Aircraft earth station
AFC	Automatic frequency control
AGCH	Access grant channel
AMSS	Aeronautical mobile-satellite service
ATM	Air-traffic management system
BCCH	Broadcast channel
BER	Bit error rate
BOL	Beginning of life
BPSK	Binary phase shift keying
CDMA	Code division multiple access
CES	Coast earth station
<i>C/N</i>	Carrier-to-noise power ratio
CNS	Communications, navigation and surveillance
DAMA	Demand assigned multiple access
DCAAS	Dynamic channel activity assignment system
DRA	Direct radiating antenna
DSC	Digital selective calling
e.i.r.p.	Effective isotropic radiated power
ELT	Emergency locator transmitter
EPIRB	Emergency position indicating radio beacon
ESA	European Space Agency
FCC	Federal Communications Commission
FDD	Frequency division duplex
FDMA	Frequency division multiple access
FM	Frequency modulation
FOV	Field of view
FSS	Fixed-satellite service
GEO	Geostationary Earth orbit
GES	Gateway earth station
GLONASS	Global Navigation Satellite System
GMDSS	Global Maritime Distress and Safety Service

GMPCS	Global mobile personal communications by satellite
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GSO	Geostationary satellite orbit
<i>G/T</i>	Receiver gain to noise-temperature ratio
HF	High frequency
ICAO	International Civil Aviation Organization
IMCO	Inter-Governmental Maritime Consultative Committee
IMO	International Maritime Organization
IMT-2000	International Mobile Telecommunications-2000
INMARSAT	International Mobile Satellite Organization
INTELSAT	International Telecommunications Satellite Organization
IP	Internet protocol
ISDN	Integrated services digital network
IWU	Inter-working unit
LEO	Low Earth orbit
LES	Land earth station
LMSS	Land mobile-satellite service
MEO	Medium Earth orbit
MES	Mobile earth station
MF	Medium frequency
MMSS	Maritime mobile-satellite service
MoU	Memorandum of understanding
MSS	Mobile-satellite service
NASA	National Aeronautics and Space Administration
NCS	Network coordination station
NV	Non-voice
OQPSK	Offset quadrature phase shift keying
PC	Personal computer
PSTN	Public switched telephone network
PSPDN	Public switched packet data network
QoS	Quality of service
QPSK	Quadrature phase shift keying

RACH	Random access channel
RTCA-MOPS	Radio Telecommunication Association minimum operational performance standards
SAR	Search and rescue
SARP	Standards and recommended practices
SAW	Surface acoustic wave
SCPC	Single carrier per channel
SES	Ship earth station
S/N	Signal-to-noise power ratio
SOLAS	Safety of Life at Sea
TDD	Time division duplex
TDMA	Time division multiple access
TT&C	Telecommand, telemetry and control
TWTA	Travelling-wave tube amplifier
UHF	Ultra high frequency
VHF	Very high frequency
WARC	World Administrative Radio Conference
WRC	World Radiocommunication Conference

CHAPTER 5

TECHNICAL AND OPERATIONAL CHARACTERISTICS OF CURRENT AND PLANNED MSS SYSTEMS

The following MSS system descriptions are provided in Chapter 5:

- 5.1 MTSAT
- 5.2 LEO ONE
- 5.3 TMI
- 5.4 N-STAR
- 5.5 Globalstar
- 5.6 Inmarsat
- 5.7 Thuraya
- 5.8 FAISAT
- 5.9 New ICO
- 5.10 EMSAT

5.1 Multi-functional Transport Satellite (MTSAT) System

5.1.1 General overview

The multi-functional Transport Satellite (MTSAT) System provides the aeronautical mobile-satellite service (AMSS) and satellite-based augmentation system (SBAS) capabilities for ATS providers and aircraft operators in the Asia/Pacific Region to implement the ICAO CNS/ATM systems for Japan operated by the Civil Aviation Bureau Japan (JCAB).

MTSAT has two missions, i.e. a meteorological mission and an aeronautical mission. The aeronautical mission of MTSAT will contribute to each element of the ICAO CNS/ATM systems, i.e. communication, navigation and surveillance.

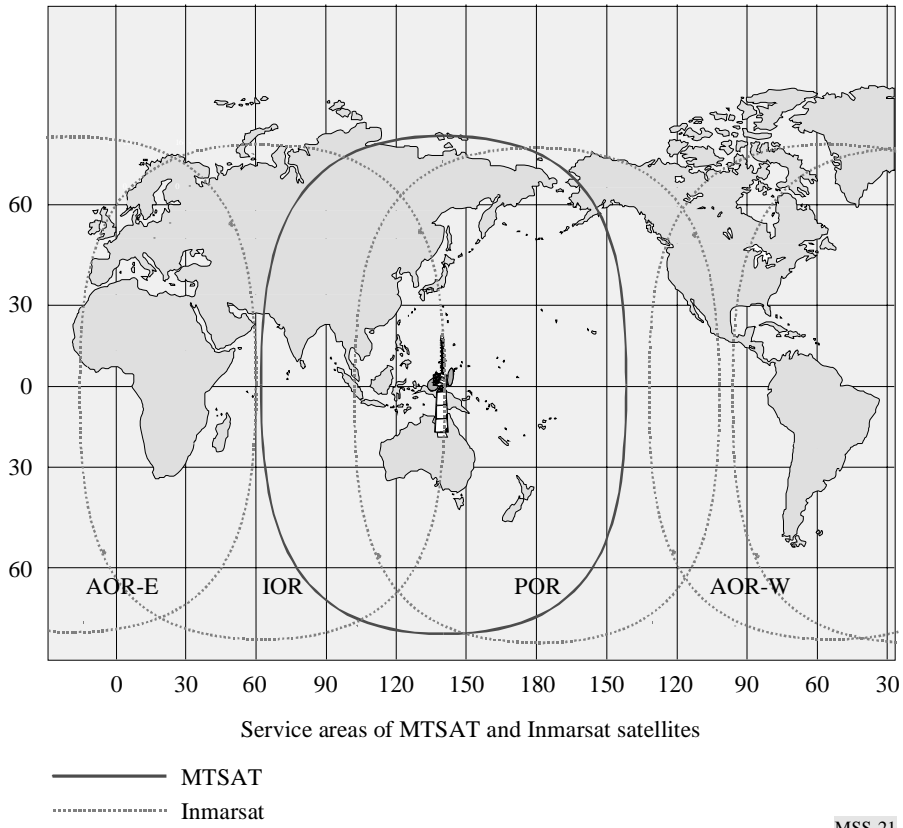
The MTSAT system has been designed to meet the ICAO SARPs and is interoperable with the existing satellite system. Two MTSATs will cover airspace throughout most of the Asia/Pacific Region. The MTSAT system will offer an opportunity for ATS providers and aircraft operators in the Asia/Pacific Region to have highly reliable communication, navigation and surveillance systems.

In order to provide service continuously, even in natural disasters, two aeronautical satellite centres have been implemented at two different locations in Japan, i.e. Kobe (approximately 500 km west of Tokyo) and Hitachi-ota (approximately 100 km northeast of Tokyo).

5.1.2 System architecture and technical characteristics

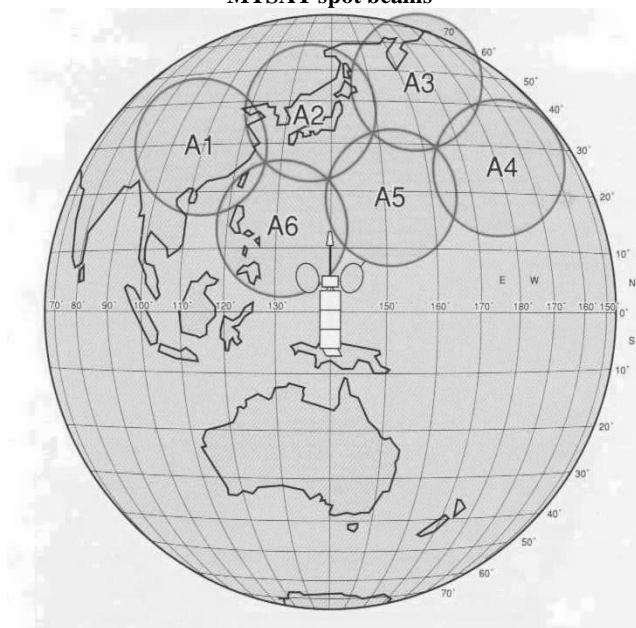
MTSAT service areas are shown in the Fig. 21 for the global-beam and Fig. 22 for the spot-beams respectively.

FIGURE 21
MTSAT global beam



MSS-21

FIGURE 22
MTSAT spot beams



MSS-22

MTSAT signal characteristics are generally based on the ICAO Annex 10 (SARPs) and Inmarsat SDM, and comply with the Radio Regulations and ITU-R Recommendations. MTSAT signal characteristics are summarized as in Table 13.

TABLE 13
MTSAT signal characteristics

Channel		Direction	Usage	Bearer rate	Modulation	Bandwidth
P	Packet mode/TDM	Forward-link	Signalling and message continuously transmitted from GES	600 bit/s	1/2 FEC A-BPSK	5 kHz
				10.5 kbit/s	1/2 FEC A-QPSK	10 kHz
R	Random access (Slotted ALOHA)	Return-link	Signalling and message	600 bit/s	1/2 FEC A-BPSK	2.5 kHz
				10.5 kbit/s	1/2 FEC A-QPSK	10 kHz
T	Reservation TDMA	Return-link	Long message	600 bit/s	1/2 FEC A-BPSK	2.5 kHz
				10.5 kbit/s	1/2 FEC A-QPSK	10 kHz
C	Circuit mode SCPC	Forward-link	Voice message	21 kbit/s	1/2 FEC A-QPSK	17.5 kHz
		Return-link		8.4 kbit/s	2/3 FEC A-QPSK	7.5 kHz

5.1.3 MTSAT space segment

Major parameters of the MTSAT space segment are shown in Table 14.

TABLE 14
MTSAT space segment

Item	Description			
Satellite orbit	135E, 140E, 145E ± 0.1°			
Type of satellite	3-axis attitude control			
Initial mass in orbit	3.3 tons			
Dry mass	1.4 tons			
Lifetime	More than 10 years			
Link	Feeder link		Service link	
Band	14/11 GHz	30/20 GHz	1.6/1.5 GHz	
Beam	4-Spot	3-Spot	Global	6-spot
Total e.i.r.p.	27 dBW	27 dBW	40 dBW	43 dBW
G/T	-1 to -4 dB/K	-1 dB/K	-9 dB/K	-2 dB/K

5.1.4 MTSAT Earth segment

5.1.4.1 GES

Major parameters of MTSAT ground earth stations are shown in Table 15.

TABLE 15

MTSAT ground earth stations

Earth station	Kobe and Hitachi-Ohta	
Freq. band	14/11 GHz	30/20 GHz
Antenna size	13 m	13 m
Total e.i.r.p.	77.8 dBW	82.2 dBW
<i>G/T</i>	36.4 dB/K	38.7 dB/K

5.1.4.2 AES

The characteristics of the MTSAT aeronautical earth station are based on the ICAO Annex 10 (SARPs) and Inmarsat SDM Module 2 as summarized in Table 16.

TABLE 16

MTSAT AES characteristics (summary)

Type	Low gain antenna	High gain antenna
<i>G/T</i>	better than -26 dB/K	better than -13 dB/K
Maximum carrier e.i.r.p. (P_{max})	more than 13.5 dBW	more than 25.5 dBW
Power control range	1 dB steps from P_{max} to $P_{max} - 15$ dB	1 dB steps from P_{max} to $P_{max} - 15$ dB
Antenna characteristics	Non-directional	Steerable BW = 45°

5.1.5 Service and applications

The MTSAT system will provide direct controller-pilot communication in voice (SAT-voice) and data (controller-pilot datalink communication: CPDLC), GPS augmentation information, and automatic dependent surveillance (ADS) capabilities. The MTSAT system will not only be capable of handling oceanic ATS communications within the Japanese FIRs, but will also be offered to the civil aviation community in the Asia/Pacific region as an aviation infrastructure, which could facilitate the implementation of the ICAO CNS/ATM systems.

The AMSS provided by the MTSAT system for the AES is interoperable with that of Inmarsat networks.

5.1.5.1 Aeronautical mobile-satellite services

The aeronautical mobile-satellite services functions of MTSAT include the provision of all the aeronautical communications defined by ICAO, i.e. air traffic services (ATS), aeronautical operational control (AOC), aeronautical administrative communications (AAC), and aeronautical passenger communications (APC). These communication services could be available for ATS providers and aircraft operators in the Asia/Pacific region through data link service providers. Direct access to MTSAT could also be possible through implementation of dedicated ground earth stations (GES) in some States.

5.1.5.2 MTSAT satellite-based augmentation system

MTSAT satellite-based augmentation system (MSAS) is a satellite-based augmentation system (SBAS), equivalent to the United States WAAS and European EGNOS. MSAS provides aircraft with GPS augmentation information to satisfy navigation performance requirements, i.e. integrity, continuity and availability requirements, which are essential to the use of GPS for aircraft operation as a sole means of navigation.

The Asia/Pacific States could implement SBAS by using MTSAT, i.e. MSAS. It would also be possible for the Asia/Pacific region to implement SBAS by the Inmarsat system, e.g. WAAS, EGNOS. In order to provide aircraft with sufficient GPS augmentation information, both MSAS and other SBASs (WAAS, EGNOS) will require a certain number of ground monitoring stations (GMS). The number and location of GMS required for each State will depend on the requirements for the level of navigation services and reception of GPS.

JCAB has implemented the MTSAT monitoring and ranging stations (MRS) in Australia and Hawaii, four GMSs and two master control stations (MCS) in Japan. For this reason, the Asia/Pacific States could implement MSAS with a lower number of GMSs than other SBASs. Since most of the Asia/Pacific region will be covered by two MTSATs, the integrity and availability are higher than other SBASs within the Asia/Pacific region.

While each SBAS (WAAS, EGNOS and MSAS) is independent from the others, in order to ensure seamless SBAS services to the world, JCAB has been participating in the SBAS Technical Interoperability Working Group (IWG) established with the United States, Europe and Canada since 1997. The MSAS has been designed to be interoperable with the U.S. WAAS and European EGNOS at the signal-in-space level. Therefore, common navigation avionics can be used for the three SBAS systems.

5.2 The Leo One system

5.2.1 General overview of the Leo One mobile satellite system

The Leo One mobile satellite system is designed to use a constellation of 48 low Earth orbit satellites to provide low cost, high quality wireless data communications for business, industry, government, and consumers worldwide. The system is projected to begin service in 2002. Operation of the Leo One system will provide low data rate, store-and-forward packet communications with coverage of all points between the Arctic and Antarctic Circles.

5.2.2 System architecture of the Leo One network

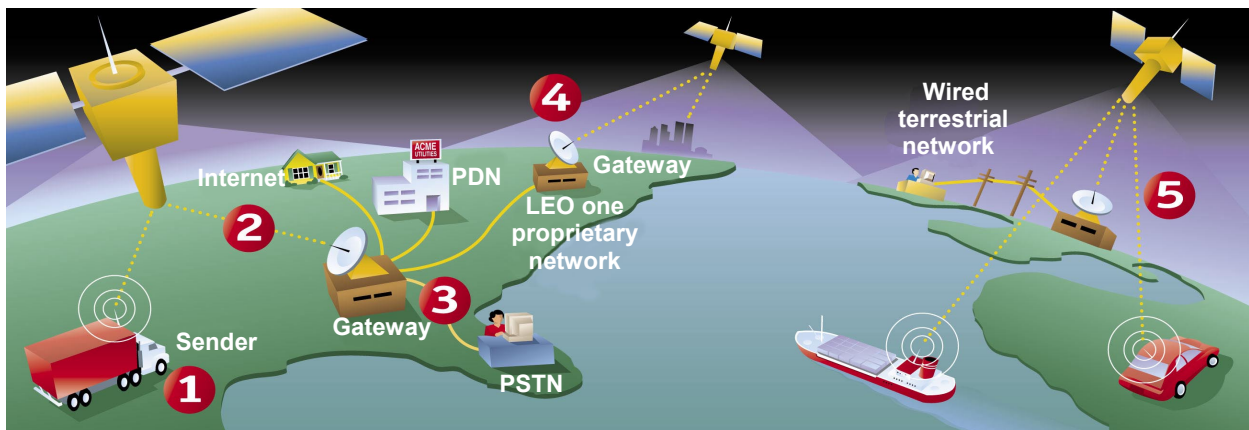
The Leo One network shown in Fig. 23 operates in conjunction with and as an extension of terrestrial data networks through the use of gateway earth stations that provide the interconnection to the existing terrestrial infrastructure. User terminals provide packet data connections with the satellites and have the ability to send and receive digital data. On the uplinks, the users access the several uplink channels and transmit data to the satellites at data rates from 2.4 to 9.6 kbit/s per second. Downlinks from the satellite are distributed over the entire satellite beam coverage area, and each user accesses only the data intended for that particular user terminal.

FIGURE 23

LEO One network and operation

Messages will be sent between users - persons or machines - where one or both are equipped with a LEO One satellite service terminal.

1. A satellite service terminal sends a message to the nearest inview LEO One satellite.
2. The satellite forwards the message to a gateway for validation and optimal routing.
3. The gateway forwards the message to its recipient via the best route - satellite, Internet, private data network (PDN), or the public switched telephone network (PSTN).
4. In some cases, the receiving gateway will route the message to another gateway and then through a satellite communications path for delivery.
5. Messages can also be initiated by users connected to the wired terrestrial network, routed to a LEO One gateway, and delivered via a LEO One satellite to a service terminal.



The satellites operate in a store and forward mode to receive, store and transmit the data as required. The overlapping beam coverage on the surface of the Earth by the Leo One satellite footprints is designed to provide near real-time communications links for the users. The satellites, in conjunction with the gateway earth stations, control the user terminal access to the network. The gateway earth stations operating with the network management centre control the network operation, including packet routing, satellite tracking and ephemeris, billing, and subscriber database.

5.2.2.1 Orbital parameters of the Leo One system

The orbital parameters of the Leo One constellation are given in Table 17. The 50° orbital plane inclination allows coverage from the Arctic Circle to the Antarctic Circle.

TABLE 17

Orbital parameters of the Leo One constellation

Orbital parameter	Value
Number of satellites	48
Altitude (km)	950
Inclination (degrees)	50
Orbit planes	8
Satellites/plane	6
Right ascension of ascending node (degrees)	0, 45, 90, 135, 180, 225, 270, 315

5.2.2.2 Space segment (satellite payload)

The Leo One network has user terminal to satellite links at 149 MHz and satellite to user terminal links at 137 MHz. Each satellite supports 15 service uplink channels and one service downlink channel. Additionally, one gateway uplink feeder channel and one gateway downlink feeder channel are available on each satellite. Satellite launch mass is 165 kg, and peak power at end of life is 550 W. The satellites are designed for seven years life.

5.2.2.3 Mobile terminals

Leo One mobile user terminals used by the subscribers have the technical parameters listed in Table 18. The user terminals are approximately 160 cubic centimeters in size, have 7 W output power, and are battery powered where necessary.

TABLE 18

Leo One subscriber terminals

Technical parameter	Value
Subscriber uplink	
Band (MHz)	148-150.05
Tx power (W)	7
Tx e.i.r.p. (dBW)	8.5
Max Tx antenna gain	0 dBi
Channel bandwidth (kHz)	15
Rate (kbit/s)	9.6/OQPSK
Polarization (Tx wave)	linear
Sat Rx G/T (dB/K)	-22.9
Max Rx antenna gain	5.7 dBi
Rx antenna pattern	Isoflux
$C/(I+N)$ (dB)	5.5
Subscriber downlink	
Band (MHz)	137-138, 400.15-401
Tx power (W)	17.5
Tx e.i.r.p. (dBW)	18.1
Max Tx antenna gain	5.7 dBi
Channel bandwidth (kHz)	25 35
Rate (kbit/s)	24/OQPSK 9.6/FSK
Polarization(Tx wave)	RHC
Subscriber Rx G/T (dB/K)	-30.8
Max Rx antenna gain	0 dBi
$C/(I+N)$ (dB)	5.1

5.2.2.4 Gateway earth stations

Leo One terminals used as gateway earth stations have the technical parameters listed in Table 19.

TABLE 19

Leo One Gateway earth stations

Technical parameter	Value
Gateway uplink	
Band (MHz)	148-150.05
Tx Power (W)	1.2
Tx e.i.r.p. (dBW)	17.8
Max Tx antenna gain	18 dBi
Channel bandwidth (kHz)	50
Rate (kbit/s)	50/OQPSK
Polarization (Tx wave)	RHC
Sat Rx G/T (dB/K)	-22.9
Max Rx antenna gain	5.7 dBi
$C/(I+N)$ (dB)	8.5
Gateway downlink	
Band (MHz)	400.15-401
Tx power (W)	15
Tx e.i.r.p. (dBW)	17.5
Max Tx antenna gain	5.7 dBi
Channel bandwidth (kHz)	60
Rate (kbit/s)	50/OQPSK
Polarization (Tx Wave)	RHC
Gateway Rx G/T (dB/K)	-9.9
Max Rx antenna gain	17 dBi
$C/(I+N)$ (dB)	8.5

5.2.3 Service and applications

Network operation

User earth stations provide data links to the satellites for sending and receiving wireless data messages as shown in Fig. 23. The sender's message goes to the nearest in-view satellite where it is linked to the local gateway for validation and optimal routing to the recipient. Approximately 20 gateway earth stations are interconnected via a global Leo One terrestrial backbone network. In the case of a mobile recipient, the message is then returned to the satellite and stored briefly (until the intended receiver is in view) before delivery to the recipient's transceiver unit. If necessary, gateway earth stations relay messages between satellites for faster delivery. If the intended recipient is a fixed site, as would be the case for a company tracking remote devices attached to a mobile fleet, the message is delivered to the dispatch recipient via interconnection with the Leo One terrestrial backbone network. In the latter example the final link from the Leo One backbone to the customer premises is via the Internet, dial up line or by a dedicated connection. The number of satellites and the orbit inclinations provide that there is always at least one satellite in view for latitudes up to 64°. Beyond that there may be a short wait. Each satellite has a beam footprint of about 12 million square kilometers. The system can provide near real-time data communications for users at data rates from 2.4 to 9.6 kbit/s. Tables 20 and 21 provide example link calculations for user and gateway earth stations in the Leo One system.

In operation, wireless data applications supplied by local service providers will include both time-sensitive and data-intensive applications, such as, asset tracking, fleet management, facility monitoring, remote control, meter reading, two-way alphanumeric paging, email, mobile messaging and location for the transportation and shipping industries, data acquisition, security, search and rescue, weather data, and business transactions.

Estimated costs

Overall installed system cost of the Leo One network is between \$ 500-\$ 600 million (US dollars). After several years of system operation, user terminal costs are estimated to be under \$ 100 (US dollars). Monthly service costs for use of the system and transmission of data would range from 1 to 50 (US dollars) per user terminal, depending on the amount of data transmitted to and from the user.

5.2.4 Leo One MSS system unique features

The number of satellites (48) and the highly inclined orbits (50°) provide near-real time communications to all areas of the Earth between the polar circles. The low satellite altitude (950 km) produces short transmitter path lengths to the satellites resulting in low transmitter power requirements for the user terminals and the satellites. This reduces the overall system cost and the consequent cost of service. Data rates ranging from 2.4 to 9.6 kbit/s allow for short duration packet data bursts (less than 500 ms).

5.2.5 Leo One website

<http://www.leoone.com>.

TABLE 20

Example link calculations for Leo One user earth station to satellite transmissions

	15° elevation		90° elevation	
	Uplink	Downlink	Uplink	Downlink
Peak transmit power (W)	7	17.5	7	17.5
Transmit antenna peak gain (dB)	0	5.7	0	-2
Pointing loss (dB)	0	0	0	0
e.i.r.p. (dBW)	8.5	18.1	8.5	10.4
Frequency (MHz)	149.0	137.0	149.0	137.0
Slant range (km)	2317	2317	950	950
Polarization loss (dB)	3	3	3	3
Gaseous loss (dB)	0.5	0.5	0.5	0.5
Total transmission loss (dB)	146.7	146.0	139.0	138.2
Receive antenna peak gain (dB)	5.7	0	-2	0
Pointing loss (dB)	0	0	0	0
Feed loss (dB)	1	1	1	1
Receiver noise figure (dB)	3	3	3	3
Antenna temperature (K)	288	760	288	760
Receiver/feed noise temperature (K)	438	438	438	438
System noise temperature at antenna (K)	726	1 198	726	1 198
G/T (dB/K)	-22.9	-30.8	-30.6	-30.8
Uncoded burst data rate (kbit/s)	9.6	24	9.6	24
Required E_b/N_0 (dB(Hz))	7.5	7.5	7.5	7.5
Implementation loss (dB)	2	2	2	2
Required C/N_0 (dB(Hz))	49.3	53.3	49.3	53.3
Link margin (dB)	18.1	16.7	18.2	16.7
Peak flux density in 4 kHz (dB(W/m ²))	-	-125.2	-	-125.1

TABLE 21

Example link calculations for Leo One gateway earth station to satellite transmissions

	15° elevation		90° elevation	
	Uplink	Downlink	Uplink	Downlink
Peak transmit power (W)	150	5	150	5
Transmit antenna peak gain (dB)	18	5.7	18	-2
Pointing loss (dB)	1	0	1	0
e.i.r.p. (dBW)	38.8	12.7	38.8	5.0
Frequency (MHz)	150	400.5	150	400.5
Slant range (km)	2317	2317	950	950
Polarization loss (dB)	1	1	1	1
Gaseous loss (dB)	0.5	0.5	0.5	0.5
Total transmission loss (dB)	144.8	153.3	136.2	145.5
Receive antenna peak gain (dB)	5.7	17	-2	17
Pointing loss (dB)	0	1	0	1
Feed loss (dB)	1	1	1	1
Receiver noise figure (dB)	3	2	3	2
Antenna temperature (K)	288	200	290	200
Receiver/feed noise temperature (K)	438	289	438	359
System noise temperature at antenna (K)	726	489	728	559
G/T (dB/K)	-22.9	-9.9	-30.6	-10.5
Uncoded burst data rate (kbit/s)	50	50	50	50
Required E_b/N_0 (dB(Hz))	8.5	8.5	8.5	8.5
Implementation loss (dB)	2	2	2	2
Required C/N_0 (dB(Hz))	57.5	57.5	57.5	57.5
Link margin (dB)	42.2	20.6	42.2	20.1
Peak flux density in 4 kHz (dB(W/m ²))	-	-133.8	-	-133.8

5.3 The TMI Communications Canadian Mobile Satellite System

5.3.1 Introduction

TMI Communications is a Canadian-based business that delivers advanced mobile communications network solutions. These solutions are delivered via TMI's mobile communications satellite to customers across North America, northern South America, Central America, the Caribbean, Hawaii, up to 250 miles offshore.

In the early 1980's, the Canadian Government realized that, although the densely populated areas of Canada enjoyed communications services that were among the best in the world, mobile communications services to the thousands of kilometers of highways and to the vast, sparsely populated areas of the country were rather limited. Early studies and experiments by the Canadian Department of Communications confirmed the feasibility of communicating with small transportable terminals via satellites, and a government demonstration program was established to define and implement a Canadian experimental mobile program. Based on positive results of commercial viability studies, the demonstration program was converted in 1984 into a commercial mobile satellite program by Telesat Canada, the Canadian domestic communications satellite carrier.

TMI Communications was formed in 1988 with a mandate to develop, construct and operate Canada's first mobile-satellite communications network. TMI Communications is owned by BCE Inc., one of the world's premier telecommunications and media companies and one of North America's largest telecommunications operators.

TMI Communications and the mobile satellite operator in the United States, American Mobile-satellite Corporation (AMSC) – now Motient, signed a contract with SPAR Aerospace Limited and Hughes Aircraft Co. for the joint procurement of two nearly identical spacecraft in order to benefit from the sharing of the nonrecurring program costs. TMI Communications and Motient have also entered into a joint operating agreement that ensures, among other things, a mutual in-orbit backup between the TMI Communications and Motient satellites to protect against catastrophic failure of either satellite.

By 1996, less than a decade after it was created, TMI Communications had completed its research and development, launched its first satellite, and begun offering mobile communications services to customers across Canada.

Since 1996, TMI Communications has successfully introduced a portfolio of mobile communications services, including voice, dial-up data, fax, dispatch radio, and packet data services.

Managing the construction, testing, and launch of the satellite, building the network ground segment, licensing the manufacture of mobile equipment were all part of the TMI Communications mandate. TMI has partnered with distributors, service providers and value-added resellers in developing innovative solutions. Visit <http://www.tmisolutions.com> for more information.

5.3.2 System description

The Canadian Mobile Satellite (MSAT) system serves a large user population, which generally has a low and intermittent traffic activity. It enables mobile terminals (MT) to communicate with a feederlink earth station (FES) providing network access or access to the public switched telephone system (PSTN) or the public switched data networks.

The main elements of the MSAT system are the space segment, which includes the satellite and satellite control centre (SCC), and the ground segment comprising the network control system (NCS), FES, and MT.

The MSAT system provides both circuit switched and packet switched communications capabilities. The MSAT system enables the circuit switched mobile terminals to communicate with base station FES for private network services, via gateway FES to public switched telephone networks or data network services or to other MTs. The packet switched mobile terminals communicate through a data hub, which supports packet data protocols such as X.25.

User access to the satellite is controlled by a network control centre (NCC). Most communication services use frequency division multiple access (FDMA) techniques with a nominal channel bandwidth of 6 kHz. The NCC assigns frequencies to the users on a first-in-first-out (FIFO) basis. A MT places a call via a signalling channel. The NCC allocates a free communications channel to the MT and the FES, again by means of the signalling channel. At the completion of the call, the channel is released and becomes available for reassignment by the NCC to another call.

The MSAT service area consists of a basic service area and other service areas, that are accessible from a geostationary orbit location of 106.5° West longitude. The basic service area at L-band includes Canada, the continental United States, and the coastal waters to the 200 nautical mile territorial limits. The basic service area at Ku-band is the same except that the coastal waters are excluded. The other service areas include Puerto Rico, Alaska, and Hawaii.

The MSAT satellites use a total of six L-band spot beams to cover the service area. This facilitates frequency reuse, and increases the satellite e.i.r.p. and G/T .

Forward link communications from the FES to the satellite utilize the 13 to 13.15 and 13.2 to 13.25 GHz Ku-bands, operating in five beam-dedicated 29 MHz wide portions which are down-linked from the satellite to the MT in the 1 530 MHz to 1 559 MHz via the East, Central, Mountain, West, and Alaska + Hawaii/Mexico + Puerto Rico beams respectively. Isolation between the West and East L-band beams is sufficiently high to permit reuse of the L-band spectrum used in each of these beams. Selection of a given L-band beam for a forward link transmission is achieved simply by allocating the FES-to-satellite transmission in the appropriate 29 MHz portion of the Ku-band uplink.

Reverse link communications from the MT to the satellite use the 1631.5 to 1660.5 MHz L-band. The reverse repeater of the satellite up-converts these transmissions from the L-band beams and downlinks them to the FES in 29 MHz, side-by-side segments of the 10.75 to 10.95 GHz Ku-band.

In order to accommodate changes in the geographical distribution of the MSAT market during the service life of the system, the payload has been designed to allow a concentration of up to 50% of the total L-band transmit RF power into any beam. A similar flexibility is provided with respect to the assignable bandwidth. Every 29 MHz band of the forward and reverse repeaters is equipped with eight surface acoustic wave (SAW) bandpass filters which can be switched in or out by ground commands, providing full flexibility for spectrum allocation among the beams.

The circuit switched basic communications services are single carrier per channel (SCPC) with a nominal bandwidth of 6 kHz, using FDMA. The packet switched communications services use a combination of time division multiplex (TDM), slotted Aloha (SA) and time division multiple access (TDMA) channels with a nominal bandwidth of 6 kHz.

Additional technical details may be obtained from references [1, 2, 3].

5.3.3 Space segment

The MSAT satellite employs the Hughes Aircraft Co. (now Boeing) HS601 service module (bus) which supports a high power L-band/Ku-band communications subsystem developed by SPAR Aerospace Ltd. (now EMS).

The communication subsystem employs a Ku-band to L-band forward repeater which connects the feederlink earth terminals to the mobile earth terminals, and an L-band to Ku-band reverse repeater providing communication from the MT to the FES.

The main elements of the repeaters are the L-band and Ku-band receivers; the up/down converters, each serving one antenna beam; the linearized Ku-band travelling wave tube amplifiers (TWTA); the L-band solid state power amplifiers (SSPA) with their matrix networks; and the antennas which include two large (5 m × 6 m) unfurlable L-band reflectors and their feed elements, and the shaped reflector Ku-band antenna which provides a single linearly cross-polarized transmit and receive beam which covers the whole service area.

The HS601's power capability, payload weight and thermal dissipation capability provide a good match for the high power MSAT payload, and its attitude control system ensures accurate pointing of the large diameter flexible L-band antennas. The MSAT satellite is operated under contract by TMI's sister company, Telesat Canada. Its 12/14 GHz Telemetry and Control system which uses command encryption, ensures satellite security. The HS601 employs a bipropellant propulsion system for station keeping, attitude control purposes, and for apogee and perigee augmentation functions. Attitude determination and control is carried out by an onboard computer, which controls the momentum wheel speed and position. The power subsystem employs a single 50 volt regulated electrical bus, two large three-panel sun tracking solar arrays, and a single nickel-hydrogen battery for eclipse operation. Battery charging is completely automatic. Dissipation of the large quantities of heat generated by the SSPAs is provided by north and south facing radiators. Heat transportation is facilitated by heat pipes.

The main system characteristics of the MSAT satellite are illustrated in Table 22.

TABLE 22

MSAT satellite main parameters

Spacecraft type	HS601
Service life	10 years
Mission life	12 years
Liftoff weight (Ariane 4)	2 514 kg
Solar array power (EOL)	3.15 kW
Payload power (EOL)	2.5 KW
Eclipse protection	60% (RF power)
e.i.r.p. L-band (95% area)	57.3 dBW
Ku-band	36 dBW
<i>G/T</i> L-band (95% area)	+2.7 dB/K
Ku-band	-3.6 dB/K
Orbit location (Canadian)	106.5° West

5.3.4 Ground segment

The ground segment of the MSAT system consists of the network control system, the feeder link earth station and the mobile terminals.

The NCS includes the network operations centre (NOC), which controls and manages all resources of the space and ground segments; the network control centre (NCC), which allocates demand period circuits to the MT; and those elements of the FES and MT which are associated with the signalling channels needed for carrying out the circuit assignments and other network control functions.

The NOC registers all MTs with their attributes, arranges for authorized MTs to access the system, records system usage for billing purposes, and accumulates network performance records to aid in long-term system planning.

The NCC assigns channels via the signalling facilities, using a priority demand assignment multiple access system. A MT places a call via a signalling channel. The NCC allocates a free communications channel to the MT and the FES, again by means of the signalling channel. At the completion of the call, the channel is released and becomes available for reassignment by the NCC to another call.

The FES is a fixed terminal employing a high gain 11.0 m antenna. It provides Ku-band transmit/receive functions for both signalling and communications to the satellite. Since atmospheric absorption at Ku-band frequencies can vary considerably as a function of weather conditions, a stable satellite-based, Ku-band beacon is used to provide automatic transmit level control which will maintain near constant Ku-band flux-density at the satellite.

For the MT, a modular architecture consisting of three basic units (external interface, transceiver, and antenna) has been adopted. A wide range of interface units are available to accommodate the various applications and selected options. The basic terminal interfaces with a simple telephone handset, offering circuit switched service only. A full featured terminal provides both circuit switched telephone service and packet switched data service, connecting computers, keyboards, personal data assistants, data displays, fax machines, printers, etc.

A variety of antenna designs are available for the MT, providing gains ranging from 3 to 15 dBic. These gains are achieved using several antenna types ranging from the simple crossed drooping dipoles to electronically steered microstrip arrays. A major challenge was the design of high performance, low cost, reliable and aesthetically acceptable antennas that track the MSAT satellite irrespective of vehicle movement.

5.3.5 Communications services

5.3.5.1 Circuit switched voice service

TMI Communications circuit switched voice service enables communication beyond the limits of traditional telephone or wireless services. Not only can one speak with people who would otherwise be impossible to reach, it can be done economically.

The circuit switched voice service offers mobile and fixed users a range of valuable digital voice features such as:

- Call forwarding (on “busy,” no answer, or unconditionally)
- Call barring
- Call waiting
- Conference calling (three-way calling).

5.3.5.1.1 Dial-up data service

TMI Communications dial-up data service is ideal for applications such as supervisory control and data acquisition (SCADA) that transmit and receive large volumes of information. The service may be used for fixed and mobile office applications such as file transfer, email, Internet, and LAN access.

Dial-up data sets up a dedicated circuit between the sender and the receiver, the same way that the PSTN operates. Dial-up data service is typically rated by the minute, by fractions of a minute (e.g., 30 s increments), or by the second.

The TMI Communications network connects MTs to public telephone and data networks, to private networks or to another MT by routing the traffic back through the satellite.

5.3.5.1.2 Fax service

TMI Communications fax service provides users with an efficient, error-free fax handling system. Mobile users can exchange facsimile messages with recipients and senders worldwide through the PSTN. The service’s unique store and forward features improve the productivity of today’s mobile workers.

The hardware fax interface unit connects to the data port (serial port) of the MT and a standard fax machine using a standard 25-pin serial modem cable. A store and forward fax system allows faxes to be sent without knowing whether the destination fax machine is available. If the destination

machine is busy, the service will attempt to establish a connection again for a specified number of times. If it continues to encounter busy signals, the service can deposit the fax into the destination subscriber's fax mailbox.

5.3.5.1.3 Dispatch radio service

TMI Communications dispatch radio service offers two-way voice dispatch or one-way voice broadcast service. It is a cost-efficient alternative to installing, maintaining, and relocating land-based radiocommunications systems.

A wireless push-to-talk network, dispatch radio service relies on establishing "talk groups" – sets of users who share a common radio channel. Each communicator can support up to 15 talk groups. Each talk group can include as many as 10000 members. When establishing talk groups, priority levels can be predetermined in order to define who will be permitted to listen and speak during each session.

Users also have the ability to dial in to a talk group from the PSTN or dial out from a talk group to the PSTN.

The TMI Communications network acts much the same as a radio tower, turning the entire continent into a single cell and transmitting signals to, and receiving signals from, subscribers on the ground. The TMI communications dispatch radio service can also be configured to provide extra security to subscribers.

5.3.5.2 Packet data services

The ability to transmit vital data between business operations is essential, whether to gather information from distant truck fleets and rolling stock, monitor remote construction equipment, or retrieve bill of lading information from delivery vehicles.

The packet data services from TMI Communications make transmitting data from isolated sites or mobile resources quick and efficient.

Packet data specialized services support wireless data applications such as: fleet and load management, credit card verification, email, vehicle position reporting, mobile computing, and data message broadcasting.

Transmissions carried by the packet data services are extremely secure. To prevent unauthorized or fraudulent use of the service, each communicator must be registered and given network access by TMI. The system also provides security against fraudulent communicator use through an access security key, which is unique to every mobile terminal.

5.3.6 References

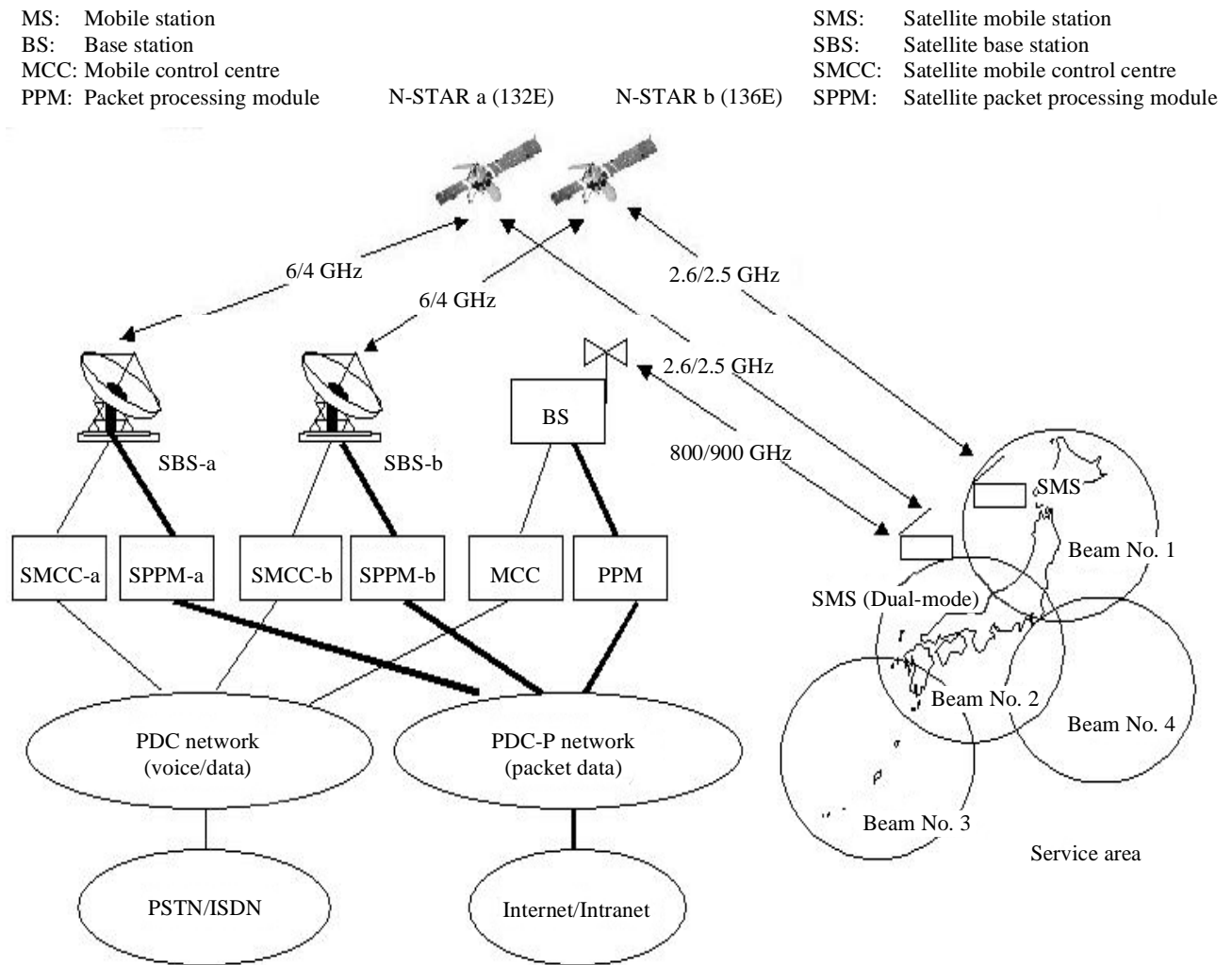
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- [2] BERTENYI, E. [1991] The North American MSAT System, Elsevier Space Communications 8, 295-302.
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5.4 N-STAR Mobile Satellite Communications System

5.4.1 General overview

In Japan, an advanced domestic mobile satellite communications system had been developed in order to expand the service area of the terrestrial land and maritime mobile services economically. This system has employed two GSO satellites, N-STAR a and b, which were launched in August 1995 and February 1996, respectively. This N-STAR system has provided voice and 4.8 kbit/s circuit switched fax/data transmission services (basic service) for those who are out of terrestrial service areas since March 1996 [1]. In addition to those services, a packet switched data transmission service (packet service) has been provided since March 2000 [2], [3]. This new packet service is an asymmetrical data service and is able to provide maximum 64 kbit/s data transmission speed for the downlink. Figure 24 shows the N-STAR system configuration.

FIGURE 24
N-STAR system configuration



MS: Mobile station

BS: Base station

MCC: Mobile control centre

PPM: Packet processing module

N-STAR a (132E)

N-STAR b (136E)

SMS: Satellite mobile station

SBS: Satellite base station

SMCC: Satellite mobile control centre

SPPM: Satellite packet processing module

PDC: Personal digital cellular

PDC-P: PDC packet

* Both systems are the Japanese standard terrestrial mobile system

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5.4.2 System architecture and technical characteristics

5.4.2.1 Major system parameters

The major system parameters are shown in Table 23.

TABLE 23
Major system parameters

Item	Basic service	Packet service
Frequency band	Service link: 2.6/2.5 GHz band (2 660-2 690/2 505-2 535 MHz) Feeder link: 6/4 GHz band (6 345-6 425/4 120-4 200 MHz)	
Channel frequency interval	12.5 kHz	Return link: 12.5 kHz Forward link: 150 kHz
Beam radius	600 km	
Access system	FDMA/SCPC	Return link: FDMA Forward link: TDM
Transmission bit rate	14 kbit/s	Return link: 14 kbit/s Forward link: 156 kbit/s
Modulation/demodulation scheme	π 4-shift QPSK/coherent detection	
Error correction method	Convolutional coding with Viterbi decoding	
Voice coding method	5.6 kbit/s PSI-CELP	
Data transmission bit rate	4.8 kbit/s	Return link: 5.6 kbit/s Forward link: up to 64 kbit/s

PSI-CELP: Pitch synchronous innovation-code excited linear prediction.

5.4.2.2 N-STAR satellite

The major parameters of the N-STAR satellite are shown in Table 24.

TABLE 24
Major parameters of the N-STAR satellite

Item	Specification	Remarks
Orbit location	N-STAR a: 132° East longitude N-STAR b: 136° East longitude	
Launch date	N-STAR a: 29 August 1995 N-STAR b: 5 February 1996	
Attitude control	Three axis control	
Lifetime	Over 10 years	
Initial Mass in orbit	Approximately 2 tons	
Satellite-mounted antenna	Three antenna reflectors: – two 2.6 × 3.0 m deployable reflectors – one 2.1 m reflector	For FSS
Transponder configuration	Ka (30/20 GHz) multi-beam	
	Ka (30/20 GHz) single beam	
	Ku (14/12 GHz)	
	C (6/4 GHz)	MSS feeder link
	S (2.6/2.5 GHz)	MSS service link

5.4.2.3 Mobile terminals

The N-STAR system is integrated with terrestrial cellular systems so that subscribers can access both systems by using a dual-mode terminal. The details of this feature are described in a later section.

Three types of terminals were developed for the basic service: portable, maritime, and car-mount. The car-mount type terminal is used as a dual-mode terminal, and the maritime-type terminal is exclusively used for the satellite system. The portable-type terminals are provided as both dual-mode use and exclusive use for the satellite system. The N-STAR system is integrated with the terrestrial cellular system. In this case, a dual-mode terminal is used. Table 25 shows the main specifications of the mobile terminal. The packet service's terminal is almost the same as the basic service's maritime-type one. Figures 25 and 26 are photographs of the packet service's terminal and portable-type terminal, respectively.

TABLE 25

Main specifications of mobile terminals

	Packet	Maritime-type	Car-mount type	Portable-type
Frequency band	Tx: 2 660-2 690 MHz Rx: 2 505-2 535 MHz			
Max. transmit power	2.0 W			
Antenna gain	10.0 dBi			
Terminal size	Antenna unit diameter: 30 cm Height: 15 cm Weight: 5 kg Terminal unit size: 15.5 cm × 25 cm × 8.8 cm Weight: 4 kg	Antenna unit diameter: 30 cm Height: 15 cm Weight: 5 kg Terminal unit size: 15.5 cm × 25 cm × 7 cm Weight: 3 kg	Antenna unit diameter: 30 cm × 34 cm Height: 5.5 cm Weight: 3 kg Terminal unit size: 15.5 cm × 25 cm × 7 cm Weight: 3 kg	Antenna and terminal unit size: 26 cm × 18.5 cm × 6 cm Weight: 2.7 kg (including the battery weight)

FIGURE 25
Packet service terminal



MSS-25

FIGURE 26
Portable-type terminal (dual-mode)



MSS-26

5.4.3 Services and applications

The N-STAR system provides two types of services. one is circuit switched service (basic service) and the other is packet switched service (packet service). in order to achieve the high channel quality, a suitable FEC scheme (rate 1/2 convolutional coding with viterbi decoding) has been adopted for both services. therefore, even if the mobile terminal is at the edge of the service area, the bit error ratio (BER) of the received mobile terminal's data is less than 1×10^{-4} .

in the basic service, the information transmission rate for voice and fax/data services is 5.6 kbit/s and 4.8 kbit/s, respectively. For fax/data services, in order to achieve error-free transmission, an advanced ARQ scheme has adopted.

In the packet service, a unique asymmetrical data transmission scheme has been adopted. Therefore, the information transmission rate for forward link and return link is maximum 64 kbit/s and 5.6 kbit/s, respectively. The detail of this unique feature is described in the following section.

The N-STAR system is mainly used on the sea or in the mountains region that is not covered by terrestrial cellular services. Therefore, the system can play a vital role in various surveillance and control operations and also play an important role in academic research and safety management fields. For example, on Mount Hossho in Kyushu Japan, an active volcano, images from a camera set up close to the crater are transmitted automatically to a volcanic research centre about 30 km away via the N-STAR system's terminal. Enabling, for example, the observation of the volume and colour of the volcanic fumes via still pictures, this system offers a useful means for collecting and analysing valuable data.

5.4.4 Unique feature

5.4.4.1 System integration

The N-STAR system is integrated with terrestrial cellular systems. In order to accept the benefit of this integrated system, subscribers use dual-mode terminals. The dual-mode terminal can receive signals from the satellite and from terrestrial cellular base stations simultaneously or by turns. Within a cellular service area, this terminal is preferentially connected to the terrestrial system. Outside the cellular service area, the terminal automatically connects to the satellite system. This selection is performed on the basis of received signal conditions. There is no necessity for subscribers to be conscious about which system they are using. The integration of terrestrial and satellite mobile systems is established to realize a more economical mobile communications system.

5.4.4.2 System reliability

In order to achieve high reliability, the N-STAR system is composed of two satellites, two satellite base stations (SBS) which receive/transmit radio signals from/to satellites and two satellite mobile communication control centres (SMCC) which deal with the call processing and interface with PSTN/ISDN. Each SBS becomes a back-up station for the other.

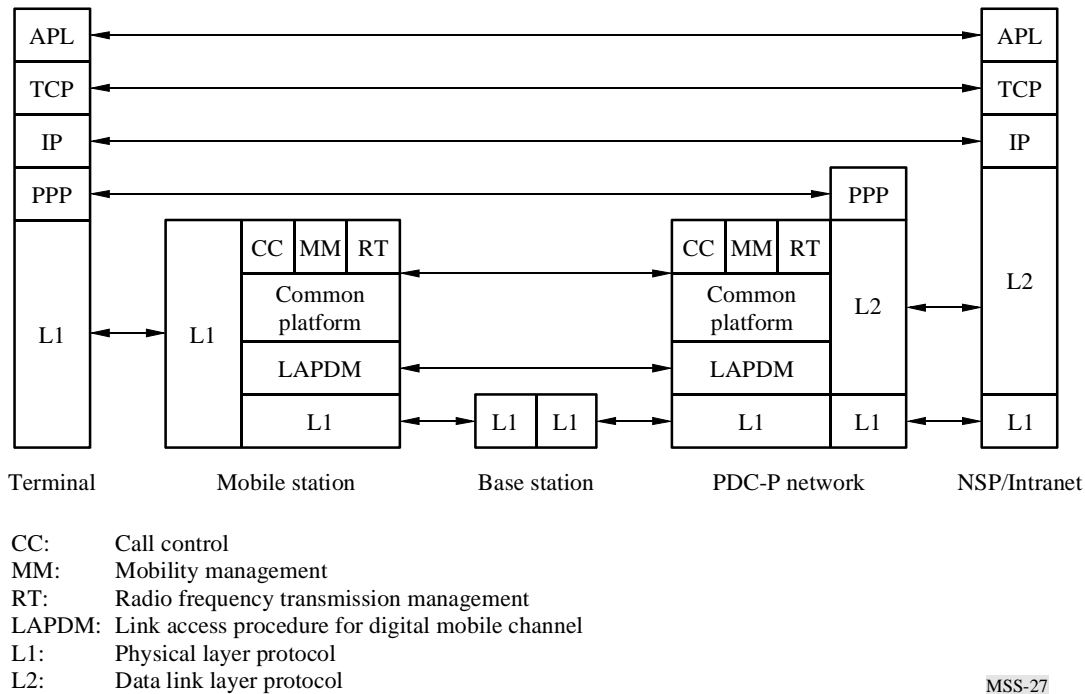
5.4.4.3 Asymmetric packet service

The N-STAR packet system was developed to provide Internet/Intranet services for those who are out of the PDC-P service area.

In many Internet/Intranet services, the forward link traffic load is dominant and the return link data rate does not greatly affect the overall throughput. Raising the return link data rate increases the emission power of mobile stations, which results in a large and heavy terminal. On the other hand, a satellite communication system can increase the forward link data rate relatively easily by assigning the power and bandwidth within the satellite capability. Considering those features, this packet system adopts an asymmetrical communication system with a high data rate of 64 kbit/s on the forward links and a low rate of 5.6 kbit/s on return links. By keeping the return link data rate the same as that of the existing system, mobile station size and power consumption are kept almost the same as the existing one.

Figure 25 is a photograph of the packet service terminal and Fig. 27 shows protocol configurations of this service.

FIGURE 27
Protocol configurations



5.4.5 Provider's web site

<http://www.nttdocomo.com>.

5.4.6 References

- [1] FURUKAWA, K., NISHI, Y., KONDO, H., UEDA, T. and YASUDA, Y. [1996] N-STAR Mobile Communication System. Proceedings of GLOBECOM'96, p. 390-395.
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5.5 The Globalstar Mobile Satellite System

Satellite-based communications – The next generation of wireless services

Globalstar is the next-generation provider of mobile satellite communication services, providing voice and data communications to remote geographical areas and to global customers seeking a simple, cost-effective solution to their communications needs. Service began in January 2000 and is being established throughout the world systematically on a region by region basis.

Our customer base consists primarily of cellular users who roam outside of coverage areas, people who work in remote areas where terrestrial systems do not exist, residents of under-served markets who can use Globalstar's fixed-site phones to satisfy their needs for basic telephony and international travellers who need to keep in constant touch.

Our "vertical markets" include maritime – shipping, pleasure boating; transportation – trucking, railways; aviation – commercial, general aviation; natural resources – oil and gas, timber/logging and government agencies – national, local.

5.5.1 Globalstar system description

5.5.1.1 System components

The Globalstar system is composed of three major components: the satellite constellation, the gateways, and the phones and data modems. Radiocommunication links are established via the satellite between the user and the gateway where connections to existing terrestrial networks are made. The communication links are established in portions of the fixed-satellite service (FSS) and mobile-satellite service (MSS) allocated frequency bands.

Frequency and polarization plans

Globalstar uses C-band FSS allocations between the satellites and the gateways for its feeder links. the satellite feeder link antennas provide Earth coverage beams. The gateways use three or four parabolic antennas which are programmed to track the satellites. Both right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP) are used for the feeder links. The feeder uplink and downlink frequencies are mapped into the sixteen beams for the MSS downlink and uplink frequencies, respectively. The specific feeder link frequency bands are:

- Feeder uplink from the gateway to the satellite: 5 091-5 250 MHz.
- Feeder downlink from the satellite to the gateway: 6 875-7 055 MHz.

Both the S-Band and L-Band satellite antennas are of multibeam design configured to produce the sixteen beams. Service link beams employ LHCP with full frequency reuse. The specific service link frequency bands for most countries are:

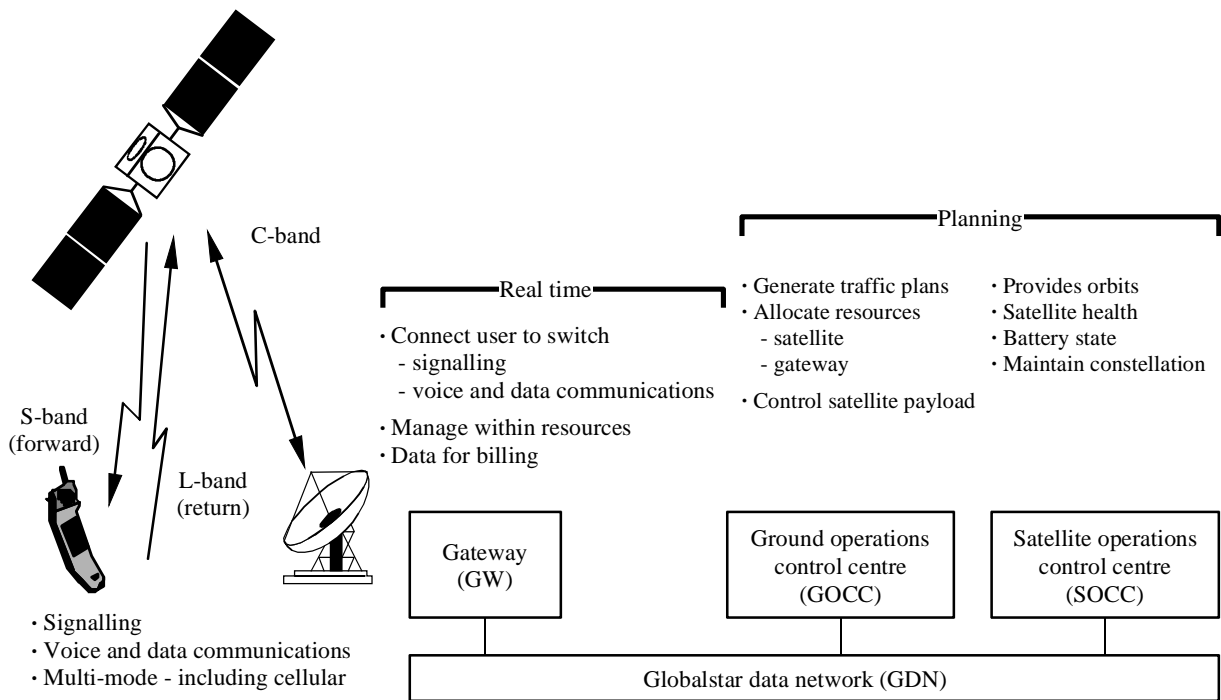
- Service uplink from the user phone to the satellite: 1 610-1 621.35 MHz.
- Service downlink from the satellite to the user phone: 2 483.5-2 500 MHz.

5.5.1.2 System operations

There are two Globalstar control centres (GCCs) in San Jose and El Dorado Hills near Sacramento, California. Each is completely capable of operating the ground network and managing the satellite constellation and each is operational 24 h a day. The centres include a ground operations control centre (GOCC) and a satellite operations control centre (SOCC).

The integrated control centre is shown in Fig. 28. The gateways depicted in the Figure interface with the GOCC and SOCC. Although not shown in the diagram, the GOCC also interfaces with the Globalstar billing office (GBO). The GOCC collects call detail records from each gateway and sends them to the GBO so that service provider invoices can be prepared each month.

FIGURE 28
Ground segment support for communications



MSS-28

The worldwide Globalstar data network (GDN) connects the GOCC to all traffic gateways, and connects the SOCC to the six gateways that have satellite telemetry and control (T&C) equipment.

The Globalstar satellites carry subscriber traffic between Globalstar phones and data modems and Globalstar gateways. The gateways then interface with the terrestrial telephone networks and cellular networks via the gateway's mobile switching centre (MSC) in the host country.

5.5.1.3 Satellite constellation

The satellite orbits are optimized to provide highest link availability in the area between 70° South latitude and 70° North latitude. Service is feasible in higher latitudes with decreased link availability. The Globalstar space segment consists of 48 operational satellites in 1414 km low Earth orbits and 4 in-orbit spares parked at a lower altitude. The low orbits permit low power user phones similar to cellular phones. The satellites are distributed in 8 orbital planes with 6 equally spaced satellites per orbital plane. Satellites complete an orbit every 114 min. User phones and data modems in any particular location on the surface of the Earth are illuminated by one of the 16 beams of the satellite antenna as it passes over the Earth. Typically, a subscriber will be in communication with more than one satellite at any given time. Figure 29 shows a pictorial of the satellite constellation in low Earth orbit and Fig. 30 shows a satellite.

FIGURE 29
Satellite constellation

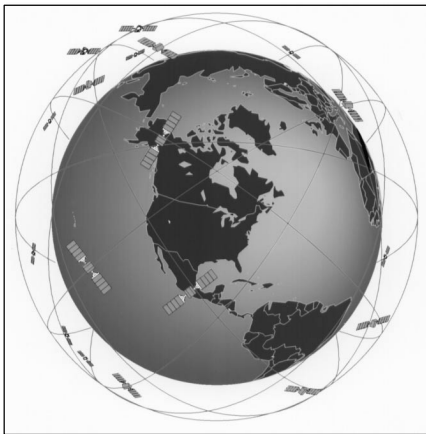


FIGURE 30
Globalstar satellite



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5.5.1.4 Gateways

Gateways are an integral part of the Globalstar ground segment, which also includes ground operations control centres, satellite operations control centres, and the globalstar data network.

Each Gateway, which is owned and managed by the service provider for the country in which the Gateway is located, receives transmissions from orbiting satellites, processes calls, and switches them to the appropriate ground network. A Gateway may service more than one country. Gateways consist of three or four antennas, CDMA processing equipment, a mobile switching centre, and equipment management. Gateways offer seamless integration with local and regional telephony and wireless networks. They utilize a standard T1/E1 interface to the existing public switched telephone network/public land mobile network (PSTN/PLMN) systems.

5.5.1.5 Ground operations control centre

The GOCC, which consists principally of computer work stations and large screen displays, is responsible for planning and management of the communications resources of the satellite constellation. The GOCC is coordinated with the SOCC, which monitors the health and status of the rest of the satellites' subsystems.

On a daily basis the GOCC generates the satellite payload instructions that sets the parameters of each satellite's communications transponder. The SOCC then transmits these commands to each satellite on behalf of the GOCC. The GOCC also generates, and sends to each gateway daily, tracking schedules for each antenna and orbital data so that antennas can be properly pointed at the assigned satellites. It also manages the amount of traffic that can be carried during a pass in order to balance the use of satellite resources such as transmit power. In addition to the planning and resource management functions, the GOCC is responsible for keeping track of service-affecting outages at the gateways, and for disseminating this information to other gateways to support roaming trouble analysis. The GOCC is also responsible for monitoring and maintaining the operational readiness of the Globalstar data network.

5.5.1.6 Satellite operations control centre

Telemetry reception: Globalstar satellites continuously transmit telemetry data, which contains orbit position data and measurements of current health and status of the spacecraft. The telemetry and command (T&C) units at selected gateways are designed to run automatically, with remote control from the on-line SOCC. The telemetry data sent from the satellites to the T&C equipment is then routed to the SOCC through the Globalstar data network. Pre-planning ensures that nominally each satellite receives a telemetry contact once per orbit.

Command transmission: Commands are sent from the SOCC through the Globalstar data network to specific T&C units, and then are immediately transmitted to a satellite. Depending upon the command, the satellite can execute the command immediately or store the command for execution at a later time. The SOCC is responsible for directing the command message to the proper T&C at the correct time for transmission to the appropriate satellite.

SOCC operations: Telemetry is routed to user workstations assigned to monitor or control specific satellites. At any one time, all satellites in contact are automatically monitored by the software, with only selected satellites directly monitored by a member of the flight operations team. A single workstation can monitor up to 6 satellites. An operations controller may have asked for up to 6 specific satellites to monitor or may have defined the criteria by which the system can automatically determine which satellites are to be monitored. For example, the controller could request to see all satellites for which real-time data is being received for which the power subsystem monitoring software detects a possible area of concern.

5.5.2 Phone products

5.5.2.1 Globalstar mobile phones

Our phones operate in either cellular or satellite mode, allowing you to stay in touch from virtually anywhere. Globalstar mobile phones, as shown in Fig. 31, are manufactured by:

- QUALCOMM (CDMA-800, AMPS-800, Globalstar modes),
- Ericsson (GSM-900, Globalstar modes), and
- Telit (GSM-900, Globalstar modes).

FIGURE 31
Globalstar mobile phones



MSS-31

5.5.2.2 Globalstar fixed phones

Our fixed products offer an innovative solution for quick, easy installation of communications in remote locations, and in areas where traditional services are not economically feasible. The Globalstar antenna is mounted at a convenient outdoor location with a clear view of the sky and connected to standard telephones using standard cable. Two fixed phone models are available:

- The Globalstar EF-200 – Designed to operate in countries where GSM 900 is the wireless network standard.
- The QUALCOMM GSP 2800/2900 – Designed for use in countries where CDMA wireless networks are used.

5.5.2.3 Globalstar car kits

Car kits provide solutions for mobile users and industries, such as, trucking, oil, and utilities, allowing professionals to maintain steady contact beyond the reach of any one cellular or terrestrial network. The car kit antenna is attached to the vehicle, and cabled inside to a cradle where the phone is mounted. The car kit allows hands-free operation providing the ability to safely receive or place calls while driving.

5.5.3 Globalstar data products

A Globalstar service provider will be able to provide a current description of available products.

5.5.4 Globalstar data services

Globalstar is currently introducing a number of different wireless data services, bringing greater functionality and convenience to customers wherever they live, work, or travel. The system's CDMA architecture is particularly well-suited to data communications, assuring users of high-quality, secure data connections for a variety of business and personal applications – on land, at sea, or in the air – at speeds similar to those currently offered by wireless cellular services.

- **Wireless Internet connectivity for PCs:** With an easy-to-use Globalstar data cable, users can quickly connect their personal computer to a Globalstar phone just as if they were plugging their PC into a conventional telephone wall socket (see Fig. 32). The computer then dials into the Internet, allowing the user to send and receive email and other Internet-based data using normal browser and mail management software. This service is not only useful for travellers who want to have data access while on the go but also for users in remote fixed locations who have no other means of connecting their PC to the Web (see Fig. 33).

FIGURE 32
Globalstar data cable

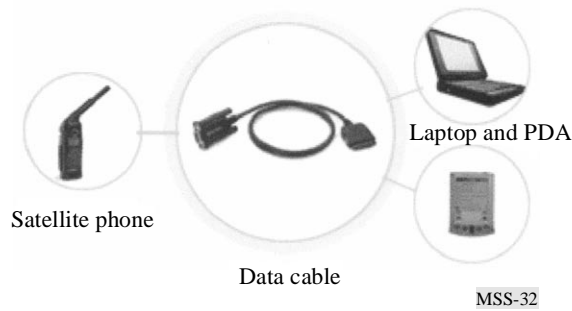
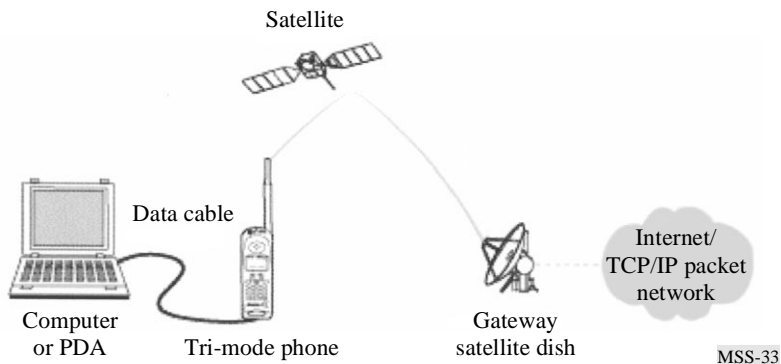


FIGURE 33
Wireless Internet connectivity



- **SCADA (supervisory control and data acquisition) data modem services:** Specially designed Globalstar data modems can automatically send and receive data from distant locations, allowing customers to remotely monitor and manage equipment and infrastructure. For example, oil pipeline operators can install Globalstar modems at various points along a pipeline to monitor throughput, pressure, and temperature, and cargo fleet managers can regularly track the location of containers and vehicles. Short bursts of data can be sent and received at very low cost, making these systems far less expensive than manual monitoring or other satellite-based systems.

Globalstar data services are provided using either circuit-switched or packet-switched protocols.

- **Circuit-switched (asynchronous) data:** This service is similar to “dial-up” Internet service that people are most familiar with for their personal use. It establishes a dedicated circuit, essentially the same as a standard voice telephone connection, and can be used for normal Internet functions (e.g. email, web browsing, etc.). To access the Internet, users dial into an Internet service provider (ISP) just as they normally would with a regular phone line connection.
- **Packet-switched data:** This service is a more efficient form of data transfer, similar to that used by DSL and cable modem connections. Users access Internet data in the same way as with circuit-switched connections and at roughly the same transfer speeds, but packet-switched connections require no ISP dial-up connection. Instead, the PC is connected directly to the Internet via the Globalstar phone.

Circuit-switched data is currently being installed throughout the Globalstar network and will be introduced market-by-market throughout 2001, starting in the second quarter. Packet-switched data became available in the United States, Canada and the Caribbean in early 2001 and will be introduced in selected other markets throughout 2001 and 2002.

5.5.5 Data speeds

Globalstar’s system architecture normally provides for 9.6 kbit/s transmission, which is similar to speeds currently available over most cellular networks and is quite adequate for sending and receiving text-based information such as email, financial data, etc. Globalstar’s CDMA architecture is also scalable, so that higher speeds may be achieved by using multiple circuits, and prototype systems have already recorded speeds of 200 kbit/s.

Globalstar is also exploring ways to improve data transfer speeds even over individual circuits. A number of options are being considered, including the adoption of Qualcomm’s HDR (high data rate) technology, which will provide 3-4 times the speed of current transfers.

5.5.6 The Globalstar advantage

Globalstar’s smart system design is based on overlapping satellite coverage so that as many as four satellites are available from any location to handle a call. This “path diversity” results in more completed calls for customers, and far fewer dropped calls.

Globalstar’s network of worldwide partners and service providers allows the company to take advantage of existing infrastructures, knowledge, technology and relationships. The use of CDMA (code division multiple access) technology results in superior voice quality and security. The 48-satellite low Earth orbit (LEO) constellation eliminates perceptible voice delay.

For additional information visit: www.globalstar.com.

5.6 Inmarsat

5.6.1 General overview

Inmarsat was the world's first global mobile-satellite communications operator. It was formed as a maritime-focussed intergovernmental organization in 1979 with a mission to provide satellite communications for ship management and distress and safety situations. Inmarsat is now a UK limited company and provides phone, fax and data communications services to maritime, land mobile and aeronautical users. There are currently (August 2001) more than 210 000 user terminals in the Inmarsat system.

5.6.2 Service and applications

Inmarsat offers a wide range of different services to cater for the requirements of maritime, aeronautical and land mobile users:

Inmarsat A

Inmarsat A is the original Inmarsat service and is based on analogue technology. It provides analogue direct dial phone, Group 3 fax, telex, and data services ranging from 9.6 kbit/s to 64 kbit/s. It also provides distress communication capabilities.

Terminals are available for use on ships and transportable terminals are available for land use. The terminals operate through the global beams. Ship terminals may be used to fulfil the requirements of GMDSS.

Inmarsat B

Inmarsat B offers similar services to Inmarsat A, but is based on digital, more bandwidth-efficient technology. Inmarsat B offers direct-dial, high quality telephone, Group 3 fax, telex, and data from 9.6 kbit/s to high-speed connections up to 64 kbit/s which can link to the ISDN. Like Inmarsat A, terminals operate through the global beams and versions for sea and land used are available. Ship terminals may be used to fulfil the requirements of GMDSS.

Inmarsat C

This is a two-way, packet data service via lightweight, low-cost terminals small enough to be hand-carried or fitted to any vessel, vehicle or aircraft. It is approved for use under the Global Maritime Distress and Safety System (GMDSS), and ideal for distributing and collecting information from fleets of commercial vessels or vehicles.

Inmarsat D+

This is a two-way data communications service from equipment the size of a personal CD player. It is available with an integrated Global Positioning System (GPS) facility for tracking, tracing, short data messaging and supervisory control and data acquisition (SCADA). Terminals can store and display up to 40 messages, each up to 128 characters. Terminals can receive tone, numeric or alpha-numeric messages.

Inmarsat E

This is a global maritime distress alerting service. An emergency position indicating radio beacon (EPIRB), measuring between 22 cm and 70 cm high and weighing about 1.2 kg, sends vessel location and an automatic message to maritime rescue coordination centres usually within two minutes of entering the water. A distress alert is forwarded to a maritime rescue coordination centre so that the appropriate action can be taken. Ship terminals may be used to fulfil the requirements of GMDSS.

Inmarsat Aero

There are three main applications for Inmarsat aeronautical services:

- Passenger services – Inmarsat services allow passengers to make phone calls and send faxes while in flight. Data services are also offered with packet mode data at up to 10.5 kbit/s and circuit mode data at up to 4.8 kbit/s.
- Air traffic control – Inmarsat aero satcoms are playing a major role in the implementation of ICAO's communications navigation surveillance/air traffic management (CNS/ATM) concept for air traffic control in oceanic and remote airspace. The Inmarsat system will support direct pilot/controller voice and data communications and automatic dependent surveillance (ADS). ADS is the reporting of position and intention information derived from the aircraft's own navigation systems. The Inmarsat Aero datalink is used for routine pilot/controller communications such as requests for clearances and advisories. Voice communications are used for non-routine and emergency communications.
- Airline operational and administrative communications – Use of a satellite datalink to integrate aircraft in-flight into airline information systems can yield significant increases in operational and administrative efficiency for the airlines. Applications include support of extended-range twin engine operations; in-flight troubleshooting of technical problems; and improved handling of irregular operations resulting from weather and other delays.

To support these applications, Inmarsat offers the following services:

- Aero-L – low speed (600 bit/s) real-time data communications, mainly for airline ATC, operational and administrative purposes.
- Aero-I – allows aircraft flying within spot-beam coverage to receive multi-channel voice, fax and circuit mode data services through smaller, cheaper terminals. Packet data services are available virtually worldwide in the global beams.
- Aero-H and H+ – provides channel rates up to 10.5 kbit/s supporting multichannel voice, fax and data communications anywhere in the global beam for passengers, operational, administrative and safety service applications.
- Aero-C – the aeronautical version of Inmarsat-C low rate data system, allows store-and-forward text of data messages – flight safety communications excluded – to be sent and received by aircraft operating almost anywhere in the world.
- Mini-M Aero – provides a single channel voice, fax of data service for small corporate aircraft and general aviation users.

Inmarsat Mini-M

This is currently Inmarsat's most popular service, offering voice, fax and 2.4 kbit/s data from a small, cost-effective phone weighing just 2 kg. The service is provided through the satellite spot beams. As well as the small portable units, terminals are also available for installation in vehicles, coastal vessels, and rural phones.

Global Area Network (GAN)

The GAN offers voice telephony and high-speed wireless data transmission at 64 kbit/s via a small terminal known as a mobile satcom unit (MSU), the size of a notebook computer. The GAN offers a choice of a circuit switched service compatible with the ISDN, or a packet data service. The circuit switched service provides a constant 64 kbit/s link which is typically used for transferring large data files, broadcast quality voice or videoconferencing. The mobile packet data service allows use of Internet compatible services such as remote LAN access, email and e-commerce. Users pay according to the amount of data sent, rather than the time spent online. An aeronautical terminal is also available, known as Swift64.

Broadband Global Area Network (B-GAN)

With the introduction of the Inmarsat-4 satellites in 2004, small spot beam coverage will be provided to most land and major maritime and aeronautical routes. The terminals, known as personal multimedia communications (PMC) terminals will operate to the high gain satellite antennas which allows the use of smaller terminals and higher bit rates. Bit rates up to 432 kbit/s will be possible.

Navigation

The Inmarsat-3 satellites also carry navigation payloads designed to enhance the accuracy, availability and integrity of GPS and GLONASS. The payloads transmit to the user at the same frequency as GPS. Data supplied to users via the payloads allow satellite navigation to meet the stringent reliability, availability and integrity requirements set by air traffic control (ATC) and maritime authorities. Land-based users are also be able to take advantage of the resulting improvements in positioning accuracy.

The Inmarsat-3 navigation transponders form an integral part of the Wide Area Augmentation System (WAAS) and European Geostationary Navigation Overlay System (EGNOS), which enhance availability, integrity and accuracy of the primary GPS and GLONASS navigation signals over North America and Europe.

5.6.3 System architecture

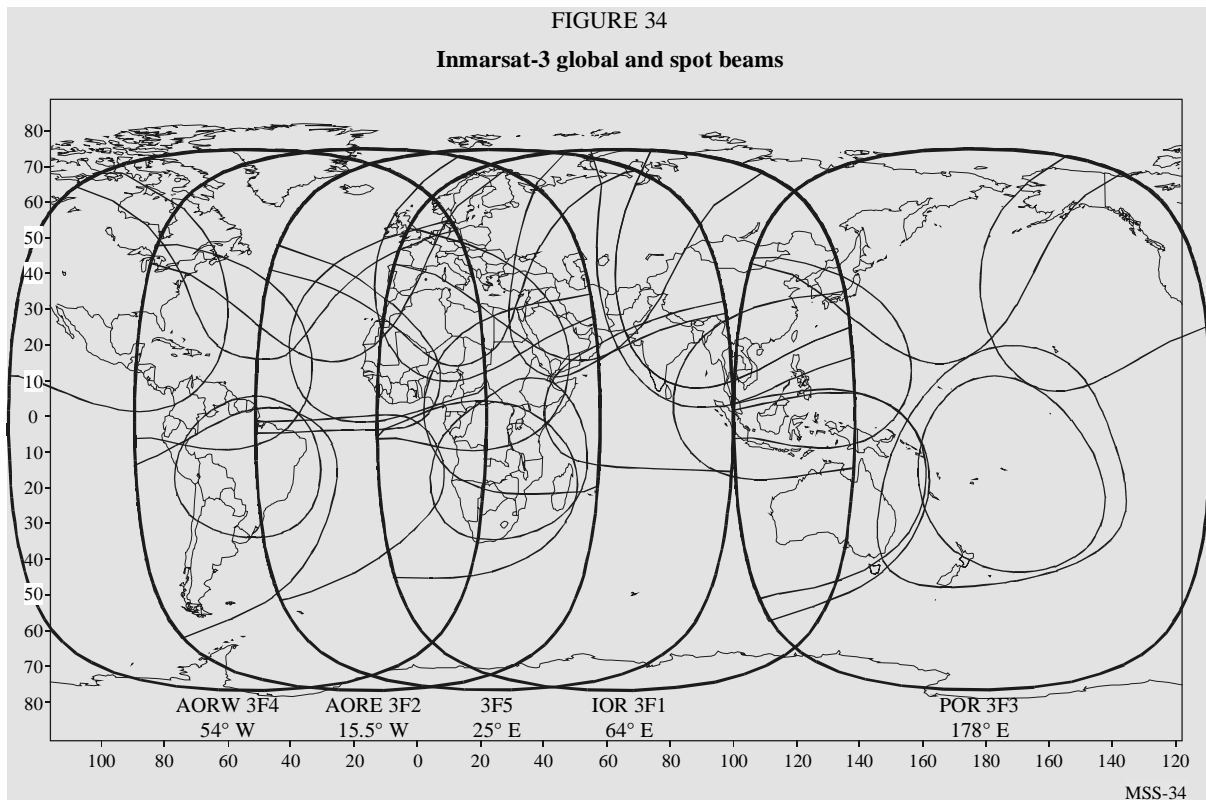
The Inmarsat system is based on a number of satellites in geostationary orbit. The service links operate in L-band spectrum (1 525-1 559 MHz paired with 1 626.5-1 660.5 MHz). Feeder links and TT&C operate in C-band spectrum (around 3.5 GHz and 6.4 GHz).

Traffic to and from the user terminals is carried by land earth stations (LESs) which provide connection to and from the terrestrial networks. Network control stations (NCSs) perform the functions associated with set up, monitoring and termination of the traffic through each satellite. These are operated centrally by Inmarsat and do not pass customer traffic. They are usually co-sited at an LES and utilize the RF and antenna system of the LES. The satellites are controlled from the satellite control centre (SCC) in London which interfaces to the satellites through four TT&C stations located in Italy, China, western Canada and eastern Canada. There is a back-up station in Norway.

5.6.3.1 Constellation

The Inmarsat system of geostationary satellites is currently based on the establishment of 4 ocean regions. Each ocean region is served by one of the third series of Inmarsat satellites, Inmarsat-3s. Figure 34 shows the beam patterns of the four prime Inmarsat-3 satellites.

Ocean region	Orbital location
Pacific	178° E
Atlantic-West	54° W
Atlantic-East	15.5° W
Indian	64° E



5.6.3.2 Space segment

The four Inmarsat-3 satellites operate global beams which together provide global coverage apart from the poles. The satellites also operate wide spot beams which through the use of high gain satellite antennas allow the use of smaller user terminals or higher bit rate services. The spot beams cover land, major aeronautical routes, coastal areas and major maritime routes.

There is also a fifth Inmarsat-3 satellite and four previous generation Inmarsat-2 satellites in operation. These are located at the four key locations to provide instantaneous backup, or are located at other orbital locations to carry additional traffic.

Inmarsat is currently developing its fourth generation satellites, Inmarsat-4s. Two satellites will be launched initially and located at the Atlantic West and Indian Ocean regions. A third satellite will initially be maintained as a spare. These satellites will provide the same global beam and wide spot beam services as the Inmarsat-3s, but will also provide small spot beam coverage of most land and major maritime and aeronautical routes. The small spot beams will allow for the introduction of smaller, broadband mobile terminals.

Technical characteristics are described in Tables 26 to 28.

TABLE 26
Spacecraft overall

	Inmarsat-3	Inmarsat-2	Inmarsat-4
Launch period	1996-1998	1990-1992	2003-2004
Launch mass	2 066 kg	1 300 kg	6 000 kg
Power	2.8 kW (end of life)	1.2 kW (initial)	12 kW (end of life)
L-band e.i.r.p.	49 dBW	39 dBW	67 dBW (aggregate e.i.r.p. on narrow spot beams)
Bus	Lockheed Martin Astro Space Series 4000	Matra/BAe Eurostar	Astrium's EUROSTAR 3000
Launchers	Atlas IIA, Proton, Ariane 4	Delta, Ariane 4	Ariane 5 and Atlas 5

TABLE 27
Inmarsat-3 communications subsystem performance

Repeater	All solid state multi-carrier linear system	
Service link options	C-L, L-C, C-C, L-L, and navigation	
Antennas	Separate transmit and receive for L-band and C-band. Single navigation antenna. Focal plane array, offset-fed, deployed reflectors for congruent L-band transmit/receive global and spot-beam coverage. C-band horns and L-band centre-fed provide global coverage.	
<i>G/T</i>	6.4 GHz global (C-C, C-L, and navigation) 1.6 GHz global (L-C and L-L) 1.6 GHz spot	-13 dB/K -11.5 dB/K -5.5 dB/K
e.i.r.p.	L-band	49 dBW, switchable between global and spot in any proportion of the total e.i.r.p.
	C-band	
	Navigation	

TABLE 28

Inmarsat-4 communications subsystem performance

Repeater	Transparent bent-pipe repeater utilizing a digital channelizer, providing 630 × 200 kHz channels on each of the forward and return links, with a digital L-band beamformer allowing the generation of different types of beams. The basic L-band coverage relies on around 200 narrow spot beams (1.2°, 3 dB beamwidth), 19 wide spot beams (4.5°, 3 dB beamwidth) and one global beam. All power amplifiers are solid state, and utilize linearisers	
Service link options	C-L, L-C, C-C, L-L and navigation	
Antennas	Separate transmit and receive for C-band and single antenna for L-band. Single L-band centre-fed navigation antenna provides global coverage. Focal plane array, offset-fed, deployed unfurlable reflector for L-band transmit/receive, producing the global and spot beam coverages. C-band horns provide global coverage. Single navigation antenna	
G/T	L-band = 10 dB/K for narrow spot beams = 0 dB/K for wide spot beams = -10 dB/K for global beam C-band = -11 dB/K	
e.i.r.p.	L-band	67 dBW aggregate e.i.r.p. for narrow spot beams. Can be continuously shared with wide spot beams and global beam
	C-band	31 dBW/polarization
	Navigation	28.5 dBW

5.6.3.3 Mobile terminals

The Inmarsat system supports a wide range of terminal types to provide solutions to a wide range of users – land, aeronautical or maritime. The terminals are not manufactured by Inmarsat but by a number of different manufacturers. For each terminal type listed in Table 29 there are therefore a number of different models which are available to the user. All will fulfil the generic requirements and meet the appropriate equipment standards, but there will be differences in the design and some features of the terminals.

TABLE 29

Inmarsat terminal types

Terminal	Typical antenna gain (dBi)	Voice	Data rate	Beam of operation
Inm-A maritime	22	✓	9.6-64 kbit/s	Global
Inm-A transportable	22	✓	9.6-64 kbit/s	Global
Inm-M portable	14	✓	4 kbit/s	Global/spot
Inm-M maritime	16	✓	4 kbit/s	Global/spot
Inm-M vehicular	12	✓	4 kbit/s	Global/spot
Inm-M fixed	29	✓	4 kbit/s	Global/spot
Inm-B transportable	22	✓	64 kbit/s (ISDN)	Global/spot
Inm-B maritime	22	✓	64 kbit/s (ISDN)	Global/spot
Inm-B fixed	29	✓	64 kbit/s (ISDN)	Global/spot

TABLE 29 (end)

Terminal	Typical antenna gain (dBi)	Voice	Data rate	Beam of operation
Inm-mini M portable	10-12	✓	2.4 kbit/s	Spot
Inm-mini M vehicular	7-10	✓	2.4 kbit/s	Spot
Inm-mini M maritime	7-10	✓	2.4 kbit/s	Spot
Inm-mini M rural	18	✓	2.4 kbit/s	Spot
Inm-mini M aero	6	✓	2.4 kbit/s	Spot
Inm-C maritime	Omni	x	600 bit/s	Global
Inm-C land mobile	Omni	x	600 bit/s	Global
Inm-D/D+	Omni	x	–	Global/spot
Inm-E maritime	Omni	x	–	Global
Aero-H	12	✓	G3 fax at 4.8 kbit/s packet data at 10.5 kbit/s	Global
Aero-H+	12	✓	G3 fax at 2.4 kbit/s packet data at 10.5 kbit/s	Global/spot
Aero-I	6	✓	600-4 800 bit/s	Global/spot
Aero-L	Omni	x	600-1 200 bit/s compatible with X.25 networks	Global
Aero-C	Omni	x	600 bit/s	Global
Swift64	12	✓	64 kbit/s circuit mode (ISDN) and packet data	Spot
Mobile satcom unit (GAN)	18	✓	64 kbit/s circuit mode (ISDN) and packet data	Spot
PMC (B-GAN)	7.5-16.5	✓	72-432 kbit/s	Inm-4 small spot

5.6.3.4 Gateway earth station

There are two types of gateway earth stations, described below:

Land earth stations (LESs) are sometimes referred to as coast earth stations (CES) or ground earth stations (GES) in the maritime and aeronautical environments respectively. In 1998, there were about 40 LESs distributed around the globe, with at least one on every continent. The LESs form the interface between mobile earth stations (via the satellites) and the terrestrial network. They are often – but not always – owned and operated independently by the signatory of the country in which the LES is located. The signatory is the entity nominated by the government of the country to invest in, and work with Inmarsat. An LES may have up to three antenna systems in areas where three operational satellites are visible, and often have bilateral agreements with LESs in other regions to provide a global service in the fixed-to-mobile direction.

Network control stations (NCSs) coordinate each service through each satellite. These are operated centrally by Inmarsat and do not pass customer traffic. They are usually co-sited at an LES and utilize the RF and antenna system of the LES. Equipment and/or site redundancy is also built-in to ensure high network availability.

5.6.4 Web site

Further information can be found at: www.inmarsat.com.

5.7 THURAYA system description

5.7.1 Introduction

Thuraya Satellite Telecommunications Company (“Thuraya”) operates a global mobile personal communications by satellite (“GMPCS”) system on a regional basis. Thuraya’s first satellite was launched on 21 October 2000 and the commercial operations were initiated from the second quarter of 2001.

Thuraya provides advanced voice, data, fax, messaging through a flexible dual mode handset. Thuraya is introducing various types of end-user terminals, such as fixed, semi-fixed, vehicular terminals, payphones and maritime terminals to suit all kind of applications and customers.

Thuraya was incorporated in April 1997 in the United Arab Emirates (UAE), as a private joint stock company enjoying a corporate personality. The founders of the Thuraya Satellite Telecommunications Company consist of prominent national telecommunications operators, sound financial investors, a regional satellite operator and a leading satellite manufacturer.

5.7.2 Technical overview

5.7.2.1 Space segment

The Thuraya program consists of two 3-axis stabilized geostationary satellites equipped with high power multiple spot beam mobile payloads. There is one satellite in orbit at 44° E and one as a ground-based spare. The second satellite will be launched after the first to provide more capacity and backup.

The satellite transmits and receives calls through a single 40 ft. (approx. 12 m) aperture antenna and using 250-300 spot beams to provide mobile telephone services that are compatible with GSM. Onboard digital signal processing routes the calls directly from one hand-held unit to another, or to the terrestrial network. The satellite system provides up to 13 750 simultaneous duplex channels to support the following communication links: gateway-to-mobile link, mobile-to-gateway link, and mobile-to-mobile link.

The system provides the flexibility to accommodate changes in Thuraya’s traffic by means of a re-programmable payload in the satellite. This supports modifications to the satellite’s coverage area after launch and optimization of performance over geographical areas where high traffic demand exists. The processor creates a large number of spot beams that can be redirected, wherever this is needed, even after the satellite is placed in orbit: from big cities or rural areas to ships at sea.

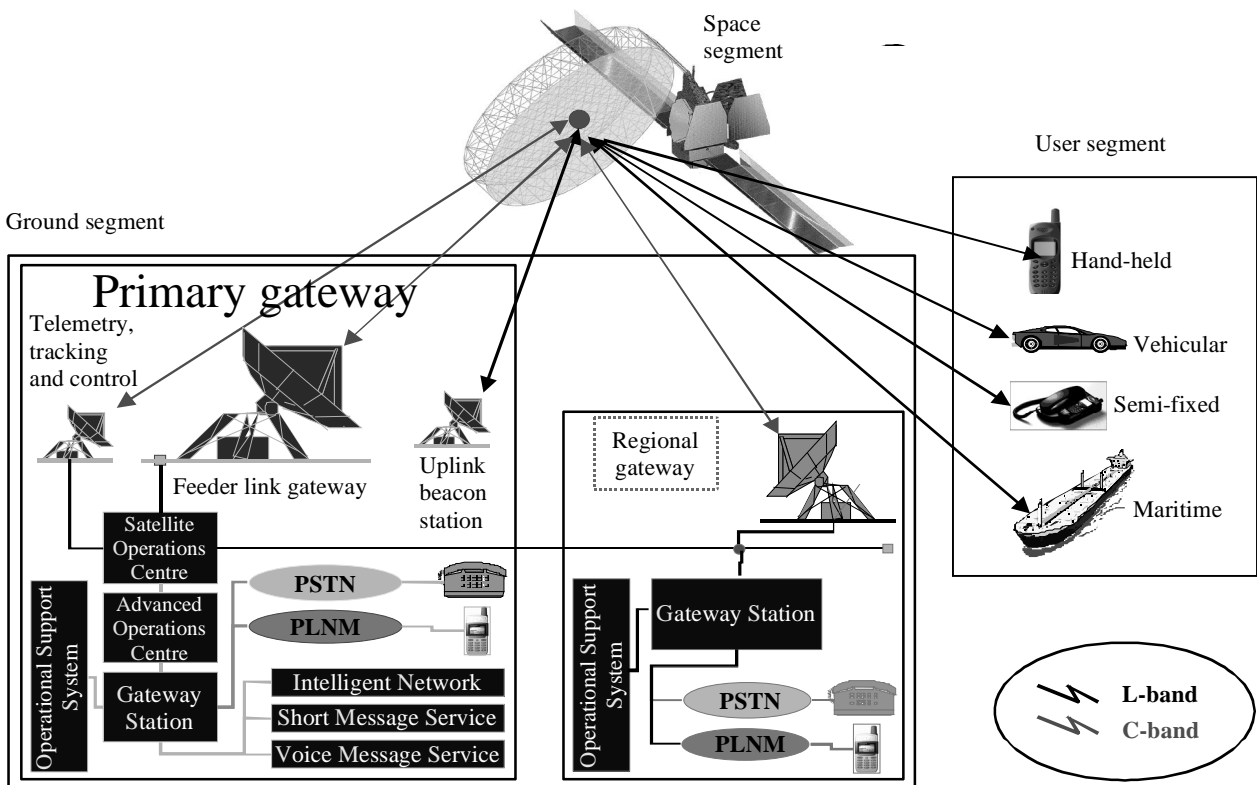
5.7.2.2 Ground segment

The ground segment consists of a primary gateway located in the UAE, which have overall control of the whole Thuraya network. The primary gateway consists of the following elements:

- The advanced operations centre (AOC) provides central management of the shared satellite resources and configures the satellite payload accordingly.
- The satellite operations centre (SOC) operates and maintains the satellite on station and with the proper orientation.

- The gateway stations (GS) provides access to the public switched telephone network (PSTN) for originating and terminating calls with mobile users, and provides access to the public land mobile network (PLMN) and public switched data network (PSDN) via the PSTN. Direct connection of signalling and trunks to the PLMN is also supported.
- The operational support system (OSS) provides the functionality for centralized customer care and billing, and the chipcard personalization and centralized network switching system (NSS) management.
- Regional gateway operators can own and operate the regional gateways. The interface with the other Thuraya gateways will be carried out via satellite and the public fixed and mobile terrestrial networks.

FIGURE 35
Thuraya system architecture



5.7.3 Thuraya user terminals

There are five types of user terminals:

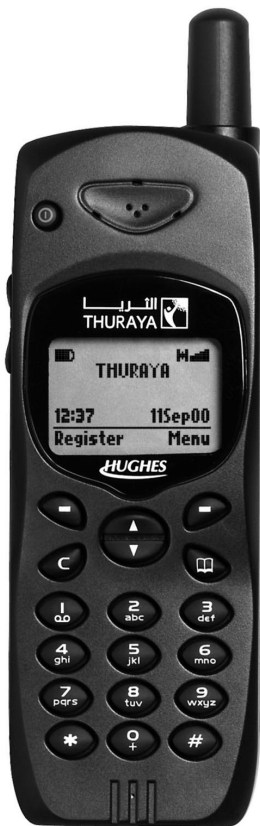
- 1 Hand-held terminals
- 2 Payphone terminals
- 3 Vehicle mounted terminals
- 4 Home/office docking unit (SATEL)
- 5 Maritime terminals (optional).

Hand-held, vehicle and maritime terminals have a dual-mode option, while the home/office docking terminals have the satellite mode only. The dual-mode terminal equipment utilizes a single SIM card for both satellite and GSM modes.

5.7.3.1 Hand-held terminal

The hand-held terminals are being manufactured by Hughes Network Systems (USA) and ASCOM (Switzerland). These terminals weigh 220 grams each and have a built-in facility to receive the signals from the global positioning system (GPS) in order to determine the user's location for the user display and network access.

FIGURE 36
Thuraya user terminals



HNS 7100



SATEL



ASCOM 21

5.7.3.2 SATEL

This product allows the usage of the Thuraya hand-held terminal in an indoor environment such as home or office. SATEL will complement the Thuraya hand-held terminal by extending its operations and functionalities inside buildings where the satellite signal is not sufficient. The physical mating of the Thuraya hand-held terminal with the SATEL is easy and straightforward by simply docking the hand-held terminal into the designated slot of the SATEL. All the standard satellite-based services such as voice, fax and data and the supplementary services will be available when the hand-held terminal is docked into the SATEL.

5.7.3.3 Vehicular docking adapter (VDA)

It provides a station for the HHT recharging and in-vehicle operations. VDA will complement the Thuraya hand-held terminal by extending its operations and functionalities in mobile dynamic environments. The physical mating of the Thuraya hand-held terminal with the VDA is easy and straightforward by simply docking the hand-held terminal into the designated slot of the VDA.

5.7.4 Thuraya Air Interface

The European Telecommunication Standardization Institute (ETSI) and the Telecommunications Industry Association (TIA) have worked together to develop the Air Interface specifications for the Thuraya satellite system. These specifications are named as Geo Mobile Radio – 1 (GMR-1) and the specifications are derived from the GSM standard. This approach is two-fold as mobile telecommunication services will be available through satellite based on a standard that incorporates most of the features of the GSM.

The GMR-1 air interface has been derived from the GSM standard but it also incorporates certain additional and important features that optimizes it for the peculiarities inherent in satellite communications. The GMR-1 standard also supports the GSM phase 2 services such as SMS, cell broadcast, etc.

5.7.5 Type approval

The Thuraya terminals comply with the relevant ITU, ETSI and IEEE specifications regarding electromagnetic compatibility and interference and radiation safety.

5.7.5.1 ITU GMPCS MoU certification

Thuraya is also a signatory to the GMPCS-MoU and as such will adhere to all the conditions and regulations attached to the GMPSC-MoU. Thuraya signed the GMPCS MoU on 20 May 1998.

Thuraya and its hand-held terminal manufacturers Hughes Network Systems and Ascom have complied with all the relevant ITU GMPCS MoU procedures as well as with the relevant standards and specifications. As a result, the ITU has authorized the Thuraya hand-held manufacturers to affix the ITU GMPCS MoU mark as a sign of compliance with the relevant specifications.

5.7.5.2 Regional regulatory authorization

A number of necessary regulatory authorizations facilitate the introduction of Thuraya services in Europe. These Decisions and Recommendations are processed and approved by the relevant subordinate bodies of the European Committee for Posts and Telecommunications (CEPT), namely the European Committee for Telecommunications Regulatory Affairs (ECTRA) and European Radiocommunications Committee (ERC) respectively.

The following two Decisions were approved by the ERC during its meeting that was held in March 2001:

- **ERC/DEC/(01)24**
ERC Decision on Free Circulation and Use of Thuraya Mobile User Terminals in CEPT Member countries.
- **ERC/DEC/(01)25**
ERC Decision on Exemption from Individual Licensing of Thuraya Mobile User Terminals in CEPT Member countries.

The following ECTRA Recommendation was approved by the joint ECTRA and ERC meeting that was held in July 2001:

- **ECTRA/REC(01)02**
ECTRA Recommendation on Milestone Compliance of S-PCS in Europe operating within the bands 1 525-1 544/1 545-1 559 MHz and 1 626.5-1 645.5/1 646.5-1 660.5 MHz.

5.7.6 Frequency spectrum

The frequency bands 1 525-1 559 MHz and 1 626.5-1 660.5 MHz were allocated on a generic basis to the mobile-satellite service by the World Radiocommunication Conference 1997. Thuraya is part of the Regions 1 and 3 GSO/MSS L-band multilateral meeting memorandum of understanding (MLM MoU) frequency coordination framework and has been assigned spectrum in the 1 525-1 559 MHz/1 626.5-1 660.5 MHz band during the First Regions 1 and 3 L-band GSO/MSS operators review meeting (ORM). This coordination process is a multilateral process as per the ITU regulations and as such recognized by the ITU and participated by all other GSO satellite operators and networks.

The Thuraya system will use the following frequency bands for the provision of Thuraya services:

User links	1 525-1 559 MHz (space-to-Earth) 1 626.5-1 660.5 MHz (Earth-to-space)
Feeder links	3 400-3 625 MHz (space-to-Earth) 6 425-6 725 MHz (Earth-to-space)

5.7.7 Thuraya services

Basic Services

- | | |
|-----------------|--|
| Teleservices | – Voice telephony
– Emergency services
– Group 3 fax
– SMS beam broadcast |
| Bearer services | – Asynchronous data services (2.4-9.6 kbit/s) |

Supplementary services

- Call forwarding, barring, waiting, hold
- Calling line identification presentation (CLIP)
- Advice of charge
- Conference calling
- Closed user group service

Value-added services

- Short message service (SMS)
- Voice mail
- Operator assisted services
- Interactive voice response (IVR)
- Prepaid services
- Hot billing

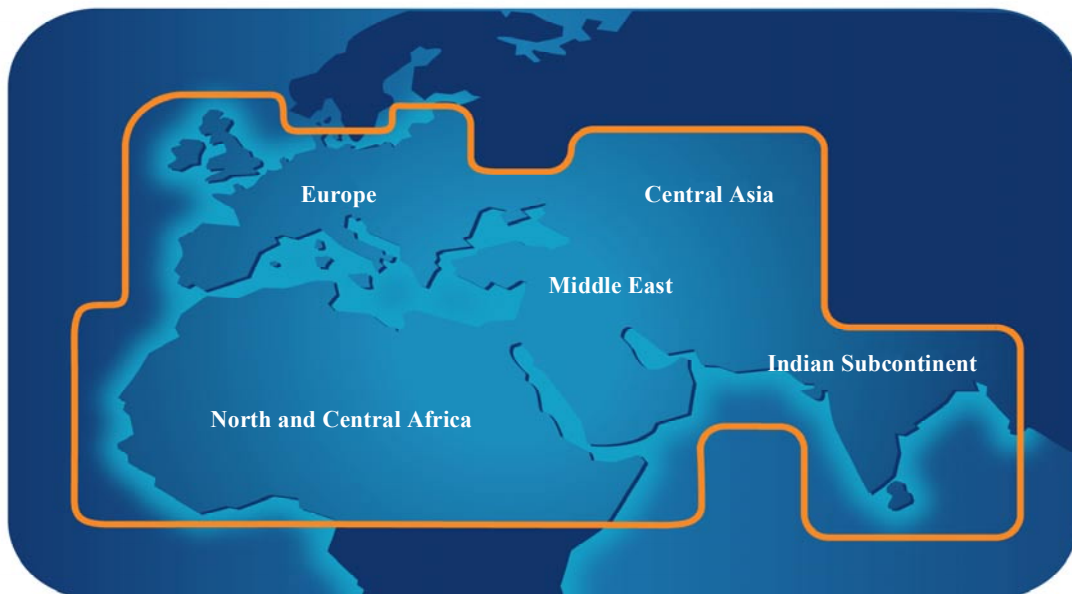
5.7.8 Coverage area

The Thuraya system will cover approximately one fifth of the landmass of the Earth, comprising 99 countries with a total population of about 2.5 billion people and a combined GNP of roughly US\$ 3.1 trillion. However, this area contains only about 130 million fixed telephone lines (excluding Western Europe). While some countries within the coverage area are among the world's wealthiest nations, many are developing economies that face enormous challenges to improve the accessibility and quality of fixed and/or mobile telecommunications.

Thuraya also plans to expand its coverage area with its second satellite to cover another region.

FIGURE 37

Thuraya coverage area



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5.7.9 Thuraya service providers

Thuraya has appointed a number of service providers throughout its coverage area.

5.7.10 Thuraya roaming agreements

Thuraya has signed a number of roaming agreements with GSM operators in different countries in Asia, Africa, Europe and Australia.

5.7.11 Contact information

Email: info@thuraya.com

Web site: www.thuraya.com

Tel No.: + 971 2 6422222

Fax No.: + 971 2 6419797

5.8 FAISAT™ global wireless system

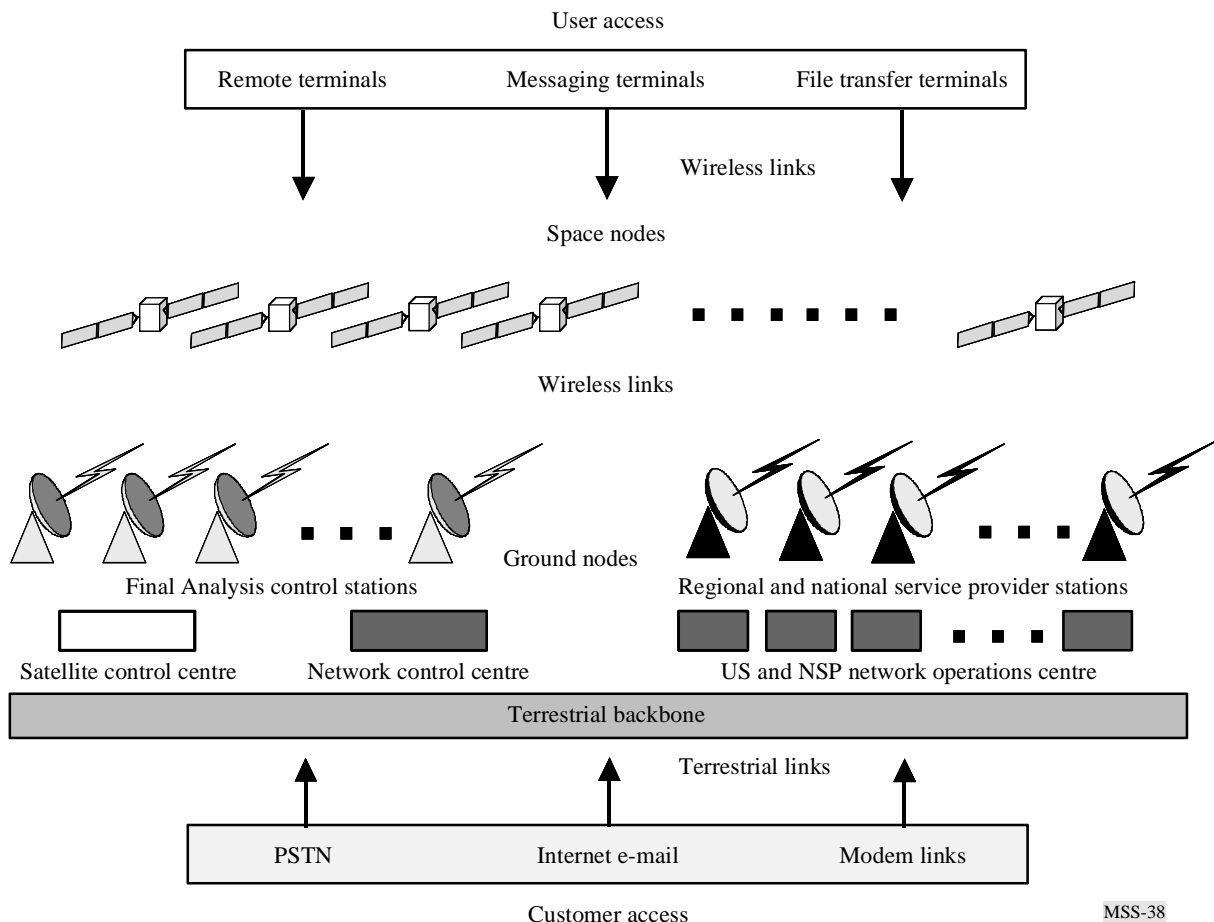
5.8.1 Introduction

This section provides a high-level overview of the FAISAT™ global wireless system, a global system being built by Final Analysis that will provide mobile wireless data and Internet services for commercial, government and consumer applications. Final Analysis' satellite and ground infrastructure construction and deployment is being led by the Company and its strategic partners and investors, including General Dynamics, Raytheon, L-3 Communications and Polyot of Russia. Initial commercial service will begin in 2003 and the full constellation of satellites is expected to be deployed in 2004. Readers may wish to check the Final Analysis web site at <http://www.finalanalysis.com/> for additional information.

5.8.2 System overview

The FAISAT system is a global data packet network. The constellation of satellites in low Earth orbit creates space-based “network nodes” for wireless user access from small user terminals. The ground segment provides local network nodes for wireline user access. The satellites are connected to the ground elements of the network through RF links to ground stations. (Fig. 38).

FIGURE 38
FAISAT global packet network



FAISAT has two constellation orbit designs:

- the currently licensed design, and
- a modified design currently under review for approval by the U.S. Federal Communications Commission (FCC). FACS has been licensed by the U.S. FCC to deploy a “little LEO” non-voice, non-geostationary system consisting of a constellation of 26 operational and 4 in-orbit spare satellites. FACS has also requested authorization to build an enhanced system consisting of a constellation of 32 operational and 6 spare satellites. The added satellites increase overall coverage, including the amount of overlap (redundancy). FACS also proposed a lower orbit inclination to provide a more robust coverage profile for the most populated regions of the Earth.

The ground nodes of the network complete the FAISAT network design. Ground nodes consist of the RF ground stations (the space-to-ground network backbone link) and network operations centres (the wireline user access points).

5.8.2.1 Operations concept

These services are provided locally, regionally, and globally in three modes of operation: real-time, near real-time and store and forward. Messaging in each mode can be scheduled and/or event-driven. The commercial services will have additional features such as those found with other packet data systems, including group broadcast, unique alert message handling, reliability assurance techniques, international seamless roaming and optional acknowledgement.

5.8.2.2 Frequency plan

The FCC has assigned to Final Analysis some of the spectrum that has been allocated for little LEO use by the World Radiocommunication Conferences (WRC) convened by the ITU. Further, work is continuing to obtain additional allocations for mobile-satellite systems operating below 1 GHz (little LEO) in the UHF and L-bands (the latter spectrum for feeder links). Consequently, Final Analysis has both assigned and to-be-assigned spectrum to consider in the frequency plan.

The current frequency plan for the Final Analysis system is shown in Table 30.

TABLE 30

Final analysis frequency plan

Link	Channel (MHz)	ITU allocation	Centre frequency (MHz)
Downlink (Service links or feeder links)	137.0-138.00	WARC 1992	Various
Service uplinks	148.0-149.9	WARC 1992	Various
Service uplinks	454-456	WRC 1995 and WRC 1997	Various
Service uplinks	459-460	WRC 1995	Various
Feeder uplink	150.0-150.050	WARC 1992	150.025
Downlink (Service links or feeder links)	400.505-400.645	WARC 1992	400.5284 400.5750 400.6217

The satellite design will accommodate a broad range of frequencies and the capability will exist to dynamically allocate channels as licensing conditions mandate in different countries and regions of the world.

Final Analysis is required to share certain frequencies with other satellite systems including other little LEO systems and international meteorology satellite systems in the above bands. Frequency sharing with the fixed and mobile systems and the other little LEOs in the uplink bands is primarily accomplished via a satellite onboard dynamic frequency assignment algorithm based on temporarily unused channels. Frequency sharing with the meteorology satellites is accomplished through transmitter and frequency switch control during periods when the footprints of the satellites overlap.

5.8.2.3 Satellite and ground segment operations

Satellite operations will be conducted from a single, centralized satellite control centre (SCC). The SCC will monitor the status, configuration, and performance parameters and send control commands to each station. In this way the ground stations are controlled in context with satellite operations, and these sites can be unmanned except for periodic preventive and corrective maintenance.

Network operations involve the monitoring and control of the overall end-to-end global network including the network control centre (NCC), the set of network operations centres (NOC), the communications payload, user terminal interfaces, and the terrestrial backbone. A distributed, two-tier network operations approach is envisioned. The NCC is the top tier of network management, performing network configuration, system monitoring and control and other network control functions.

The second tier of network operations is the network operations centres (NOCs). The NOCs provide network monitor and control to the local service area including NOC internal operations and the final mile of network service out to customers and/or value-added reseller (VAR) application centres. NOCs are owned and operated by the national service providers (NSPs).

5.8.2.4 Messaging capability

The Final Analysis system is uniquely designed for packet data burst type communications. Short bursts (under 450 ms) from user terminals will transmit user messages in the form of data packets. Data packets are variable in size and range from 10 to 20 to approximately 512 bytes. Strings of packets can be assembled to transmit larger messages or files.

5.8.2.5 Commercial applications

Final Analysis has targeted three major service applications:

- Wireless messaging
- Data acquisition, monitoring and control services
- Asset management.

Wireless email applications, with mass market appeal, include business messaging and remote information access enabling mobile employees to exchange messages and to enable access to web sites tailored for mobile communications systems (web clipping). In the enterprise services categories, **data acquisition applications** include inventory management and control, automated meter reading, vehicle telematics, supervisory control and data acquisition (SCADA) and remote diagnostics. This group of applications covers measurements, monitoring, and control of remotely-located field asset elements. **Asset management applications** include more efficient management of mobile assets and workforces, and theft control.

5.8.3 Element description

5.8.3.1 Space segment

The space segment consists of a constellation of low Earth orbiting satellites that provides wireless user access to the global data packet network. The satellites are a single design produced in quantity and deployed in a series of launches. The satellites are small and selectively redundant with a 7-year design life.

The communications payload consists of the flight radio and flight antennas, which provide the communications capability for commercial data messaging operations and for satellite control.

The radio will have multiple receive and transmit channels and groups of shared band modems. Both transmitters and receivers are capable of operating in the VHF, UHF and L-band frequency bands.

5.8.3.2 FAISAT ground segment

The satellite control centre provides the capability to control the space segment. The SCC is a distributed processing system with modular and expandable workstations connected to a LAN. Located at the main Final Analysis facility, the SCC interfaces with the remote FAISAT ground stations and the network control centre to coordinate operations of the space segment within the context of the overall network.

The NCC provides global network management, switching across regions, system performance analysis, customer service support to NOCs, constellation-level planning, coordination with the satellite control centre, and logistics support.

Ground stations are unmanned, and will consist of tracking antennas, RF equipment (receivers, demodulators, transmitters, modems, etc.) and interface equipment for RF communications with a complete back-up suite of equipment. The ground stations provide service link, feeder link, and TT&C link RF communications in support of satellite command and control and network commercial data messaging operations. Final Analysis will own RF ground stations in the U.S. and select locations overseas.

The terrestrial backbone is the network of links connecting the ground stations to the SCC, the NOCs to the NCC, and the NOCs to their ground stations.

5.8.3.3 NSP ground segment

The national service providers (NSPs) will procure, install, and operate additional RF ground stations that augment and extend the ground nodes of the network beyond those owned by Final Analysis. NSP ground stations are similar to the Final Analysis ground stations. They provide feeder link connectivity from the local NOC to the satellites for more robust, quicker delivery of data messages.

The NSP ground stations are unmanned stations consisting of a tracking antenna, RF equipment, digital data handling equipment, and network interfaces.

The NSP network operations centres provide the full complement of local network management, including control, performance monitoring, message processing and routing, data archiving, logistics support, sales information services, direct customer service, and wholesale and retail billing.

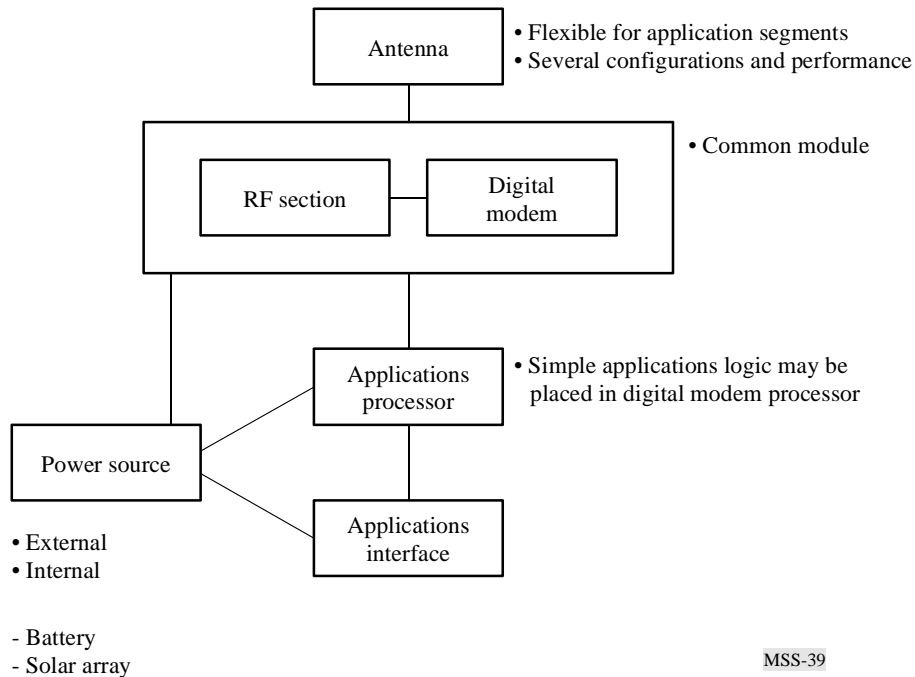
5.8.3.4 User segment

User terminals will be produced in a variety of shapes, sizes, and variations as needed for each market segment and application.

User terminals have several main functional elements (Fig. 39). A core terminal module is common across all market segments and provides the basic capability for wireless communications with the satellite. This module consists of an antenna, a RF module, a processor module, and a modem module.

FIGURE 39

User terminal block diagram



The terminals will be mass-produced and sold by the NSPs and VARs to the customer/end user. Terminals can be configured with a variety of antenna options ranging from patch to whip to hat antennas. They will be powered in several ways as needed by the market.

5.8.3.5 Launch segment

Final Analysis has secured the launch services provided by the Cosmos rocket, manufactured by Polyot of Russia. Of the six launches planned, there will be four launches of six satellites each (the 6-pack configuration) to the four mid-inclination planes and two launches to the high inclination planes. The last two launches will be piggyback opportunities.

5.8.4 Summary

The FAISAT global network will provide wireless data and Internet services for commercial, government and consumer applications. The system will provide mobile data and messaging services to target markets, including wireless messaging for email and other Internet-related services; mobile asset management for transportation applications; and data acquisition, monitoring and control services. Final Analysis plans to begin launching in 2002 with full constellation deployment in 2004. Through state-of-the-art technology, the FAISAT network will enable data messaging and data communications services to be available globally and specifically in areas where previously such services could not be provided.

5.9 New ICO Global Communications (“New ICO”)

5.9.1 Introduction and purpose

The primary objective of New ICO is to build on the existing platform developed by ICO to assemble the global networks, distribution capabilities and operations systems necessary to become a leading provider of global data and enhanced voice services.

New ICO is well qualified in its corporate and financial capacities to provide services worldwide through the New ICO network. New ICO also possesses the requisite technical capacity and business experience to serve global markets. New ICO’s financial strength is evidenced by the financial strength of its principal stockholders Craig O. McCaw; Clayton, Dubilier & Rice and William H. Gates III.

5.9.2 Technical characteristics of the New ICO network (NIN)

The key features of the New ICO system are shown in Fig. 40. The New ICO infrastructure, which consists of the space and ground segments, provides a means for New ICO users to connect with each other or to users connected to an existing terrestrial network. A New ICO user (on foot, in a car, on a plane, at home, at the office, or on a ship) begins a session by communicating directly with one of the satellites that comprise the New ICO space segment. The satellite receives the user’s signal, and transmits it to one of 12 satellite access nodes (SANs) that, together with the fiber optic links that interconnect them, make up the ground segment called ICONET. At the SAN, the signal is demodulated, decoded and routed towards its final destination which could be another New ICO terminal or a public network. Messages to other users of the New ICO network are routed via a fiber optic link to a SAN in the recipient’s service area, and then to an appropriate satellite, which retransmits it back to Earth. Messages to recipients not on the New ICO network are routed from the SAN to a public network. Conversely, messages from public networks are routed through the ICONET to the satellite serving the New ICO user. In addition to carrying voice and data generated by New ICO users, the ICONET is also designed to carry third-party voice and data traffic.

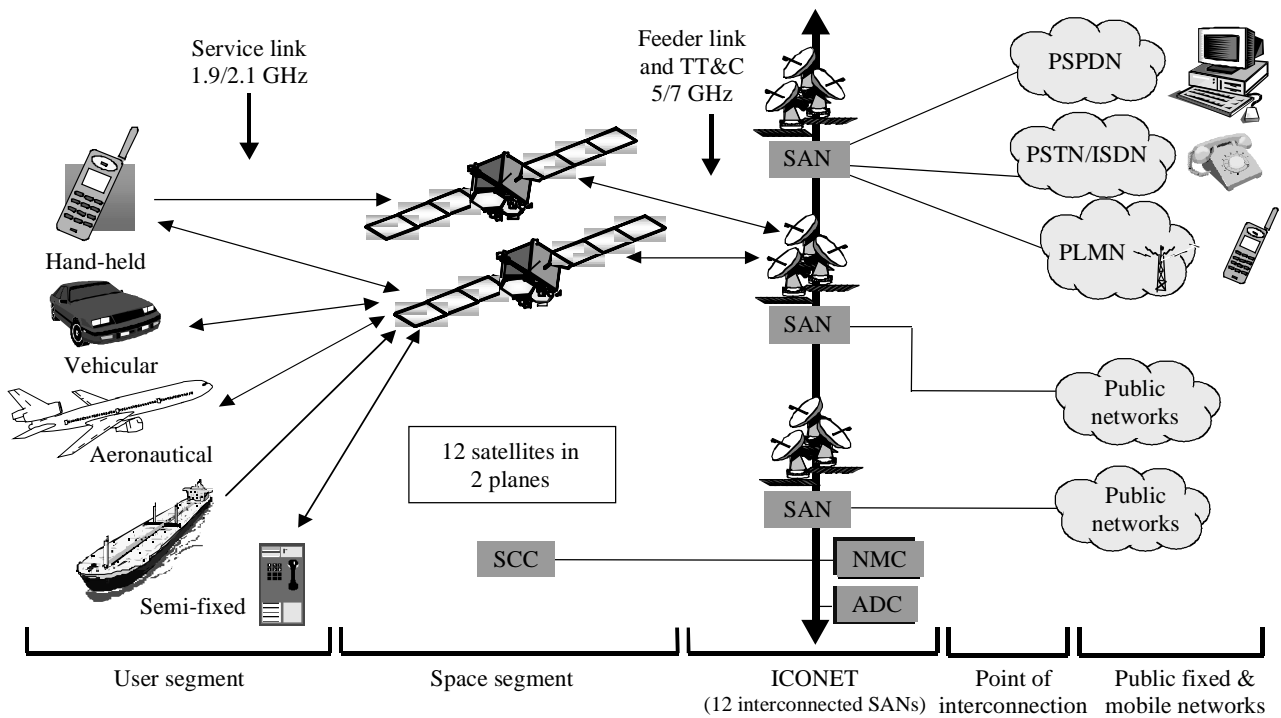
Key features of the New ICO network (NIN) include:

- the ability to support a wide range of user equipment;
- the air interface, a communications protocol similar to that employed by cellular systems, that allows user equipment to communicate with the network. The air interface, to be incorporated in the user equipment and ground stations, will be developed to permit some user equipment to network through the satellites at data rates up to 144 kbit/s;
- a constellation of 12 satellites in medium Earth orbit, enabling high call completion rates and global coverage; and
- a ground segment called ICONET, comprising 12 SAN earth station facilities interconnected by high capacity links.

The New ICO network is designed around the philosophy of minimizing complexity and maximizing flexibility. This has primarily been achieved by designing the satellites as “bent pipes” that convert in frequency, amplify and retransmit signals between the ground segment (ICONET) and the user equipment. The New ICO network relies on its ground segment to perform the

complex signal processing required to demodulate and decode the signal, and determine the optimum route to its final destination. Global connectivity is achieved through SANs interconnected through fiber optic cables, and large satellite footprints that offer truly global coverage, including the oceans and poles. The use of satellites that act as “bent-pipes” and a network of inter-connected SANs also provides the flexibility needed to increase capacity and introduce new services without modifying the space segment.

FIGURE 40
The new ICO system configuration



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The design of the New ICO network ensures high service quality through several elements, including:

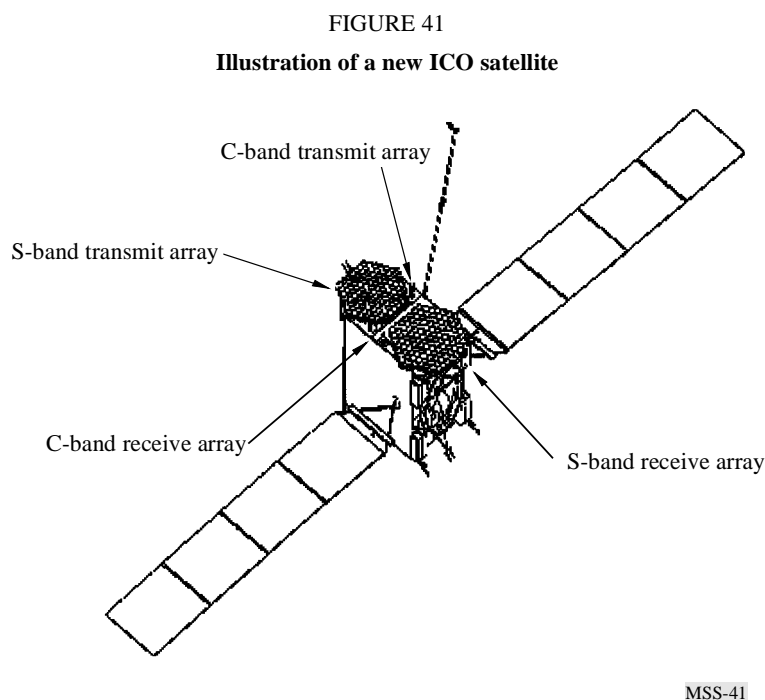
- high average satellite elevation angles, which reduce the chance that a ground obstruction will block a connection;
- high call completion rates and low call drop rates as a result of efficient management of capacity at all times;
- low end-to-end call set up times and latency (signal delay); and
- call quality that is comparable to current terrestrial mobile wireless services.

5.9.2.1 Space segment

The satellite constellation will consist of 12 medium Earth orbit satellites orbiting the Earth in two planes. Each orbital plane will incline at 45° to the equator, with six satellites per plane. This configuration minimizes cost and scheduling demands, particularly satellite construction and

replacement time. Each satellite will orbit at an altitude of approximately 6 400 miles (10 390 km) above the Earth's surface and will circle the Earth approximately once every six hours. Because of the relatively high altitude of the satellite constellation, each satellite will have a significantly larger footprint than a typical low Earth orbit satellite. The footprint of New ICO's medium Earth orbit satellites will have a diameter of approximately 9 300 miles (14 880 km), encompassing more than 30% of the Earth's surface.

A typical New ICO satellite is shown in Fig. 41. The C-band and S-band antennas are used, respectively, to communicate with the SANs and user terminal. In the forward link (SAN to user terminal), the signals are received from the SAN in both polarizations via C-band global beams, down-converted to an intermediate frequency and transmitted through to 490 filters, each of which forms a 170 kHz channel. The outputs of these filters are routed to one of 163 S-band spot beams for transmission to a user terminal.



Similarly, in the return link (user terminal to SAN), 170 kHz signals from the user terminal are received individually via one of 163 S-band spot beams, down-converted, digitized, inputted to TWT amplifiers, and transmitted to the SANs via C-band antennas that form a global beam. Each satellite typically will be in direct contact with two to four SANs at any one time. The allocation of filters to beams is based on traffic demand and a four-cell frequency reuse pattern. This signalling technology results in efficient use of the allocated frequency spectrum.

New ICO satellites in medium Earth orbit will provide link availability that is superior to that of competing low Earth orbit systems. This is due, in part, to a higher average elevation angle for the satellites, which minimizes the probability that a user's signal will be obstructed. Also, as a result of their higher altitude, New ICO satellites will move across the sky significantly more slowly than low Earth orbit satellites. This will result in fewer "handovers" from one satellite to another during a call and minimize the possibility of dropped calls. In addition, this satellite configuration reduces the complexity and operating cost of the space segment.

New ICO has a supply agreement for the construction of the space segment with Hughes Space and Communications International, Inc. Under this agreement, Hughes will construct all of New ICO's satellites and the related telemetry, tracking and control equipment. The Hughes satellite contract, together with New ICO's launch services contracts and satellite insurance costs, comprise substantially all of New ICO's investment in the space segment.

In working with Hughes, New ICO developed the design of the satellite platform from an existing model, the Hughes HS601 satellite platform. The design life of the satellites is twelve years, nearly twice the average life of a typical low Earth orbit satellite. A key feature of the satellite design is that the satellite service-link transmit and receive antennas are separate. These separate antennas simplify the manufacture of the satellites and minimize interference between transmission and reception during operation. To enhance the reception of signals from the user equipment, the service-link antennas have a diameter of more than six feet. The satellites carry more computing power than 600 Pentium III-based computers; feature innovative transmit and receive antennas allowing direct air link to users; and use a so-called "smart processor" that is capable of adapting beam configuration to match usage and make the most efficient use of the bandwidth available. These features give New ICO unprecedented flexibility to meet ever-changing market demands on a global basis.

Upon launch, New ICO will control communications between the ground stations and the satellites from the primary and back-up control centres. New ICO will perform in-orbit operation and control of the satellites through the primary satellite control centre located near London. New ICO has the equipment necessary for telemetry, tracking and control functions at five ground stations, with a sixth planned to be in operation by launch of commercial services. These ground stations will provide nearly continuous monitoring of the satellites in orbit, permitting New ICO to control the satellites and respond rapidly to any anomalies that may occur. Initially, the satellite control centre will communicate with the ground stations through a dedicated data support network. As the New ICO network is deployed, it will integrate these communications into the ICONET. New ICO has installed, and is now testing, the primary satellite control centre at the London facilities. The telemetry, tracking and control equipment at five ground stations has also been fully installed and tested.

5.9.2.2 Ground segment

The satellites will be linked to a ground network (the ICONET) which will interconnect twelve earth stations (which New ICO refers to as satellite access nodes ("SANs")) located throughout the world (see Fig. 42). Each SAN consists of earth stations with multiple antennas for communicating with satellites, and associated switching equipment and databases. The ICONET and SANs will implement the selection of traffic routings to ensure the highest possible quality and availability of service to system users. SANs will be the primary interface between the satellites and the public networks. They will also house the equipment that will route the satellite signals for distribution to the appropriate public networks. Each SAN will track the satellites within its sight, direct communications traffic to the optimal satellite for the most robust link and, where appropriate, execute hand-offs between satellites to maintain uninterrupted communication.

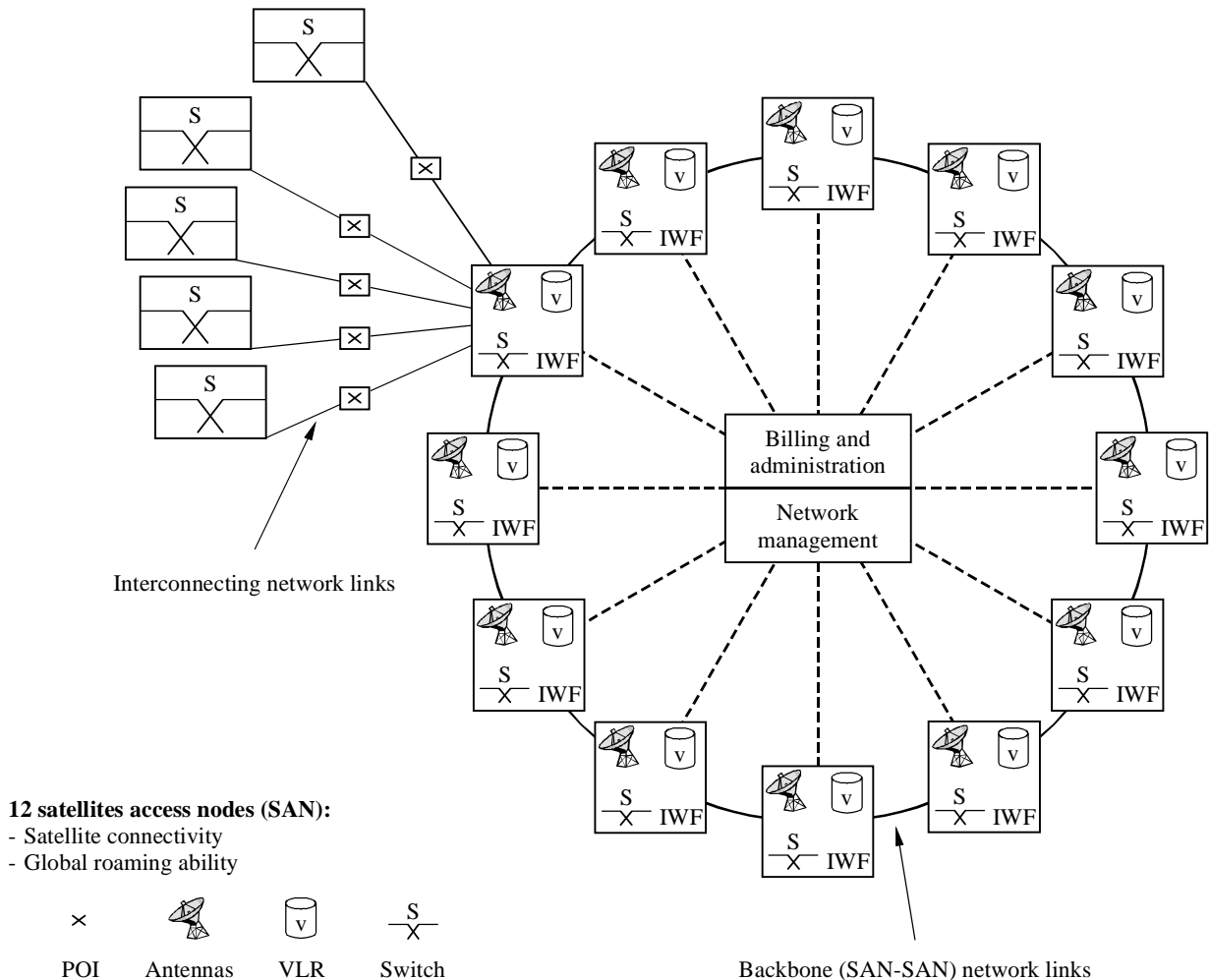
5.9.2.3 ICONET

The ICONET will be a worldwide telecommunications network consisting of 12 ground stations and the primary and backup network management centres, all linked together primarily over redundant high capacity fiber optic cables.

FIGURE 42
Ground network of the new ICO system

Interconnection with other networks

– Point of interconnection (POI) between
ICONET and connecting networks (PSTN,
PLMN, PSPDN)



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Each ground station will provide an interface between the satellites and terrestrial networks, and will manage routing over the New ICO network. Each ground station will consist of five main elements:

- five ground-based antennas, each with associated equipment to communicate with the satellites;
- both packet and circuit-switched nodes to route traffic on the ICONET and to inter-connecting land-based fixed and mobile networks;

- registers to support mobility, call and service access management;
- platforms to provide value-added services such as voice, facsimile and data messaging services; and
- general packet radio services, or GPRS equipment, which will direct traffic and store data and support a range of Internet protocol services.

Each ground station will track the satellites within its range of sight via the ground-based antennas and will manage traffic routing between the ground and satellite antennas so as to maintain uninterrupted communications. In addition to managing usage of the radio links, New ICO will depend on ground stations, as controlled by the network management centre, to direct the allocation of frequency spectrum and satellites in a manner consistent with traffic and the regulatory requirements applicable in the country where the user terminal is located. The entire ground segment will be operated so as to provide consistent, high quality services and to manage inter-connection costs.

The ICONET circuit and packet switching system is designed based on the GSM and IP standards. ICONET switches will utilize computer databases, known as network registers, to control a customer's access to the telecommunication services. These switches will set up, route and complete calls on the New ICO network and record service usage for billing. New ICO has constructed SAN ground station sites for eleven SAN ground stations and is currently working on an arrangement for a twelfth SAN ground station site in China.

The network registers in each earth station store details of New ICO end-user devices registered to that SAN ground station. These registers will permit New ICO to manage customer access to the services and the routing of traffic to New ICO end-user devices. Authentication software will be employed to check the identity of users, which significantly reduces the potential for fraudulent use of the New ICO network. New ICO has already installed and tested switching equipment at 11 SAN ground stations, of which 10 are fully tested.

The SAN ground stations will interconnect the ICONET with the land-based fixed and mobile networks in the host country and, via international switching facilities in that country, to other countries. The SAN ground stations can transfer calls to the local land-based fixed and mobile systems.

The interconnections between the ICONET and local land-based fixed and mobile networks will transmit data via fiber optic links having capacity for two megabits per second, or multiples of two megabits per second. These high capacity links will carry user traffic, signalling traffic and network administration traffic.

New ICO will add packet-mode network services with routers located at the SAN ground stations with selected breakout points to Internet gateways. The network management centres will monitor and control activity on the ICONET. The overall network architecture has been designed such that many functions can be centrally managed, and the provision of both primary and back-up network management centres, should ensure a high degree of availability.

5.9.2.4 Interworking functions

Circuit-mode operations: New ICO plans to use the GSM standard as the digital communications technology platform. The GSM standard is currently the leading digital mobile standard, and the use of this platform will enable New ICO to deliver services to all customers whose home network is

based on this system without the need for additional technological developments. In addition, New ICO is developing the service capabilities, called interworking functions, necessary to enable users of the New ICO network to roam across mobile networks using other existing standards, such as, for example, ANSI-41 (TDMA and CDMA).

Packet-mode and IP operations: New ICO will support GPRS-type services and other types of IP-based services making maximum use of off-the-shelf equipment based at the ground stations.

5.9.2.5 Systems integration

To bring the New ICO network into service, New ICO will fully integrate the space segment, the ground segment, the ICONET, New ICO user equipment and the business operations support systems (“BOSS”) with interconnecting fixed and mobile networks, and with the systems of the distributors. New ICO plans to carry out these integration activities under contract with several systems integration distributors, including existing suppliers, and under other contracts relating to the development of the New ICO network.

5.9.2.6 Network capacity

New ICO anticipates that the New ICO network will be able to support more than 14 million subscribers.

5.9.3 Description of New ICO products, services

At service launch, New ICO expects to offer a variety of products and services to individual consumers and businesses, which will include:

5.9.3.1 Hand-held mobile service

New ICO’s hand-held mobile services will permit customers to make telephone calls in locations where they would otherwise be unable to receive traditional mobile telephone signals, where terrestrial alternatives are otherwise inadequate or where the low number of users in a given area favours a satellite-based solution. Upon full deployment, customers will be able to access this service by using an accessory that customers can use to adapt a standard mobile phone for satellite communication utilizing short-range wireless technology. New ICO expects that its hand-held mobile service will support high quality voice and other IMT-2000 services, such as short message services, voicemail, call forwarding, as well as circuit-switched data, and Internet access. New ICO expects that prospective customers will find hand-held portability and high-quality wireless services, at prices competitive with alternative services, very attractive.

5.9.3.2 Mobile installed service

New ICO will deliver services tailored to the needs of users in the trucking, maritime, aviation and other mobile industries. New ICO expects third party manufacturers to design and manufacture low cost user equipment for trucks, ships and aircraft through which customers would have access to voice and Internet protocol data services wherever their fleets travel. Benefits to these customers include improved operational effectiveness of fleets as well as making a variety of services available to crew and passengers.

5.9.3.3 Stationary service

New ICO will offer service to customers in areas under-served by existing terrestrial networks. This service will be designed to operate through the installation of an outdoor antenna that is mounted on a customer's home or office. The outdoor antenna will communicate with a customer's indoor device either through wired or wireless means. New ICO expects to offer both data and voice as part of this service. Examples of potential users include remote business sites such as oil-drilling platforms and mining sites and residential users in isolated areas faced with long delays in obtaining traditional terrestrial communications services, or where service is non-existent.

5.9.3.4 Two-way messaging services

New ICO will design this service to provide two-way messaging to or from any location in the world. The principal target markets include the transportation, maritime and aviation industries. This service will permit customers in these and other markets to exchange position reports and location information. The two-way messaging service is suitable for integration with existing and planned communications systems offered by other providers. This two-way messaging service will enable fleet operators to manage logistical and operational activities, track assets for delivery updates, monitor and schedule preventive maintenance of equipment and prevent theft and fraud. Real-time messaging is expected to permit real-time location inquiry, while near-real-time messaging is expected to allow railcars and other vehicles to report on their location at regular intervals. As currently envisioned, this messaging service will impose no limits on the length of messages transmitted.

5.9.3.5 Mobile IP services

The upgrade of the New ICO network to a packet-based data system will allow New ICO to offer Internet protocol data services. New ICO will target these services to customers whose connectivity needs are not met through terrestrial services. In addition to voice services, New ICO is designing its network to support any Internet protocol or application that runs over current terrestrial networks, for instance email and web access.

By providing global connectivity and Internet access, New ICO will allow businesses and consumers to access the Internet from anywhere in the world at speeds comparable to those currently available only in developed urban areas. The New ICO network initially is expected to be capable of providing two-way packet data services at data transmission rates of up to 56 kbit/s.

5.9.4 Radio-frequency spectrum matters

5.9.4.1 Spectrum requirements of the New ICO system

Taking into account the ITU allocations made at the 1992 World Administrative Radio Conference (WARC-92) and the 1995 World Radio Conference (WRC-95), New ICO satellites have been designed to operate:

- Service links in the bands 1 980-2 015 MHz (uplink) and 2 170-2 200 MHz (downlink).
- Feeder links between SANs and satellites in the bands 5 150-5 250 MHz (uplink) and 6 975-7 075 MHz (downlink).

New ICO's SAN earth stations will utilize the feeder link frequencies only in those countries where SANs are located (Brazil, Chile, Mexico, USA, Germany, South Africa, UAE, India, China, Indonesia, Korea, and Australia).

Due to regional variations in ITU frequency allocations to the mobile-satellite service (MSS), the New ICO service link frequencies available for assignment within the ranges of operation specified above are as follows:

<i>Service link:</i>	<i>Earth-to-space</i>	<i>space-to-Earth</i>
ITU Region 1	1 980-2 010 MHz	2 170-2 200 MHz
ITU Region 2	1 990-2 015 MHz	2 170-2 200 MHz
ITU Region 3	1 980-2 010 MHz	2 170-2 200 MHz

Region 1 comprises Europe, Africa, the Middle East and the Commonwealth of Independent States, Region 2 consists of the Americas and Region 3 includes Asia, Australia and Oceania.

Initially, New ICO must utilize 15 MHz in each of the Earth-to-space (1 995-2 010 MHz) and space-to-Earth (2 185-2 200 MHz) bands to meet the projected traffic requirements for the New ICO satellite system. Initially New ICO may also wish to operate in spectrum adjacent to the bands 1 995-2 010 MHz and 2 185-2 200 MHz to ensure compatibility of usage between different countries in the initial start-up phase of operations.

The frequencies used by the New ICO satellite network are being coordinated under the provisions of Resolution 46 (S9.11A) of the ITU Radio Regulations. The request for coordination of the New ICO system has been published by the ITU, as ICO-P, in the Special Sections RES46/C/167 (Circular 2256/03.12.1996), RES46/C/167 MOD-1 (Circular 2291/19.08.1997) and RES46/C/167 MOD-2 (Circular 2301/28.10.1997).

5.9.5 Conclusion

New ICO is committed to being the leading provider of truly global, high-quality data and voice services anywhere on Earth. To this end, the key elements of New ICO strategy are:

- delivering services using an integrated packet-based communications network consisting of a constellation of satellites and a global ground telecommunications infrastructure;
- delivering high bandwidth data and voice services at competitive prices with call quality equal or better than today's terrestrial wireless networks;
- leveraging the New ICO network, which will be upgraded by service launch to include a packet-based system, to offer a range of new next generation wireless IMT-2000 services and expand markets; and
- establishing effective distribution by utilizing existing distribution channels and developing new direct sales channels.

New ICO is committed to bringing the benefits of its system, products and services to the global markets.

5.10 EMSAT European Mobile Satellite

5.10.1 General overview

European Mobile Satellite (EMSAT) is a satellite communication system, provided by the Italian satellite communications operator Telespazio and distributed by EUTELSAT, which operates via the ITALSAT F2 geostationary satellite in communication with the ground station at Lario (Northern Italy) and with remotely located or mobile satellite telephones, within the extended European coverage of the satellite. The system offers access to digital telephony/data/fax services, where previously existing terrestrial based communication systems, such as mobile trunking or cellular telephones could not provide coverage.

In addition the EMSAT system provides features such short messaging (including emergency) as well as optional GPS positioning and reporting system.

5.10.2 System architecture

The EMSAT system allows users to make telephone/fax/data calls from the mobile satellite telephone via the satellite and the system ground station to the PSTN telephone network (see Fig. 43).

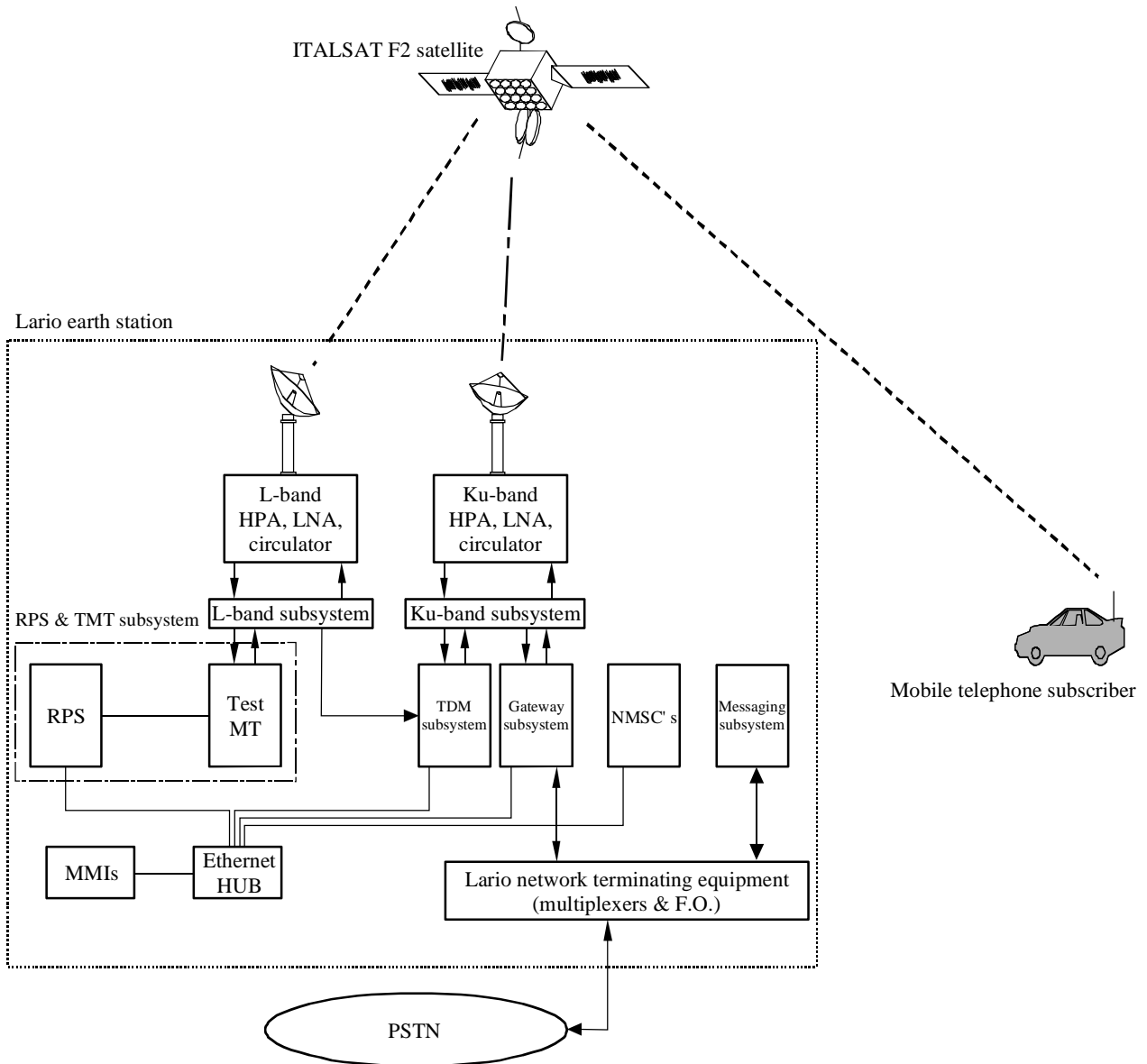
The current EMSAT system comprises the following major elements:

- Space segment
- Ground station
- Mobile telephone transceivers (mobile satellite telephone).

5.10.3 Space segment

Communications between the EMSAT ground station and the mobile satellite telephone are via the ITALSAT F2 geostationary satellite launched in August 1996 which carries on board the EMS payload that is equipped with transponders to translate the Ku-band frequencies, transmitted from the ground segment, to L-band frequencies required for the mobile satellite telephone operation. Transmissions from the mobile satellite telephone are in turn translated from L-band frequencies to the Ku-band in the satellite and sent to the ground station (see Fig. 44).

FIGURE 43
EMSAT system block diagram

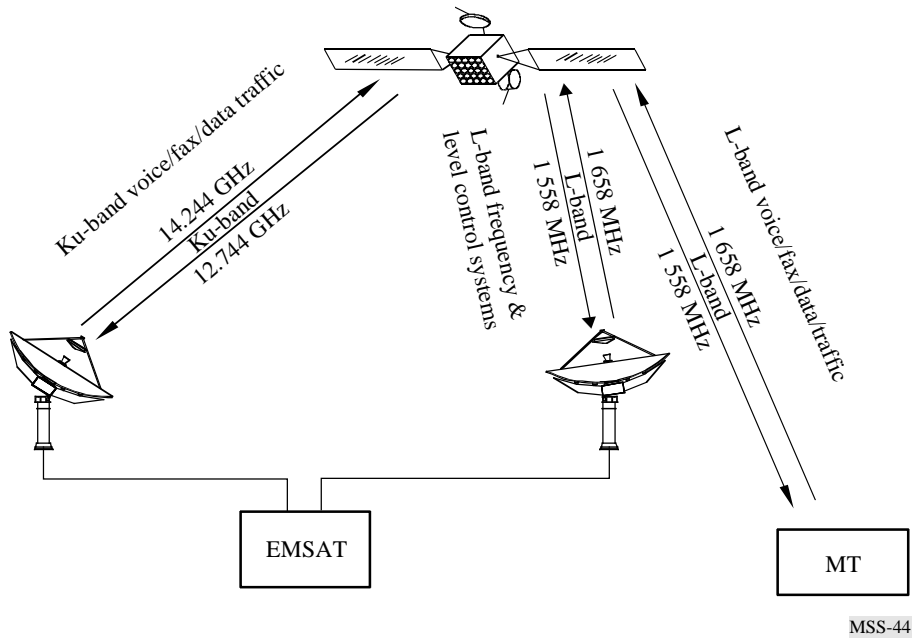


----- L-band
 - - - - - Ku-band

PSTN: Public switched telephone network
 MT: Mobile telephone
 RPS: Remote processor supervisory
 HPA: high power amplifier
 LNA: Low noise amplifier

NMSC: Network management system computer
 RPM: Remote processor messaging
 TDM: Time division multiplex
 MMI: Man machine interface

FIGURE 44
Space segment communications



MSS-44

The following frequencies are the EMS payload operating frequencies:

TABLE 31
EMS payload operating frequencies

	Band		Frequency range (MHz)
Ground station ↔ satellite	Ku-band	Transmit	14 236.0-14 240.0 14 246.0-14 250.0 14 241.0-14 245.0
		Receive	12 736.0-12 740.0 12 746.0-12 750.0 12 741.0-12 745.0
Satellite ↔ mobile telephone	L-band	Transmit	1 631.5-1 635.5 1 641.5-1 645.5 1 656.5-1 660.5
		Receive	1 530.0-1 534.0 1 540.0-1 544.0 1 555.0-1 559.0

Space segment backup will be provided using leased capacity over one of the Inmarsat-3 satellites having the adequate spot beam European coverage. A dedicated C-band antenna at Lario E/S will be properly upgraded in order to provide EMSAT system restoration over the Inmarsat space segment in case of major failure of the EMS payload or ITALSAT satellite.

5.10.4 Ground station

The EMSAT ground station contains the necessary hardware and software to establish satellite communications and interconnect to the PSTN telephone network.

The ground station comprises a number of duplicated subsystems controlled by duplicate computers. Resources are allocated and monitored whenever a phone call is established, so that in the advent of system or subsystem failure, redundancy hardware is automatically activated so as to maintain system operability.

The ground station is composed of the following basic subsystems, which perform specific tasks in the setting up and control of the communications channels :

- Network management system (NMS)
- Time division multiplex (TDM) group
- Gateway (channel units)
- Ku-band and L-band RF system
- 5 MHz reference
- Messaging subsystem
- Monitoring and control equipment (RPS).

5.10.5 Mobile terminals

The terminals are composed by two or three pieces, depending on the MT manufacturer: transceiver, to which the handset is connected, antenna control unit and antenna.

The different terminal antennas available for the EMS system are the following:

- Mast:* 80 cm long and 2 cm diameter whip, providing omni-directional in azimuth and shaped gain in elevation. The antenna gain is 7.3 dBi. Easy mountable on any kind of vehicle.
- Dome:* 20 cm × 25 cm × 16 cm steerable, 9 dBi gain antenna. Designed for trucks.
- Low Profile:* motorized antenna for applications where low antenna height is required. The gain is 7.8 dBi.
- Planar fixed:* typical antenna for portable fixed application. Has to be manually pointed, both in azimuth and elevation, The gain is 14 dBi and allows optimal performance and use of satellite power.
- Maritime:* for maritime applications which require stabilized antennas in order to allow continuous communications. The gain is 16 dBi.

5.10.6 Applications

The EMSAT system has been designed to support a range of services and features, which can be readily accessed by a variety of users and organizations. The ability to rapidly deploy and commission a new telephone service, within a few hours, means that virtually instantaneous communications can be made available for a multitude of users, including those located in the most remote regions.

Area wide communications coverage and the transportability of the mobile-satellite telephone will enable the economical and rapid deployment of communication services at locations that may not otherwise be economically or practically accessible by more conventional forms of terrestrial communications. Some typical applications for the EMSAT system may include:

- **Government authorities**
 - Road, electricity and water authorities
 - Health, forestry departments and national parks
 - Agriculture and primary industries
 - Defense
 - Coast guard
 - **Temporary emergency communications**
 - **Medical services**
 - **Utilities**
 - Monitoring river and catchment area water levels or aqueduct water flow
 - Monitor and control of pipe line pumping and compressor station functions
 - Monitor and control of control valve and power sub stations
 - **Mining and oil and gas platforms**
 - **Rail and road transport**
 - Position, speed and fuel consumption
 - Refrigeration temperatures
 - **Fixed station**
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