ABSTRACT

THE MOBILE SATELLITE SERVICE(MSS) SYSTEMS FOR GLOBAL PERSONAL COMMUNICATIONS

by
Kiho Lee

A worldwide interest has arisen on personal communications via satellite systems. The recently proposed mobile satellite service(MSS) systems are categorized in four areas: geostationary earth orbit(GEO) systems, medium earth orbit(MEO) systems, low earth orbit(LEO) systems, and highly elliptical orbit(HEO) systems. Most of the systems in each category are introduced and explained including some technical details. The communication links and orbital constellations of some systems are analyzed and compared with different categories, and with different systems. Some economical aspects of the systems are mentioned. The regulatory issues about frequency spectrum allocation, and the current technical trends in these systems are summarized.

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by
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This thesis is dedicated to
my wife Mi-Hyung, my sons Hong-Seok and Hong-Je,
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CHAPTER 1

INTRODUCTION

During the last few years, a worldwide interest has arisen on personal communications via satellite systems. The mobile satellite service(MSS) systems will play a strategic important role in the universal integrated communications services. The MSS with their blanket coverage capabilities could provide global personal communication services to vast and remote geographical areas where the terrestrial-based systems could not do so economically. The technological development for mobile satellite is based upon the advancements of the commercialization of military communications satellite technology. The MSS may be divided into four somewhat competing categories: Geostationary Earth Orbit(GEO) systems, Medium Earth Orbit(MEO) systems, Low Earth Orbit(LEO) systems, and Highly Elliptical Orbit(HEO) systems.

The GEO system is placed at an altitude of 35,786 km, so that it makes one complete revolution in twenty-four hours. Its orbit lies in the plane of the equator and it appears to remain stationary to an observer placed on the surface of the earth. Therefore, communications are available for twenty-four hours a day in the coverage area. For global coverage with GEO satellite designs only three or four satellites are needed. However, they require more than one hundred narrow beams, complex transponders and large amounts of power with very large antennas whenever small hand-held terminals are used. For mobile to mobile traffic it is necessary to demodulate and route the signal inside the satellite. The large delay does not permit a dual hop operation.

The MEO system would be capable of providing combined global services with about fifteen to eighteen satellites. These are circular inclined orbits of six to eight-hour period at altitude of about 10,000 km in between the two Van Allen radiation belts. As a result of their altitude, the satellites are moving slowly relative to the users, and remain in visibility for periods of time of about one to two hours. The elevation angle is typically larger than 40· degree for half of the time. The propagation delay is 75~100 msec. MEO satellite systems would provide the lowest cost per circuit year: total investment for space and ground segments, useful subscriber capacity, and investment lifetime. The Table 1.1 and 1.2 shows the brief summary of proposed systems in each categories.

Table 1.1 The Brief Summary of GEO and MEO Systems

- Geostationary Earth Orbit Systems
  - INMARSAT-A,AERO,B,C,M(INMARSAT)
  - MSAT(AMSC/TMI)
  - MOBILESAT(Optus Communications)
  - CELSTAR(Celsat Inc.)
  - NORSTAR(Norris Satellite Communications)
  - SPACEWAY(Hughes Communications Inc.)
  - PASS(Jet Propulsion Laboratory)
  - LLM(European Space Agency)
  - COMETS(National Space Development Agency)
  - OMNITRACS/EUTELTRACS(Qualcomm/Eutelsat)
  - GEOSTAR/LOCSTAR(Geostar)

- Medium Earth Orbit Systems

	Altitude	Constellation
- ODYSSEY(TRW/Teleglobe)	10,354km	12 satellites
- MAGSS-14(ESA)	10,355km	14 satellites
- INMARSAT-P(INMARSAT)	10,300km	10 satellites

Source: Refer to the REFERENCES

Table 1.2 The Brief Summary of LEO and HEO Systems

	Altitude	Constellation
• Low Earth Orbit Systems		
o Big LEOs		
- IRIDIUM(Motorola)	780km	66 satellites
- GLOBALSTAR(LQSS)	1,389km	48 satellites
- ARIES(Constellation Com)	1,018km	48 satellites
- TELEDESIC(Microsoft)	700km	840 satellites
- BOPSAT(CNES/CNET)	1,400km	48 satellites
- MOBILSATCOM(Mitre Co)	1,000km	192 satellites
o Little LEOs		
- ORBCOMM(Orbcomm)	785km	26 satellites
- STARSYS(Starsys)	1,300km	24 satellites
- TEMISAT(Telespazio)	950km	2 satellites
- VITASAT(VITA)	800km	2 satellites
- SHARP(Telesat Canada)	21km	T.B.D.*
- LEOSAT(Leosat Inc.)	970km	18 satellites
- S-80/TAOS(CNES)	1,208km	5 satellites
- SAFIR(OHB)	690km	6 satellites
- ITAMSAT(Italian Radio A)	T.B.D.	T.B.D.
- GONETS(Smolsat)	1,390km	36 satellites
- FAISAT(Final Analysis)	T.B.D.	26 satellites
- GEMNET(CTA)	T.B.D.	38 satellites
- EYESAT(Interferometrics)	T.B.D.	48 satellites
- LEO ONE USA	T.B.D.	48 satellites
• Highly Elliptical Orbit Systems		
	Perigee/Apogee	Const.
- ELLIPSO(MCHI)	426/2,903km	24 sat.
- LOOPUS-MOBILE-D(MBB)	5,784/41,449km	9 sat.
- M-HEO(ESA)	1,000/27,000km	6 sat.
- ARSENE(RACE)	17,200/37,000km	T.B.D.

Source: Refer to the REFERENCES

* T.B.D.: To Be Determined

The LEO system consists of a constellation of several tens of satellites in circular orbits at altitudes ranging from 500~2,000 km below the radiation belts, and high enough to avoid atmospheric drag. The satellites can either have inclined, or polar orbits, or a combination of the both. The coverage area and duration depend essentially on the number of satellites in the constellation, their altitudes and their orbit inclinations.

Satellites are visible for a short period of time, typically ten minutes, and this implies frequent handovers from satellite to satellite, and even more frequent from beam to beam. Therefore, LEO satellite should be equipped with multibeam antennas. The propagation delay is 5~35 msec. The LEO system can be divided into two categories: "Big LEO" systems above 1 GHz providing voice/data services at L/S band, and "Little LEO" systems below 1 GHz providing substantially store and forward messaging services to trucks, automobiles, search and rescue(SAR) vehicles etc.

The HEO systems dwell near apogee(highest point) of elliptical orbit with inclination equal to 63.4 degree to ensure the orbit stability. They offer enhanced duration of coverage(four to eight hours) of the region located under apogee which is useful for telecommunications. With proper phasing and orbital parameter selection, three to six satellites can provide multi-regional coverage. As a result of the apogee altitude(25,000~45,000 km), the propagation delay is not smaller than with geostationary satellites. Moreover satellites orbit through the two Van Allen radiation belts twice each orbit, and this has implications on the life time of the satellites.

CHAPTER 2

DESCRIPTIONS OF THE MOBILE SATELLITE SERVICE SYSTEMS

2.1 Geostationary Earth Orbit Systems

2.1.1 INMARSAT

International Maritime Satellite Organization(INMARSAT) is a multi-national organization affiliated with the United Nations International Maritime Organization(IMO). It has seventy-five signatories, each of which is responsible for the marketing of the services in its own region. Inmarsat typically has provided maritime voice communications services using geostationary satellites operating at L-band(1.53~1.64 GHz) and C-band(4.19~6.43 GHz) [3]. All current Inmarsat systems use the same four ocean region FDMA-based geostationary satellite network using 2.5 kHz channels with mobile telephone circuit-switched and store-and-forward data services, and have near global coverage except for the extreme polar regions beyond 70 degree north and south of the equator. The communicating vessels may establish links directly, or more commonly, through inter-connecting networks, both of which along with the users are able to implement the required mobility management.

INMARSAT-A uses frequency modulation(FM) signals and accommodates large ships, and provides analog FM toll quality voice, telex, 9.6 kbps voice band data and 64 kbps high speed data options. The mobile earth station(MES) features effective isotropically radiated power(EIRP) of 36 dBW, gain/noise temperature(G/T) of -3.5 dB/°K, carrier/noise density(C/No) of 53 dB/Hz, and radio frequency(RF) bandwidth of 50 kHz [1].

INMARSAT-AERO provides digital voice at a raw rate of 9.6 kbps, and 600 bps data to aircraft. Voice signals are convolutionally encoded at rate 1/2 and Offset Quaternary Phase Shift Keying(OQPSK) modulated with 17.5 kHz RF bandwidth, and data signals Aviation Binary Phase Shift Keying(ABPSK) modulated. The MES features EIRP of 26 dBW, G/T of -13 dB/°K, and C/No of 48 dB/Hz [2].

INMARSAT-B is a digital successor to INMARSAT-A, and an Open System Interconnection(OSI) compliant system that provides near toll quality digital voice of 16 kbps Adaptive Predictive Codec(APC) and data at a raw rate of 9.6 kbps to thousands of ships and aircraft. Signals are convolutionally encoded at rate 3/4, interleaved, and OQPSK modulated with 20 kHz RF bandwidth. The MES features EIRP of 33 dBW, G/T of -4 dB/°K, and C/No of 49 dB/Hz [2].

INMARSAT-C provides two-way data at 600 bps only. Signals are convolutionally encoded at rate 1/2, interleaved, and BPSK modulated with 5 kHz RF bandwidth. The MES features EIRP of 13 dBW, G/T of -23 dB/°K, and C/No of 37 dB/Hz [2].

INMARSAT-M fills the gap between INMARSAT-B and INMARSAT-C. The digital voice rate is 4.8 kbps using Codebook Excited Linear Predictive(CELP) codec, and the data rate is 2.4 kbps. Signals are convolutionally encoded at rate 1/2, interleaved, and OQPSK modulated with 10 kHz RF bandwidth. The MES features EIRP of 25/27 dBW, G/T of -10/-12 dB/°K, and C/No of 42 dB/Hz. Table 2.1 shows the technical characteristics of the Inmarsat systems [2].

Table 2.1 The Technical Characteristics of the Inmarsat Systems

• Mobile Terminal	Inmarsat-B	Inmarsat-C	Inmarsat-M	Inmarsat-AERO
- Antenna Gain	20 dBi	1 dBi	12/14 dBi	12 dBi
- Antenna Type	Dish	Quadrifilar Helix	Backf/Lin Array	Phased Array
- Antenna Size	1-meter Dia	100 x 25mm Cyl	0.4m D/0.5m L	0.5 x 0.5 meter
- EIRP	33 dBW	13 dBW	25/27 dBW	26 dBW
- G/T	-4 dB/°K	-23 dB/°K	-10/-12 dB/°K	-13 dB/°K
• Satellite EIRP	16 dBW	21.4 dBW	17 dBW	21 dBW
• Voice Coding Rate	16 kbps APC	N/A	4.8 kbps CELP	9.6 kbps
• User Data Rate	9.6 kbps	600 bps	2.4 kbps	9.6 kbps
• Channel Rate	24 kbps	1.2 kbps	8 kbps	21 kbps
- Channel Spacing	20 kHz	5 kHz	10 kHz	17.5 kHz
- C/No	49 dB/Hz	37 dB/Hz	42 dB/Hz	48 dB/Hz
- Modulation	OQPSK	BPSK	OQPSK	OQPSK
- Interleaving Time	N/A	8.64 second	0.12 second	0.04 second
• Forward Link				
- Signalling Rate	6 kbps	1.2 kbps	6 kbps	600 bps
- Modulation	BPSK	BPSK	BPSK	ABPSK
- FEC	1/2 Conv.	1/2 Conv.	1/2 Conv.	1/2 Conv.
• Return Link				
- Signalling Rate	24 kbps	1.2 kbps	3 kbps	600 bps
- Modulation	OQPSK	BPSK	BPSK	ABPSK
- FEC	3/4 Conv.	1/2 Conv.	1/2 Conv.	1/2 Conv.

Source: H.C. Haugli. "Implementation of Inmarsat Mobile Satcom Systems." *The Second International Mobile Satellite Conference(IMSC '90)*, Ottawa (1990): 8-12.

2.1.2 MSAT

MSAT, an advanced satellite program conceived jointly, in 1984, by National Aeronautical and Space Administration(NASA), Canada's Department of Communication(DOC), Telesat Canada, and American Mobile Satellite Corporation(AMSC), which is planned to be operational by the mid '90s. NASA has been planning and coordinating MSAT between the Government, universities, industry, FCC, and AMSC. On the Canadian side, DOC has been coordinating the efforts of the Canadian Government and Telesat Mobile Inc.(TMI). AMSC is the designated provider and operator authorized by the FCC in 1988, and NASA has provided the high-risk research and development for the advanced enabling technologies.

In 1990 contracts were awarded to Hughes Aircraft Co. with SPAR as a major subcontractor for the development and production of two nearly identical FDMA-based geostationary satellites to provide mobile satellite services(MSS) to North America. One of these satellites will be owned and operated by AMSC while the other will be owned and operated by TMI. These satellite will be launched in 1994 with an approximate service start date in mid-1994. The antenna coverage patterns and transponder design of both these satellites are nearly identical allowing the companies to provide mutual satellite backup for their operations. Comsat was awarded a contract to complete the system definition, design and specification phases of the ground segment procurement [5].

The MSAT satellite acts as a "bent pipe" repeater, receiving and transmitting modulated signals to and from the mobile terminals at L-band and relaying them to terrestrial users via Feederlink Earth Stations(FES) at Ku-band. The AMSC network will provide mobile telephony and data services primarily to vehicles like automobiles, trucks, ships, and aircraft. The voice will be digitally encoded at a nominal rate of 4.8 kbps, and data rate will be 6.4 kbps. The digital voice, data and facsmile signals will modulate a narrow-band carrier using $\pi/4$QPSK modulation with 5 kHz RF bandwidth while the basic analog voice modulation scheme is Amplitude Companded Single Side Band(ACSSB) [4]. The modulated signals from the mobile terminals and the FESs will access the satellite using demand assigned multiple access-single carrier per channel(DAMA-SCPC).

Two Elliptical unfurlable mesh antennas provide the L-band(29 MHz bandwidth) coverage for the satellites with six spot beams. These antennas are offset feed and are six by five meters in size. A single Ku-band(200 MHz bandwidth) antenna is 30-inch shaped reflector designed to provide coverage for all the land masses of North America including Hawaii and Puerto Rico using two feed horns. The forward link transponder receives Ku-band SCPC signals from the FESs and translates them to L-band with amplification, and return link reverses by receiving L-band signals from the various beams and translating them to Ku-band with amplification. The system features L-band EIRP of 54 dBW, and G/T of 1.8 dB/°K [6]. The advanced payload concept is using the baseband processor at 4 GHz, and the standard transponder bandwidth 72 MHz. On reception, the frequency division multiple access(FDMA) and FDMA/TDMA(time division multiple access) 8PSK signals go through a Multi-Channel Demultiplexer and demodulator(MCD), and next forward error correction(FEC) decoder and deinterleaver. The outer codec uses a Reed-Solomon(RS) code while the inner code is convolutional using

Viterbi Algorithm decoding. Table 2.2 shows the link characteristics of the MSAT system [7].

Table 2.2 The Link Characteristics of the MSAT System

• Mobile Link(L-band)	
- Frequencies(uplink)	1631.5~1660.5 MHz
(downlink)	1530.0~1559.0 MHz
- Satellite	
Transmitted power/carrier	17.0 dBm
Antenna gain	44.5 dBi
EIRP	60.5 dBm
Receiver noise temperature	25.6 dB°K
G/T	19.4 dB/°K
- Ground Terminal	
Transmitted power	30.0 dBm
Antenna gain	10.0 dBi
EIRP	39.0 dBm
Receiver noise temperature	22.3 dB°K
G/T	-12.3 dB/°K
- Eb/No(uplink)	29.7 dB
(downlink)	20.0 dB
- Polarization	RHCP
• Feeder Link(Ku-band)	
- Frequencies(uplink)	13~13.15/13.2~13.25 GHz
(downlink)	10.75~10.95 GHz
- Aggregate EIRP	36 dBW
- G/T	-3.6 dB/°K
- Polarization	Linear
• Antennas	
- L-band: two 6x5 meter elliptical unfurlable mesh	
- Ku-band: 30 inch shaped reflector	
• Six Spot Beams	

Source: S.A. Ames, and R.K. Kwan. "Advanced Communications Payload for Mobile Applications." *The second International Mobile Satellite Conference(IMSC '90)*, Ottawa (1990): 403-409.

2.1.3 MOBILESAT

MOBILESAT is an Australian dedicated mobile satellite which will provide circuit-switched, full duplex, high quality digital voice and data, and packet-switched data services to land, maritime, and aeronautical mobile users. The voice circuits will operate over a digital channel at the data rate of 6.6 kbps using 4.2 kbps voice coding and $\pi/4$QPSK modulation in 5 kHz bandwidth, and will utilize error correction mechanisms. The fax/data circuits will provide users with 2.4 kbps asynchronous data transmission with $\pi/4$QPSK modulation. The channels will be protected by a rate 3/4 convolution code for FEC and an Automatic ReQuest(ARQ) scheme to ensure error free trans-mission even under heavy shadowing. Packet-switched messaging will facilitate the transmission of short messages between a Mobilesat telephone and user dispatch centers. The packets will comprise of short binary messages 24 or 44 bits in length [8].

The digital transportable type of mobile terminal will provide access for individual users to the Mobilesat system with minimum G/T of -14 dB/°K, average output EIRP of 10 dBW, and Right Hand Circular Polarization(RHCP). The signalling and messaging information will be sent using a 96 bit signal unit, protected with rate 3/4 convolutional code. A slotted ALOHA random access protocol will be used for the inbound channels, and 32 inbound channels will be allocated to a single outbound channel. Inbound channels will operate at 2.4 kbps using aviation BPSK modulation with 5 kHz channel spacing [10]. The Optus second generation satellite, referred to as Optus-B1 and B2 will consist of Ku-band capacity, and Ku-band to L-band and L-band to Ku-band transponder. The L-band transponder will support a bandwidth of 14 MHz with a single national beam, and will provide a usable L-band EIRP of 48 dBW [9]. Table 2.3 shows the technical parameters of the MOBILESAT telephone [8].

Table 2.3 The Technical Parameters of the MOBILESAT Telephone

• Mobile Link	
- Output EIRP	10 dBW
- Minimum G/T(class 1)	-18 dB/ K
(class 2)	-14 dB/ K
- Antenna polarization	RHCP
• Voice Channel	
- Modulation	$\pi/4$QPSK
- Channel rate	6.6 kbps
- Voice codec rate	4.2 kbps
- C/No	47 dB/Hz
- Channel spacing	7.5 kHz
- Nominal bandwidth	5 kHz
• Fax/Data Channel	
- Modulation	$\pi/4$QPSK
- Channel rate	6.6 kbps
- Information rate	2.4 kbps
- FEC coding	3/4 convolutional
- Channel spacing	7.5 kHz
- Nominal bandwidth	5 kHz
• Outbound Signalling Channel	
- Modulation	$\pi/4$QPSK
- Channel rate	9.6, 4.8 kbps
- FEC coding	3/4 convolutional
- Channel spacing	10 kHz
• Inbound Signalling Channel	
- Modulation	Aviation BPSK
- Channel rate	2.4 kbps
- FEC coding	3/4 convolutional
- Channel spacing	5 kHz
- Nominal bandwidth	5 kHz

Source: M. Wagg. "MOBILESAT: Australia's Pioneer for the Region." *Mobile Satellite Communication in Asia*, Hong Kong (1993).

2.1.4 CELSTAR

CELSTAR will provide a high-speed digital network for voice, data, fax, and position-determination services in 1996. The system deploys two satellites with multi-beam antennas covering more than 100 "super cells". Each satellite would have a 20-meter reflector with 149 beams using code division multiple access(CDMA) spread spectrum transmissions supporting 50,000 mobile voice channels. This system expects to charge subscribers less than US$ 0.25 per minute, and to design and manufacture handsets priced under US$ 500 [51].

2.1.5 NORSTAR

Norris was granted a construction permit for a single satellite in mid-1993 [44]. Norstar 1 will provide fixed satellite service(FSS), direct broadcasting service(DBS), mobile satellite service(MSS), and personal communications satellite services to the United States, and operate in the 30/20 GHz Ka-band for at least ten years at 90 degree west orbit [50].

2.1.6 SPACEWAY

The Spaceway global network would consist of four interconnected regional satellite systems which could be expanded to seventeen satellites eventually. This project looks like the satellite industry's reaction to the Global Information Infrastructure initiative, providing dial-up voice, video and data services to anyone in the world with 26-inch antenna. Spaceway satellites will deploy high-powered spotbeams, on-board signal processing and switching, and extensive frequency reuse. Each satellite will employ a total 48 spotbeams of 120 MHz for uplink and downlink, and 120 times reusing of 500 MHz spectrum [44]. This system will charge subscribers US$ 6.00 for 30-minute tele-conference with terminal cost under US$ 1,000. Table 2.4 shows the main features of the SPACEWAY system [42].

Table 2.4 The Main Features of the SPACEWAY System

- Number of satellites	9~17
- Cost of system	US$ 3.2~8 billion
- Altitude	35,786 km
- Charge	US$ 6 for 30-minute teleconference
- Terminal cost	< US$ 1,000
- Services	Fixed broadband data
- Antenna size	26 inch
- Multiple access	FDMA/TDMA
- Spectrum band	Ka-band
- Rollout date	1998
- Realistic capacity	2,500 T1

Source: G. Gilder. "Gilder's Telecosm." *Forbes ASAP* (Oct.10, 1994): 133-150.

2.1.7 PASS

Personal Access Satellite System(PASS) proposes to implement ubiquitous voice, data, low-rate broadcast using Ka-band (20 GHz on the downlink and 30 GHz on the uplink). The concept of PASS is similar to the mobile satellite systems except that it takes advantage of the Ka-band to offer users more flexibility(accessibility and mobility). The system would be capable of handling data rates ranging from less than 100 bps for emergency and other low-rate services, to 4.8 kbps for voice communications and hundreds of kbps for computer file transfers [13]. The major elements of PASS are one or more satellites, gateway stations, and three types of mobile terminals: Basic Personal Terminal(BPT), Enhanced Basic Terminal(EBT), and telemonitors. The BPTs are compact, hand-held personal terminals that provide the user with voice and data services at 4.8 kbps. The EPTs are essentially mini-VSATs that can handle up to T1 rates. The telemonitors would be used for remote data collection and monitoring [11]. Table 2.5 shows the salient features of the PASS system [13].

Table 2.5 The Salient Features of the PASS System

• Frequency(up/down)	30/20 GHz
• Mobile Link	
- EIRP(uplink)	16.8 dBW
(downlink)	57.0 dBW
- G/T(uplink)	23.4 dB/°K
(downlink)	-9.0 dB/°K
- C/No(uplink)	46.9 dB/Hz
(downlink)	58.8 dB/Hz
- Antenna gain(uplink)	22.8 dBi
(downlink)	19.3 dBi
• Feeder Link	
- EIRP(uplink)	60.7 dBW
(downlink)	6.4 dBW
- G/T(uplink)	-1.2 dB/°K
(downlink)	30.3 dB/°K
- C/No(uplink)	69.9 dB/Hz
(downlink)	50.3 dB/Hz
• Satellite Antenna	
- Spotbeam(142 beams)	
Size(up/down)	2/3 meter
Gain	52.5 dBi
Beamwidth	0.35 degree
- CONUS beam	
Gain	27.0 dBi
Beamwidth	7.7 degree

Source: M.K. Sue, K. Dessouky, B. Levitt, and W. Rafferty. "A Satellite-Based Personal Communication System for the 21st Century." *The second International Mobile Satellite Conference(IMSC '90)*, Ottawa (1990): 56-63.

A fixed station(or hub, base station) communicates through the satellites with mobile users scattered over Continental United States(CONUS). The satellites could be bentpipe or onboard baseband processing type, and use spotbeams to alleviate the EIRP burden on the user terminal. A combined TDMA/FDMA or advanced TDMA/CDMA promises a capacity of 30,000 channels requiring a total bandwidth of 300 MHz. TDMA is used for the forward direction, and FDMA for the return direction. In the forward direction each transponder has a narrowband pilot channel plus two high rate data and voice channels. In the return direction, access to the system is provided using DAMA-SCPC. In the CDMA architecture hybrid time division multiplexing(TDM)/CDMA scheme is used for forward direction, and random access CDMA(RACDMA) is used for return direction [12].

2.1.8 LLM

L-band Land Mobile(LLM) is a multibeam reconfigurable mobile payload to provide preoperational land-mobile satellite services at L-band over Europe. The LLM features high capacity, efficient use of the L-band spectrum, and flexibility in reconfiguring the allocation of bandwidth and RF power resources to the different beams. The mobile link uses 1.6/1.5 GHz at L-band, and 14/12 GHz at Ku-band for the feeder link. The L-band EIRP will provide a good balance between RF power and spectrum availability. The capacity is approximately 1,000 voice channels of 4.8 kbps data rates with rate 3/4 Viterbi encoding, QPSK modulated with a channel spacing of 10 KHz [15]. The main characteristics are like that single Eurobeam and six spotbeams, 11 MHz bandwidth, EIRP and G/T(L-band Eurobeam: 45.9 dBW and 4.9 dB/ K, L-band Spotbeam: 51.4 dBW and -1.2 dB/ K, Ku-band Eurobeam: 38.3 dBW and -1.5 dB/ K), and carrier to interference(C/I) for L-band is greater than 16.1 dB and for Ku-band is greater than 21.1 dB [16]. The technological challenges for this system are passive inter-modulation product(PIMP) control, large high gain antenna, L-band power generation and combination, channelization with Surface Acoustic Wave(SAW) filter, and linearization of Ku-band amplifiers. Table 2.6 shows the main characteristics of the LLM payload [14].

Table 2.6 The Main Characteristics of the LLM Payload

- Coverage	Global European
- Bandwidth	11 MHz
- L-band EIRP	
Eurobeam	45 dBW
Spotbeam	51 dBW
- L-band G/T	
Eurobeam	-2 dB/ K
Spotbeam	2.5 dB/ K
- Ku-band EIRP	38 dBW
- Ku-band G/T	-2 dB/ K
- Payload mass	160 kg
- Payload DC power	750 watt

Source: G. Perrotta, and F. Rispoli. "L-band Payloads for European Land Mobile Applications: Technology Issues." *13th AIAA Inter-national Communication Satellite Systems Conference and Exhibit*, Los Angeles (1990): 8-13.

2.1.9 COMETS

The COMmunications and broadcasting Engineering Test Satellite (COMETS) is a research and development satellite to demonstrate advanced mobile satellite communication, inter-orbit communications, and advanced satellite broadcasting experiments in Japan [17]. The concept of advanced mobile satellite communication system is to provide a voice or a message using handy terminals, a TV phone or a facsimile using mobile terminals, a TV conference using very small aperture terminal(VSAT), and one-hop connection among VSATs, mobile and hand-held terminals. A transmission rate of signals would vary from low bit rate of 4.8 kbps to 500 kbps. For the on-board processing, eight channels of SCPC signals are inputted to one regenerative MODEM and one TDM signal is outputted. A transmission rate of SCPC signal is 24 kbps or 4.8 kbps and BPSK modulation, rate 1/2 convolutional coding and Viterbi decoding are used. The two meter antenna has three beams and is used for both Ka and millimeter-wave bands. The antenna has two spot beams in Ka-band(48 dBi) and one spot beam in millimeter-wave(55 dBi) [18].

2.1.10 OmniTRACS, EutelTRACS

These are CDMA-based, packet switched, two-way messaging and position location/reporting systems which were initially developed by Qualcomm and Omninet Communication Services. The OmniTRACS operates, as a secondary basis under FCC rules, in the Ku-band(12/14 GHz) where the primary basis is given to Fixed Satellite Services (FSS). The system has three components, a network management facility(NMF), the two transponders, and a two-way data commu-nication and radio determination satellite service(RDSS) mobile VSATs. The forward link uses the first transponder to receive hybrid spread spectrum triangular FM dispersal modulated signals, and the return link uses the second transponder. The spreading is done in two stages, first with direct sequencing over a 1 MHz spread band, and then with frequency hopping over a total spread bandwidth of 54 MHz. The forward link data rate is 5~15 kbps continuous data stream, and return link is ranging from 55 to 165 bps depending on the link quality [19].

The mobile satellite terminal transmits a signal which is amplified by 1 watt power amplifier in the 14~14.5 GHz band, via the steerable antenna that has a maximum gain of 19 dBi for a total transmit power of 19 dBW. The forward link modulating signal is binary data at variable rates of 4,960.3~14,880.9 bps with rate 1/2 block encoding. These code symbols are used to drive a BPSK modulator at rates of 9,921~29,762 symbols per second, respectively. The return link modulating signal is binary data at 55.1 bps with rate 1/3 convolutional encoding. These code symbols are used five at a time to drive a 32-ary frequency shift keying(FSK) modulator at a rate of 33.1 FSK baud [20]. The EutelTRACS, European version of OmniTRACS, is the first operational RDSS in Europe as a joint venture between Eutelsat, Qualcomm and Alcatel. This system uses shared capacity on Ku-band commercial communication satellites operated by Eutelsat [50]. Table 2.7 shows the forward/return link power density of the OmniTRACS system [20].

Table 2.7 The Link Power Density of the OmniTRACS System

• Forward Link	
- Satellite EIRP	44.0 dBW
- Bandwidth	2 MHz
- Transmit power density	17.0 dBW/4kHz
• Return Link	
- Transmit power	1.0 dBW
- Antenna gain	19.0 dBi
- Bandwidth	48 MHz
- Number of uplinks	250
- System EIRP density	0.2 dBW/4kHz

Source: I.M. Jacobs. "An Overview of the OmniTRACS: The First Operational Two-way Mobile Ku-band Satellite Communications System." *Space Communications* 7 (1989): 25-35.

2.1.11 GEOSTAR, LOCSTAR

GEOSTAR is a two-way messaging system which sends messages to the mobile terminal through encoding 1.2 kbps data stream with a rate 1/2 convolutional encoder. Direct sequence spread spectrum techniques are used to produce a chip rate of 1.228 MHz, and then BPSK modulated. The mobile terminal receives the signal in the 4 GHz band. The mobile terminal transmits data at a rate of 15.625 kbps with a burst of data containing position, status information, and a short message. As with the forward direction, rate 1/2 convolutional coding is used. A chip rate of 8 MHz is obtained using direct sequence spread spectrum techniques. The resulting signal is BPSK modulated and transmitted to the satellite in the RDSS band(1,610~1,626.5 MHz). The terminal can also receive signals from a second satellite to offer LORAN-C or Global Positioning System(GPS) receiver functionality. LOCSTAR is European version of GEOSTAR system [52].

2.2 Medium Earth Orbit Systems

2.2.1 ODYSSEY

ODYSSEY will provide high quality voice, data, paging, radio determination, and messaging services worldwide from satellites. This MEO system will be an economical approach to providing global wireless communications. The selected constellation features twelve satellites at an altitude of 10,354 km with four satellites in each of three orbit planes inclined at 55 degree to provide continuous coverage with dual satellite visibility in some regions. This dual visibility leads to high line-of-sight elevation angles, thereby minimizing obstructions by terrain, trees and buildings. Odyssey will provide a link between mobile subscribers and the public switched telephone network(PSTN). Each satellite generates a multibeam antenna pattern that divides its coverage area into a set of contiguous cells. The communication system architecture employs spread spectrum CDMA scheme on both the uplink and downlink, which permits band sharing with other systems and applications [22].

Frequencies for satellite based personal mobile communications were designated at the 1992 WARC. Uplink transmissions from user to satellite are conducted at L-band(1,610~1,626.5 MHz), while downlink transmissions are at S-band(2,483.5~2,500 MHz). The 16.5 MHz allocation is divided into three 4.83 MHz communication bands. A single subband is assigned to each of the nineteen beams of the satellite multibeam antenna. Spread spectrum modulation, fully occupying the 4.83 MHz bandwidth, will be used on each of the communication channels. Transmissions between the ground stations and the satellites take place at Ka-band. In the forward direction, the satellite demultiplexes the FDM uplink transmission into its subband signals following translation from Ka-band to S-band. The composite subband signals are then routed to the various downlink antenna feeds. In the return direction, the composite signals received from the different cells are frequency division multiplexed(FDM) prior to translation from L-band to Ka-band.

The handheld personal telephone(HPT) will transmit approximately 0.5-watt average power which will be adequate for both voice and digital data transmission. Since the ODYSSEY system operates with high elevation angles of greater than 30 degree, relatively small margin is required for path loss due to rain, vegetation, path distance, etc. The HPT will be compatible with terrestrial cellular using antenna of a quadrifilar design. Multipath fade protection will be provided in the handset [23]. These terminals will be manufactured for as little as US$ 300 and sold for US $500. The service cost is based on US$ 0.65 per minute and a subscriber base of one to two million subscribers [21]. The spacecraft employs 2.25-meter L-band reflector and 1.4-meter S-band reflector. Two Ka-band antennas are gimbal mounted on the Earth-facing panel. The spacecraft points the S-band and L-band antenna by body steering scheme.

2.2.2 MAGSS-14

A Medium-Altitude Global Mobile Satellite System(MAGSS-14) has been designed to provide global mobile communication services such as 4.8 kbps voice and data to hand-held and portable/vehicle terminals. MAGSS-14 is a very attractive satellite constellation which shows both regional and global superiority in coverage performance for personal communications. This constellation with fourteen satellites, 10,354 km orbital altitude, six hour orbital period and seven orbital plane with 56 degree inclination, is the best single-visibility Rosette of fourteen satellites. MAGSS-14 offers global coverage twenty-four hour per day with elevation angles greater than 28.5 degree [25]. The antenna is a phased array and comprises sixty-one elements for a design with separate L-band and S-band antennas or eighty-one elements for a combined L/S-band antenna.

The architecture for payload is a transparent repeater with a SAW filter channelizer which allows power and bandwidth flexibility. The forward link(S-band) budget requiring C/No of 39 dBHz with 1.5 dB shadowing margin is total satellite EIRP of 48 dBW with 323-watt RF power, mobile G/T of -25 dB/°K, and 1.5-meter satellite antenna with 24.5 dBi gain. The return link(L-band) budget with same requirements is mobile EIRP of -3 dBW with 0.5 W RF power and satellite G/T of -4 dB/°K with 2.4-meter antenna. The feeder link spectrum of 8.5 MHz at C-band is required (with dual linear polarization) and the maximum capacity assigned to one beam is 1 MHz. A frequency reuse factor of two is planned for the mobile link, resulting in a mobile spectrum of 2.5 MHz required per satellite.Table 2.8 shows the forward/return link budget of the MAGSS-14 system [24].

Table 2.8 The Link Budget of the MAGSS-14 System

• Forward Link(S-band)	
- Satellite transmit power	323 watt
- Satellite antenna	
Diameter	1.5 meter
Gain	24.5 dBi
- Total satellite EIRP	48.0 dBW
- Voice activation	4 dB
- Number of duplex circuits	1,000
- Satellite EIRP per circuit	22.0 dBW
- Mobile G/T	-25 dB/ K
- Downlink C/No	41 dB/Hz
- Elevation angle	30 degree
• Return Link(L-band)	
- Mobile transmit power	0.5 watt
- Mobile antenna gain	0 dBi
- Mobile EIRP	-3 dBW
- Satellite antenna diameter	2.4 meter
- Repeater noise temperature	28.5 dB K
- Satellite G/T	-4 dB/ K
- Uplink C/No	40.9 dB/Hz
- Overall C/No	40.5 dB/Hz

Source: P. Rastrilla, P. Rinous, and J. Benedicto. "Payload for Medium Altitude Global Mobile Satellite System." *The Third European Conference on Satellite Communications (ECSC-3)*, Manchester (1993): 320-324.

2.2.3 INMARSAT-P

INMARSAT established its own concept(Project-21) of global mobile satellite communications services, called INMARSAT-P, using handheld satellite phone the size of a cellular phone. Project-21 will lead to the introduction of INMARSAT-P service by means of a new, more powerful, satellite generation. The INMARSAT-P handheld terminal will be a dual-mode device that will work with the terrestrial personal communication services(PCS) network, when available, and the satellite system when the terrestrial network is not available. The system will offer line-of-sight satellite voice services, with a voice quality similar to that of digital cellular systems [26]. The US$ 2.6 billion constellation will use twelve

S-band satellites(ten operational and two spares), orbiting in two orbital planes at 10,300 km above the earth with an inclination of 45 degree [41].

The provision of INMARSAT-P service will require the addition of an advanced space-segment and an associated terrestrial network infrastructure. The ground-segment infrastructure has to be capable of supporting the satellite phone service on a stand-alone and global basis as well as in national/regional cellular extension mode. Inmarsat will become the first major supplier of services using the Future Public Land Mobile Telecommunication Systems(FPLMTS) frequencies. An advantage of the FPLMTS band(uplink:1,980~2,010 MHz, downlink: 2,170~2,200 MHz) is easier to build a dual mode handheld unit since the frequencies are contiguous [43]. The features of terminal will be size of less than 300 cm^3, weight of 300~450 grams, medium penetra-tion call announcement, duplex data, group-III fax, position determination, and smart card. The end-user charge will be US$ 2 per minute, and the terminal cost will be US$ 1,500 [40].

2.3 Big Low Earth Orbit Systems

2.3.1 IRIDIUM

The IRIDIUM system is a satellite-based, wireless personal communications network designed to permit any type of telephone transmission—voice, data, fax, paging, messaging, RDSS—to reach its destination anywhere on the earth, at any time. The IRIDIUM network of sixty-six satellites(689 kilogram each) will orbit at an altitude of 780 km, six orbital planes with an inclination of 86.4 degree, and eleven operational satellites with one on-orbit spare per plane [48]. The LEO system will provide better performance than GEO system: wider global coverage, better spectrum conservation, shorter propagation delay, and lower EIRP requirement, resulting in a cheaper hand unit. The IRIDIUM system will use FDMA/TDMA multiplexing to make the most efficient use of limited spectrum. Table 2.9 shows the main features of the IRIDIUM system [42].

Table 2.9 The Main Features of the IRIDIUM System

- Number of satellites	66
- Cost of system	US$ 3.4 billion
- Altitude	780 km
- Charge per minute	US$ 3.00
- Terminal cost	US$ 2,500
- Services	Voice, fax and paging
- Antenna size	6 feet
- Multiple access	TDMA
- Spectrum band	L/S-band
- Rollout date	1998
- Intersatellite link	Yes

Source: G. Gilder. "Gilder's Telecosm." *Forbes ASAP* (Oct.10, 1994): 133-150.

Each satellite employs a phased array antenna complex that forms 48 interlaced spot beams, and intersatellite connectivity which is essential to provide truly global coverage. The radio links between users and satellites will operate in the region of L-band and the gateway feeder links in Ka-band, while the intersatellite links will operate in S-band [42]. The 4.8 kbps Vector-Sum Excited Linear Predictive Codec(VSELP) vocoder output data stream is rate 3/4 convolutionally encoded with FEC and QPSK-modulated with TDM and FDM. The handheld unit can operate for twenty-four hours on a single recharge: twenty-three hours of standby plus one hour of continuous calling time [53]. The subscriber charge will be about

US$ 3 per minute, and terminal cost will be about US$ 1,000 [45]. The total system cost is expected to be US$ 3.37 billion [46].

2.3.2 GLOBALSTAR

The GLOBALSTAR system is a LEO satellite-based mobile communications system that is interoperable with the current and future Public Land Mobile Network(PLMN). The system will provide affordable and reliable voice, data, facsimile and position location services to customers worldwide. The GLOBALSTAR exploits the technologies of CDMA with power control, voice activity factor, spot beam antenna, multiple satellite coverage, and soft handoff [28]. The forty-eight satellite constellation can provide high-quality mobile communications services to users through multiple coverage which increases system capacity and provides path diversity. This CDMA-based system is also very friendly with respect to frequency sharing [27].

The space segment is comprised of a constellation of forty-eight satellite orbiting in eight orbital planes at 1,389 km above the earth with an inclination of 52 degree, which provides global coverage, avoids exposure to the radiation of the Van Allen belts, and allows a low-power handheld user terminals without requiring large deployable antennas [29]. The ground segment consists of gateway stations: the telemetry, tracking and command(TT&C) stations, the satellite operation control center(SOCC), and the network control center(NCC). The GLOBALSTAR system will use the L-band(1,610~1,626.5 MHz) spectrum for the uplink and S-band(2,483.5~2,500 MHz) for the downlink. The C-band is allocated for feeder link: 6,484~6,541.5 MHz for the feeder uplink and 5,158.5~5,216 MHz for the feeder downlink.

The CDMA techniques used by GLOBALSTAR result in a very efficient use of the 16.5 MHz L-band and S-band spectrum. CDMA techniques will allow full frequency reuse of adjacent beams and excellent performance in multipath environment The vocoder design uses a 20 msec frame interval and produces four different data rates(9.6, 4.8, 2.4, and 1.2 kbps) which can vary every 20 msec frame. Vocoders operating at 4.8 kbps produce an adequate communications quality grade of service. The 9.6 kbps rate is available for those subscribers who desire a higher grade of service, approaching that of toll quality. The subscriber charge will be about US$ 0.30 per minute, and terminal cost will be about US$ 700 [45]. The total system cost is expected to be US$ 1.7 billion [46]. Table 2.10 shows the main features of the GLOBALSTAR system [42].

Table 2.10 The Main Features of the GLOBALSTAR System

- Number of satellites	48
- Cost of system	US$ 1.8 billion
- Altitude	1,389 km
- Charge per minute	US$ 0.30
- Terminal cost	US$ 750
- Services	Voice, fax and E-mail
- Antenna size	3 feet
- Multiple access	CDMA
- Spectrum band	L/S/C-band
- Rollout date	1998
- Spectrum sharing	Yes

Source: G. Gilder. "Gilder's Telecosm." *Forbes ASAP* (Oct.10, 1994): 133-150.

2.3.3 ARIES

ARIES is designed to provide two-way telephony, dispatch voice, data/facsimile transmission, position determination and reporting, data collection and distribution, and control services [50]. The service will be particularly useful in developing countries, where terrestrial networks are unlikely to extend beyond major urban areas [51]. ARIES constellation will use forty-eight polar orbiting satellites in four orbital planes at 1,018 km above the earth. The system will employ TDMA/CDMA multiple access, and L/S band for user links and C-band for feeder links within 5 MHz bandwidth. The coding rate will be 4.8 kbps for voice and 2.4 kbps for data. [46]. The system cost is estimated to be US$ 294 million. The subscriber terminals are both vehicle-mounted and portable units, and expected to cost about US$ 1,500.

2.3.4 TELEDESIC

TELEDESIC network is embodied in a constellation of 840 LEO satellites orbiting the Earth at an altitude of 700 km with twenty-one orbital planes inclined at 98.2 degree. This sun-synchronous orbit allows savings in solar power arrays and cooling of satellite's electronics. Each satellite is a switch node in the network and is linked with up to eight adjacent satellite through intersatellite links to form a robust mesh topology that is tolerant to faults and local congestion. The system uses Ka-band frequencies and recent advances in active phased arrays, fast-packet switching, and adaptive routing technology. TELEDESIC's applications include ubiquitous computer commu-nications, video dial tone, multimedia services and multirate integrated services digital network(ISDN). Subscriber terminals communicate directly with the satellite network connecting with other network terminals or, through a gateway interface, with the PSTN [30].

A combination of a high mask angle(40 degree), high-gain antennas, and small cell size compensate for the rain attenuation and terrain blocking characteristics of Ka-band frequencies and minimize interference with terrestrial systems. A unique earth-fixed-cell technology minimizes the 'hand-off' and frequency coordination problems associated with LEO networks. Earth-fixed-cell technology relies on accurate knowledge of the satellites; position and attitude, timing information, and precision beam steering. The basic channel rate is 16 kbps for the payload and 2 kbps for signalling and control. The channel bandwidth can be selected on demand from terminals: mobile terminals at 16 kbps, facsimile channel at 64 kbps, video channel at Nx64 kbps, and primary ISDN at T1/E1(1.544/2.048 Mbps) rate. The fast packet switching technology similar to the asynchronous transfer mode(ATM) combines the advantages of a circuit switched network and a packet switched network. This technology is ideally suited for the dynamic nature of a LEO network. Table 2.11 shows the main features of the TELEDESIC system [42].

Table 2.11 The Main Features of the TELEDESIC System

- Number of satellites	840
- Cost of system	US$ 9 billion
- Altitude	700 km
- Charge per minute	US$ 0.04 for basic channel Teleconference
- Terminal cost	US$ 1,000(64 kbps) and US$ 6,000~8,000(2 Mbps)
- Services	Broadband computer data and video teleconferencing
- Data rate	16~2,048 kbps
- Antenna size	10 inch
- Multiple access	FDMA/TDMA
- Spectrum band	Ka-band(19~30 GHz)
- Rollout date	2001
- Realistic capacity	100,000 T1

Source: G. Gilder. "Gilder's Telecosm." *Forbes ASAP* (Oct. 10, 1994): 133-150.

Intersatellite links can use from one to eight 138 Mbps(1 GHz) channels, depending on the required capacity. Fixed and mobile terminal-satellite links will support larger, high gain terminals and small, moderate gain terminals, respectively. Terminals will use FDMA on the uplink and asynchronous TDMA(ATDMA) on the downlink. The ATDMA which takes advantages of the bursty nature of most communications, does not use a fixed assignment of time slots to terminals. The satellite transmits a series of packets addressed to terminals within that cell during each cell scan interval. The satellite bus and payload are designed to have a lifetime of ten years. The satellite uses a multi-panel antenna system with multiple active element phased array antenna facets using Gallium Arsenide(GaAs) monolithic microwave integrated circuit(MMIC) and beam steering circuits. These technique will provide dynamic control of gain, beam shape and power control. The subscriber charge will be about US$ 0.04 per minute for basic channel, and terminal cost will be about US$ 1,000 for 64 kbps and US$ 6,000~8,000 for 2 Mbps. The total system cost is expected to be US$ 9 billion.

2.3.5 BOPSAT

The BOPSAT is a Low Earth Orbit satellite system for personal communications by France Telecom CNET and French Space Agency CNES. Two major drivers in designing this system are the maximization of compatibility with existing or planned ground cellular systems and the minimization of investment to set-up the system. BOPSAT will use forty-eight satellites orbiting in eight orbital planes at 1,400 km above the earth with an inclination of 52 degree. This constellation is optimized for latitudes between 20 and 55 degree offering with higher than 10 degree elevation angle. The BOPSAT satellite is composed of C/S-band and L/C-band transponders providing links between C-band gateways(feederlink) and L/S-band mobile terminals. Each satellite offers eight beams in L and S-band, each beam acting as a cell of a ground cellular mobile network. The highly elliptical parallel beams allow to maximize the time during which the user remains in the same beam. Mobile link(uplink:1,610~1,626.6 MHz, downlink:2,483.5~2,500 MHz) spectrum is 16.5 MHz wide and feeder link(6.5/5.2 GHz) band-width is 132 MHz. The average S-band EIRP is 30 dBW and the minimum L-band G/T is -21 dB/ K.Table 2.12 shows the main mission parameters of the BOPSAT system [31].

Table 2.12 The Main Mission Parameters of the BOPSAT System

- Frequency band	
Mobile link(up)	1,610~1,626.5 MHz
(down)	2,483.5~2,500 MHz
Feeder link	6,500/5,200 MHz
- Transponder(forward)	C/S 8 channel
(return)	L/C 8 channel
- S-band mean EIRP	30 dBW
- L-band minimum G/T	-21 dB/ K
- Satellite lifetime	7.5 years

Source: B. Coulomb, P. Fraise, P. Jung, D. Rouffet, P. Voisin, J. Jarlier, L. Ruiz, and T. Roussel. "Low Earth Orbit Satellite Payload for Personal Communications." *The Third European Conference on Satellite Communications(ECSC-3),* Manchester (1993): 315-319.

2.3.6 MOBILSATCOM

MOBILSATCOM is an alternative satcom architecture supporting military and quasi-military voice/data communications users through circuit-switched network. The space segment is to be comprised of 192 LEO gravity gradient stabilized satellites orbiting in sixteen orbital planes(eight at 45 degree and eight at 80 degree) at 1,000 km above the earth, and single GEO relay satellite. Satellites within a plane and GEO relay links interconnecting planes, are interconnected by simple direct-detection laser intersatellite links. The relay satellite is comprised of nineteen-mirror lasercom transponder with Manchester modulation/demodulation and a state-of-the-art 15,000-channel crossbar switch. Table 2.13 shows the UHF/SHF link characteristics of the MOBILSATCOM system [32].

Table 2.13 The Link Characteristics of the MOBILSATCOM System

• UHF Link	
- Satellite transmit power	14.4 dBW(28 watt)
- Satellite antenna gain	4 dBi(60 off-axis)
- Terminal transmit power	0.8 dBW(1.2 watt)
- Terminal antenna gain	5 dBi
- Elevation angle	10 degree
- G/T	-26 dB/ K
- Frequency(up/down)	240~400 MHz
- Eb/No(BER=10^{-3})	7 dB
- Data rate	2400 baud
- Modulation	8-FSK
- FEC	10^{-6}
• SHF Link	
- Satellite tx. power/channel	1dBW(1.26 watt)
- Satellite antenna gain	5.5 dBi(55 off-axis)
- Terminal transmit power	6.2 dBW(4.2 watt)
- Terminal antenna gain	25.3 dBi
- Elevation angle	20 degree
- G/T	-10 dB/ K
- Frequency(up/down	8/7 GHz
- Eb/No(BER=10^{-3})	7 dB
- Data rate	2400 baud
- Modulation	8-FSK
- FEC	10^{-6}

Source: J.M. Ruddy, R.T. Carlson, T.J. Ferguson, R.A. Haberkorn, N.D. Hulkower, and G.F. Providakes. "Concept for a Cost/Technology-Driven Mobile Satellite Communications (MOBILSATCOM) System." *13th AIAA International Communication Satellite Systems Conference and Exhibit*, Los Angeles (1990): 720-730.

The small briefcase-sized 1-watt ultra high frequency(UHF:225~400 MHz) terminal supports a single secure 2.4 kbps, full-duplex circuits. The 4-watt super high frequency(SHF:8/7 GHz) terminal employs a 106 element transmit and eighty-one element receive phased array antenna with a 10 degree beamwidth. The SHF link will use frequency hopping to counter mobile jammers with 500 MHz bandwidth and 43 dB processing gain. The UHF link will use pseudo-random noise(PN) spread spectrum technique to limit interference with 5 MHz bandwidth.

2.4 Little Low Earth Orbit Systems

2.4.1 ORBCOMM

The ORBCOMM system provides the user with data messaging capabilities which can compose, transmit and receive messages on very small handheld devices or devices integrated with palm-top computers anywhere in the world. The space segment is comprised of twenty-six small satellites in orbit 785 km above the earth with five orbital planes at inclination of 50/90 degree. The ORBCOMM system uses 137~138 MHz for downlink and 148~150.5 MHz for uplink in very high frequency(VHF) band with differential phase shift keying(DPSK) modulation. This system provides the following advantages; availability of Doppler shift in signal for integrated position determination, use of proven inexpensive VHF electronics and shared omnidirectional VHF antennas, and excellent overall link availability independent of local terrain features. The subscriber terminals are full function compact, light-weight devices with long-life batteries, 5~8 watt transmitters, antenna(G/T: 28 dB/°K), keypad and liquid crystal display(LCD) screens. Terminals will have RS-232 data ports and some will be integrated with

GPS receivers, lap-tops and palm-top computers, and other systems [33]. The data rates are 2.4 kbps for uplink, 4.8 kbps for downlink, and 56 kbps for feeder link. The total system cost is expected to be less than US$ 200 million [35]. Table 2.14 shows the RF characteristics of the ORBCOMM system [33].

Table 2.14 The RF Characteristics of the ORBCOMM System

• Uplink	
- Frequency	148~150.05 MHz
- Data rate	2400 baud
- Modulation	DPSK
- Power	5~8 watt
• Downlink	
- Frequency	137~138 MHz
- Data rate	4800 baud
- Modulation	DPSK
- G/T	28 dB/ K

Source: T. Hara. "ORBCOMM: Low Earth Orbit Mobile Satellite Communication System US Armed Forces Applications." *Conference Record of Milcom '93*, Boston (1993): 710-724.

2.4.2 STARSYS

The STARSYS will feature non-voice, digitally encoded data-only messages, transmitted in very brief radio bursts in frequencies below 1 GHz. The constellation of twenty-four satellites will be distributed in circular orbits of 1,300 km altitude with six orbital planes at an inclination of 60 degree. The STARSYS system will support remote geopositioning, two-way remote data messaging, and one-way remote data collection. These functions are provided with mobile transmitter terminals and user application centers, a coordinated and interconnected network of ground receiving stations, and satellites. The system will transmit from ground stations to the satellites using a 50 kHz signal in the

149.9~150.05 MHz, and forwarding those signals to mobile terminals in the 400.15~401 MHz, using a hybrid narrowband communication/spread spectrum technique. Mobile terminals will transmit to the satellites in the 148~149.9 MHz using spread spectrum, with the satellite relaying those signals to the ground station in the 137~138 MHz. The terminal cost will vary from under US$ 100 to about US$ 350 [34]. The data rates are 4.8 kbps for uplink and 9.6 kbps for downlink. The total system cost is expected to be less than US$ 200 million [35].

2.4.3 TEMISAT

The TElespazio MIcroSATellite(TEMISAT) will implement a data collection and distribution service for geophysical environmental monitoring based on an autonomously managed network. The total system cost is expected to be less than US$ 10 million. The environmental data are acquired and collected through earth-based sensor subsystems, and temporarily stored on the ground and logged by autonomous user terminals until the polling from satellite, then transmitted to data collection centers. The space segment will consist of two microsatellites orbiting an altitude of 950 km at an inclination of 82.5 degree using TDMA/SCPC scheme. The data rates are 2.4 kbps for user link and 9.6 kbps for data collection center downlink [35].

2.4.4 VITASAT

Volunteers IN Technical Assistance(VITA) proposes a non-profit International store-and-forward communications system for developing countries consisting of two LEO microsatellites. The satellites will exploit sun-synchronous orbit at an altitude of 800 km, frequency shift keying(FSK) modulation, and 9.6 kbps transmission rate. The frequency range is 150 MHz for uplink and 400 MHz for downlink. The system uses VHF/UHF for both user and feeder link with 9.6 kbps data rate. The total system cost is expected to be US$ 10 million [35].

2.4.5 SHARP

The Stationary High Altitude Relay Platform(SHARP) concept which can be classified into a type of Very Low Earth Orbiting Satellites(VLEOS), is originally developed by Canadian Department of Communications to provide a wide range of personal communications services. A SHARP is an unmanned, fuel-less aircraft powered by microwave transmitters on earth, flying in a circular plane of about 1 km radius at an altitude of 21 km, and carrying communication or radar payloads up to 1,000 kilograms. The system has negligible transmission delay, propagation loss, and very high frequency reuse factor due to smaller coverage [36].

2.4.6 Other Little LEOs

LEOSAT(Leosat Inc.) is comprised of a constellation of eighteen satellite orbiting in three orbital planes at 970 km above the earth with an inclination of 40 degree. This system will use VHF for user link and UHF for feederlink with 4.8 kbps data rate. The total system cost is expected to be US$ 100 million [35].

S-80/TAOS(CNES) is a complex position location and two-way messaging system for mobile communications in France using a constellation of five satellites. Radio determination is performed through either Doppler measurement or GPS. The total system cost is expected to be US$ 5 million [35].

SAFIR(OHB) is a data collection and distribution system developed in Germany, using six satellites in sun-synchronous orbit at an altitude of 690 km. The system uses VHF/UHF for both user and feeder link with 0.3/9.6 kbps data rate respectively. The total system cost is expected to be US$ 20 million [35].

ITAMSAT(Italian Radio Amateur) is a 50-kilogram store-and forward satellite operating at VHF/UHF bands, implemented at the cost of less than US$ 300,000 by students and volunteers [35].

GONETS(Smolsat) is a Russian constellation of thirty-six satellites orbiting in six orbital planes at 1,390 km above the earth with an inclination of 83 degree. This system will employ VHF/UHF bands for user link with 4.8 kbps data rate. The total system cost is expected to be US$ 300 million [35].

FAISAT(Final Analysis Communication Services) is seeking to launch a twenty-six satellite constellation by 2000. The system is expected to cost US$ 140 million. The first satellite FAIsat-1 will be launched as a piggyback payload on a Russian Cosmos rocket [54].

GEMNET(CTA Commercial Systems) is thirty-eight satellite constellation which will provide asset tracking and monitoring, utility meter reading, E-mail, global paging, buoy and environmental sensor reading, and direct-to-home communications services by 1999 [54].

EYESAT(GE Americom/Interferometrics) is proposed to launch a constellation of forty-eight satellites. Eyesat-1 was launched as a supplemental payload on an Ariane rocket [54].

Leo One USA hopes to launch forty-eight satellites for its global communications system [54].

2.5 Highly Elliptical Orbit Systems

2.5.1 ELLIPSO

ELLIPSO is a constellation of ultimately twenty-four satellites in two sun-synchronous elliptical orbits with perigee of 520 km and apogee of 7,800 km at an inclination of 116.6 degree, and one equatorial orbit with apogee of 7,800 km and perigee of 4,000~7,800 km. The system will be operated in the 1,610~1,626.5 MHz(L-band) for uplink and 2,483.5~2,500 MHz(S-band) for downlink. The system provides mobile voice and position determination services using BPSK modulation and spectrum efficient FDMA/CDMA scheme. Table 2.15 shows the communication subsystem parameters of the ELLIPSO system [37].

Table 2.15 The Communication Subsystem Parameters of the ELLIPSO System

• Uplink	
- Frequency	1,610~1,626.5 MHz
- G/T(widebeam)	-17 dB/ K
(spotbeam)	-3 dB/ K
- Antenna beamwidth	60 degree
- Polarization	Dual circular
• Downlink	
- Frequency	2,483.5~2,500 MHz
- Bandwidth per segment	1.4 MHz
- RF Power	170 watt
- Antenna beamwidth	60 x20
- Polarization	Circular
- Total EIRP	35 dBW

Source: D. Castiel. "The ELLIPSO: Elliptical Low Orbits for Mobile Communications and Other Optimum System Elements." *The Workshop on Advanced Network and Technology Concepts for Mobile, Micro and Personal Communications*, Jet Propulsion Laboratory, Pasadena (1991): 101-117.

Each satellite has a bandwidth of operation of 16.5 MHz which is divided into 1.4 MHz segments matched with the spreading of digital CDMA cellular systems. The CDMA carrier provides 4.8 kbps digital voice using 1.28 megachips per second(Mcps) chip rate and 1/2 rate FEC coding, and 0.3/9.6 kbps data rate. The communication subsystem provides the EIRP of 35 dBW, and G/T of -17 dB/°K for widebeam and -3 dB/°K for spotbeam. The mobile terminal provides the EIRP of 11 dBW, and G/T of -21 dB/°K for 15 degree elevation angle and -24 dB/°K for 5 degree [37]. The total system cost is expected to be US$ 600 million [46].

2.5.2 LOOPUS-MOBILE-D

The Quasi-geostationary Loops in Orbits Occupied Permanently by Unstationary Satellites(LOOPUS) orbit has its perigee of 5,784 km and apogee of 41,449 km at an inclination of 63.4 degree. LOOPUS satellites with the same payload weight as GEO will have only about half launch mass due to no transferring to GEO orbit. The baseline concepts of the system are as follows: complementary to existing mobile communication networks as well as to the group special mobile(GSM), universally applicable for land, sea or air traffic, and future support of small compact mobile terminals. The basic communication performance features are telephone and data services, digital audio broadcast, paging, and navigation. The mobile link uses 14~14.1 GHz for uplink and 12.1~12.2 GHz for downlink, and the feederlink uses 14.15~14.25 GHz for uplink and 11.2~11.3 GHz for downlink. The information rate of full channel is 13 kbps using Linear Predictive Codec(LPC), and FEC data rate is 22.8 kbps [38].

2.5.3 M-HEO

The multiregional Highly Elliptical Orbit(M-HEO) is a constellation of six satellites orbiting in three orbital planes at perigee of 1,000 km and apogee of 27,000 km with an inclination of 63.435 degree. This system will provide direct satellite radio broadcasting(DBS-R) services worldwide with unprecedented high-quality digital sound at an elevation angle of better than 40 degree. The M-HEO allows low cost, around-the-clock coverage of three different regions of the earth; Europe, Far East, and North America. The satellite employs a 2-meter reflector antenna with a 7 degree half-power beamwidth at 1.5 GHz for DBS-R [39].

2.5.4 ARSENE

Ariane Radioamateur Satellite ENseignement Espace(ARSENE) is developed for the French Radio Amateur Club del'Espace(RACE) by a fairly large team of students and engineers from aerospace industries utilizing spare parts of satellites. The satellite is orbiting an elliptical orbit of 17,200 km perigee and 37,000 km apogee. The ARSENE payload is composed by two repeaters transmitting at VHF(uplink:435.1 MHz) and UHF(downlink:2,446.54 MHz). User terminal is transmitting 50~80 watt RF power and receiving via 2-meter dish [35].

CHAPTER 3

COMMUNICATION LINK BUDGET

The links of satellite-to Earth(downlink) and Earth-to-satellite(uplink) can be described as functions of the satellite and handheld mobile terminal features, and the constellation parameters. For medium and high altitude constellation, the onboard antenna diameter is determined primarily by the uplink equation, whereas the downlink equation determines the size of the spacecraft in terms of onboard DC power consumption for a given satellite capacity. Furthermore, the greater the altitude, the lower the efficiency of the satellite link is in terms of RF power and the ability to reuse the frequency spectrum by spatial discrimination, which means that increasingly large onboard antenna must be used.

3.1 Mobile Uplink

The mobile uplink largely determines the size of the spacecraft antenna. Thus, for a given mobile terminal EIRP, and a given link margins and service availability, the minimum size of onboard antenna required to route one voice channel in the return link can be determined. The following expression for the satellite antenna gain G in dB can be derived from the uplink equation:

$$G = \left(\frac{C}{No}\right)up - EIRP_{mob} + L + T_{sat} - 20 \log \frac{3}{4 \times 10^{4} Hf} - 228.6$$

where f is the RF frequency in GHz, H the orbital height in km, T_{sat} the system noise temperature at the satellite in dBK, L the link margin plus scan losses in dB, and $(C/No)_{up}$ the carrier-to-noise power density ratio in the uplink in dBHz.

Considering the spacecraft dish antenna diameter D and the radiation efficiency , this diameter can be expressed as follows:

$$D = 1.486 \times 10^{-8} H \left(\frac{10^{L/10} T_{sat} (C/No)_{up}}{EIRP_{mob}} \right)^{1/2}$$

where D is in meters, H in km, T_{sat} in K, L in dB and $(C/No)_{up}$ in Hz.

The antenna diameter does not depend on the frequency and is mainly fixed by the EIRP at the mobile terminal.

3.2 Mobile Downlink

The determination of the spacecraft size in terms of RF power demand, DC power consumption, and number of channels routed in the forward link is given by the downlink equation. From this equation the following expression for the satellite EIRP per channel in dB can be obtained:

$$\left(\frac{EIRP}{ch}\right)_{sat} = \left(\frac{C}{No}\right)_{down} - \frac{G}{T_{mob}} + L - 20 \log \frac{3}{4 \times 10^{4} Hf} - 228.6$$

where f is the RF frequency in GHz, H the orbital height in km, $(G/T)_{mob}$ the ratio of the antenna gain to the system noise temperature of the mobile terminal dB/K, L the link margin plus scan losses in dB, and $(C/No)_{down}$ the carrier-to-noise power density ratio in the downlink in dBHz.

3.3 RF Link Budget Comparison

These equations can be used to calculate forward and return link budget for mobile satellite service systems. The Table 3.1 shows the RF link budget comparison of the major MSS systems.

Table 3.1 The RF Link Budget Comparison of the Major MSS Systems

	MSAT	MOBILESAT	PASS	MAGSS-14	MOBILSATCOM	ELLIPSO
• Uplink	L-band	L-band	Ka-band	L-band	UHF/SHF	L-band
- Mobile Terminal						
Power	0 dBW	N/A	-5.2 dBW	-3 dBW	0.8/6.2 dBW	N/A
Antenna Gain	10 dBi	N/A	22.8 dBi	0 dBi	5/25.3 dBi	N/A
EIRP	9 dBW	10 dBW	16.8 dBW	-3 dBW	5.1/29.5 dBW	11 dBW
- Propagation Loss	-189 dB	-189 dB	-214 dB	-178.5 dB	-153/-177 dB	-174 dB
- Satellite						
Antenna Gain	45 dBi	N/A	52.5 dBi	24 dBi	4/5.5 dBi	N/A
G/T	19.4 dB/°K	-1.5 dB/°K	23.4 dB/°K	-4 dB/°K	N/A	-3 dB/°K
- C/No	N/A	48.5 dB/Hz	46.9 dB/Hz	40.9 dB/Hz	N/A	48.6 dB/Hz
- Eb/No	29.7 dB	N/A	8.5 dB	N/A	7 dB	6 dB
• Downlink	L-band	L-band	Ka-band	S-band	UHF/SHF	S-band
- Satellite						
Power	23 dBW	N/A	57 dBW	25.1 dBW	14.4/1 dBW	22.3 dBW
Antenna Gain	44.5 dBi	N/A	52.5 dBi	24.5 dBi	4/5.5 dBi	N/A
EIRP	60.5 dBW	48 dBW	55 dBW	48 dBW	17.7/0.8 dBW	35 dBW
- Propagation Loss	-188.5 dB	-188.5 dB	-210.5 dB	-182.4 dB	-153.3/-177 dB	-177.9 dB
- Mobile Terminal						
Antenna Gain	10 dBi	N/A	19.3 dBi	0 dBi	5/19.1 dBi	N/A
G/T	-12.3dB/°K	-14 dB/°K	-9 dB/°K	-25 dB/°K	-26/-10 dB/°K	-21 dB/°K
- C/No	N/A	N/A	58.8 dB/Hz	41 dB/Hz	N/A	42.7 dB/Hz
- Eb/No	20 dB	N/A	N/A	N/A	7 dB	6 dB

Source: Refer to the References.

CHAPTER 4

REGULATORY ISSUES

The traditional spectrum allocations for mobile satellite service(MSS) are in the L-band(1.6/1.5 GHz). To allow more flexibility in the use of the available L-band spectrum, the World Administrative Radio Conference(WARC) MOB-87 proposed a new generic mobile satellite service category to accommodate the emerging land mobile satellite services(LMSS). The WARC-92 allocated 1,525~1,530 MHz band to the downlink of the new generic MSS, which produces a balanced 34 MHz uplink/downlink spectrum allocation. The "Big LEO" systems will use newly allocated L-band and S-band frequencies to offer voice and data services, while the "Little LEO" systems will use newly allocated VHF and UHF frequencies to offer only data services. The total bandwidth allocated was 16.5 MHz in the 1,610~1,626.5 MHz bands(uplink) and 2,483.5~2,500 MHz(downlink). The 1.6/2.4 GHz bands are designated for all types of MSSs, however, the FCC has proposed that all U.S. systems using these frequencies must be "Big LEO" systems that cover the world 75 percent of the time, and provide continuous phone service to the entire United States. Therefore, MSAT using part of this spectrum would not meet this requirements.

New S-band frequencies(2,670~2,690 MHz for uplink and 2,500~2,520 MHz for downlink), and FPLMTS spectrum(1,980~2,010 MHz for uplink and 2,170~2,200 MHz for downlink) was allocated to to the MSS as a satellite component on a worldwide basis [43]. Both frequencies do not become effective until January 1, 2005 that many administrations want to be moved forward. The frequency bands allocated to the MSS in the U.S. were 1,970~2,010(uplink) and 2,160~2,200 MHz(downlink). The Table 4.1 shows the new frequency allocation for MSS after WARC-92 [55].

Table 4.1 The New Frequency Allocation for MSS after WARC-92

137~138 MHz	MSS	N-GSO, ("small LEO")
148~149.9 MHz	MSS	N-GSO, ("small LEO")
149.9~150.05 MHz	LMSS	N-GSO, ("small LEO")
312~315 MHz	mss	
387~390 MHz	mss	
400.15~401 MHz	MSS	N-GSO, ("small LEO")
1,525~1,530 MHz	MSS	(in Rerion 1: MSS+lmss)
1,530~1,533 MHz	MSS+LMSS	(MSS in Region 2)
1,533~1,544 MHz	MSS+lmss	(MSS in Region 2)
1,544~1,545 MHz	MSS(D&S)	NOC
1,545~1,555 MHz	AMSS(R)	NOC
1,555~1,559 MHz	LMSS	(MSS in Region 2)
1,610~1,626.5 MHz	MSS	(+RDSS)
1,626.5~1,631.5 MHz	MSS	(in Region 1: MSS+lmss)
1,631.5~1,634.5 MHz	MSS+LMSS	(MSS in Region 2)
1,634.5~1,645.5 MHz	MSS+lmss	(MSS in Region 2)
1,645.5~1,646.5 MHz	MSS(D&S)	NOC
1,646.5~1,656.5 MHz	AMSS(R)	NOC
1,656.5~1,660.5 MHz	LMSS	(MSS in Region 2)
2,483.5~2,500 MHz	MSS	(+RDSS)

Source: K. Arasteh. "Spectrum Planning and Management of Satellite Services in a Deregulated Environment." *Mobile Satellite Communication in Asia*, Hong Kong (1993)

Several important issues regarding the MSS which not decided at WARC-92, will fill up the upcoming WRC-95 referred to as a "Mobile WRC". According to the present Radio Regulation, geostationary MSSs have priority over non-geostationary MSSs for the new L/S-bands, and non-geostationary feeder link networks are not allowed to cause interference to geostationary MSS networks. In this regard frequencies in the Ka-band(30/20 GHz) as well as reversed frequencies(uplink band for downlink and vice versa) of C and Ku-bands are being considered for feeder links to non-geostationary satellites.

CHAPTER 5

CURRENT TRENDS IN MSS SYSTEMS

The trends in mobile satellite services(MSS) systems are similar to the trends in other sectors of the satellite communications: the smaller and less expensive terminals with cheaper service charges. The architectures of MSS systems are complex and variable with their constellations(orbital planes, altitudes, and inclinations). The satellite appears to be more sophisticated with large number of beams, on-board processing, frequency translation, power amplification, signal routing, and dynamic allocation of power and bandwidth. The multibeam antenna makes it possible to provide many simultaneous transmissions and high frequency reuse factor for low power terminals. The choice of orbital altitude or the size of the spacecraft antenna is influenced by the uplink power levels of the mobile handheld terminals which should be low enough to avoid any health hazard. The gain of mobile terminal antenna is in the range of 2~8 dBi.

If the ground coverage area is kept constant, the increasing altitude requires the reduced beamwidth, and the increased gain and size of the satellite antenna. The signal delay consists of coding, propagation, and processing delay. The LEO may have relatively larger processing delay than propagation delay while the GEO's significant propagation delay distracts a voice conversation. The selection of the multiple access scheme is an important technical and operational decision, because it can influence critical parameters of service availability, system capacity, and network flexibility. The spread spectrum property of CDMA reduces the tendency of causing interference and sensitivity to interference. The voice coders use linear prediction which increases the time delay due to the requirement to store a segment of speech into a memory. The more complex coders will have the more physical circuitry and power that results in difficulty of making compact handheld terminal.

The recent interest in non-geostationary orbits(MEO, LEO) for mobile satellite communications takes advantages of the lower time delay and higher elevation angles. However, the success in this business will be decided by the timely implementation of service, risk-free technology, user satisfaction, and finantial performance.

APPENDIX A

PARAMETERS OF THE GEO SYSTEMS

Mobile Sat. System	INMARSAT-B	INMARSAT-C	INMARSAT-M
Organization	INMARSAT	INMARSAT	INMARSAT
Services	Voice, Data	Data	Voice, Data
Coverage	Global	Global	Global
Initial Service	1993	1990	1993
Voice Coding Rate	16 Kbps APC	N/A	4.8 Kbps CELP
Data Rate	9.6 Kbps	600 bps	2.4 Kbps
Modulation	OQPSK	BPSK	OQPSK
Channel Spacing	20 KHz	5 KHz	10 KHz
Multiple Access	FDMA	FDMA	FDMA
Mobile Terminal			
Antenna	1 m(20 dBi)	100x25 mm(1 dBi)	0.4x0.5 m(14 dBi)
EIRP	16 dBW	21.4 dBW	17 dBW
Mobile Link			
Frequency	L-band	L-band	L-band
Bandwidth			
EIRP			
G/T			
Polarization			
HPA			
Feeder Link			
Frequency			
Forward(Rx)			
Return(Tx)			
Bandwidth			
EIRP	33 dBW	13 dBW	22 dBW
G/T	-4 dB/K	-23 dB/K	-12 dB/K
Polarization			
Receive			
Transmit			
HPA			
Spacecraft	INMARSAT-II	INMARSAT-II	INMARSAT-II

Mobile Sat. System	MSAT	MOBILESAT
Organization	AMSC/TMI	OPTUS
Services	Voice, Data	Voice, Data
Coverage	North America	Australlia
Initial Service	1994	1992
Voice Coding Rate	4.2 Kbps	4.2 Kbps
Data Rate	6.4 Kbps	2.4/4.8 Kbps
Modulation	ACSSB, Pi/4 QPSK	Pi/4 QPSK
Channel Spacing	5 KHz	5 KHz
Multiple Access	FDMA/SCPC	FDMA/SCPC
Mobile Link		
Frequency	L-band	L-band
Forward(Tx)	1530.0~1559.0 MHz	1545.0~1559.0 MHz
Return(Rx)	1631.5~1660.5 MHz	1646.5~1660.5 MHz
Bandwidth	29 MHz	14 MHz
EIRP	56.6 dBW(EOC)	48.0 dBW
G/T	2.7 dB/K(EOC)	-1.5 dB/K
Polarization	RHCP	RHCP
HPA	SSPA(16x32 W)	
Feeder Link		
Frequency	Ku-band	Ku-band
Forward(Rx)	13.0~13.15/14~14.2 GHz 13.2~13.25 GHz	14.0115~14.0255 GHz
Return(Tx)	10.75~10.95/11.7~11.9 GHz	12.2635~12.2775 GHz
Bandwidth	200 MHz	14 MHz
EIRP	36.0 dBW	34.0 dBW
G/T	-3.6 dB/K	-1.5 dB/K
Polarization(Rx/Tx)	Vertical/Horizontal	Vertical/Horizontal
HPA	TWTA(100 W)	
Spacecraft	HS601	HS601x2
Orbital Position	101/62/139/106.5 W	
Service Life	10 Years	
Weight	2900 Kg	
Power	3600 W(EOL)	
Spot Beam	6	
Antenna		
L-band	6x5 m(Unfurlable, 32 dBi)	
Ku/Ka-band	30"(Shaped, 25 dBi)	

Mobile Sat. System	PASS	LLM	COMETS
Organization	JPL	ESA	NASDA
Services	Voice, Data	Voice, Data	Voice, Data
Coverage	CONUS	EUROPE	Japan
Initial Service	1993	1993	1997
Voice Coding Rate	4.8 Kbps	4.8 Kbps	
Data Rate	100/300 Kbps		24/4.8 Kbps
Modulation		QPSK	BPSK
Channel Spacing		10 KHz	
Multiple Access	TDMA/CDMA	FDMA/CDMA	SCPC/TDM
Mobile Link			
Frequency	Ka-band	L-band	
Forward(Tx)	20 GHz	1530.0~1559.0 MHz	
Return(Rx)	30 GHz	1631.5~1660.6 MHz	
Bandwidth		11 MHz	
EIRP	16.8/57 dBW	45/51 dBW	
G/T	23.4/-9 dB/K	-2.0/2.5 dB/K	
Polarization		Circular	Circular
HPA		SSPA	SSPA(20/10 W)
Feeder Link			
Frequency	Ka-band	Ku-band	
Forward(Rx)		14.0~14.5 GHz	
Return(Tx)		11.45~11.70 GHz	
		12.50~12.75 GHz	
Bandwidth		29.5 MHz	
EIRP	60.7/6.4 dBW	38.0 dBW	
G/T	-1.2/30.3 dB/K	-2.0 dB/K	
HPA		TWTA(20 W)	
Spacecraft		ARTEMIS	ETS-VI
Service Life		10 Years	3 Years
Weight	7300 lbs	150 Kg(P/L)	2 ton
Power	3400 W	600 W(P/L)	
Spot Beam	142	6	2
EIRP		51 dBW	
G/T		2.5 dB/K	
Antenna			
L-band	2/3 m(52.5 dBi)	5x5.6 m(Unfurlable)	27.5/33.5 dBi
Ku/Ka-band	27 dBi	450 mm	2 m(53/48 dBi)

Mobile Sat. System	SPACEWAY	OMNITRACS	GEOSTAR
Organization	Hughes Comm. Inc.	Qualcomm	Geostar
Services	Voice, Data	Data	Data
Coverage			
Initial Service	1998	1988	1989
Voice Coding Rate			
Data Rate	384 Mbps	5~15 Kbps	
Modulation			BPSK
Channel Spacing			
Multiple Access	FDMA/TDMA	CDMA	CDMA
Mobile Terminal			
Antenna	66 cm		
EIRP		1.0 dBW	
Data Rate		55~165 bps	
Mobile Link			
Frequency	Ka-band	Ku-band	C-band
Forward(Tx)			
Return(Rx)			
Bandwidth		2 MHz	
EIRP			
G/T			
Polarization			
HPA			
Feeder Link			
Frequency			
Forward(Rx)			
Return(Tx)			
Bandwidth		48 MHz	
EIRP		44 dBW	
G/T			
Polarization			
Receive			
Transmit			
HPA			
Spacecraft	HS601x17		
Orbital Position	101/99/50W, 110/25/175E		
Spot Beam	48		

APPENDIX B

PARAMETERS OF THE MEO SYSTEMS

Mobile Sat. System	ODYSSEY	MAGSS-14	INMARSAT-P
Organization	TRW	ESA	INMARSAT
Services	Voice, Data	Voice, Data	Voice, Data
Coverage	Global	Global	Global
Initial Service	1998		1998
Voice Coding Rate	4.8 Kbps	4.8 Kbps	
Data Rate	9.6 Kbps	4.8 Kbps	
Multiple Access	CDMA		TDMA/CDMA
Mobile Terminal			
Antenna	Quadrifilar Helix	0 dBi	
EIRP		-3 dBW	
G/T		-25 dB/K	
Power	0.5 W	0.5 W	0.25 W
Mobile Link			
Forward(Tx)	S-band	S-band	L-band
Return(Rx)	L-band	L-band	S-band
EIRP		48 dBW	
Polarization		Linear	
HPA		SSPA(3.5 Wx37)	
Feeder Link	Ka-band	C-band	Ka-band
Spacecraft			
Altitude	10,354 Km	10,355 Km	10,355 Km
Inclination	55 Degree	56 Degree	50.7 Degree
Orbital Plane	3	7	2/3
Constellation	12(3x4)	14(7x2)	12(2x6/3x4)
Min. El. Angle	22 Degree	28.5 Degree	
Orbital Period	6 Hours	6 Hours	
Visibility	2 Hours	1 Hour	
Weight	2500 kg	140 kg(P/L)	2 Ton
Power	1800 W	500 W(P/L)	
Spot Beam	19	37	65(85)
Antenna	2xSteerable(Gimbal)	1.5 m(24.5 dBi)	1.2/1.8 m

APPENDIX C

PARAMETERS OF THE BIG LEO SYSTEMS

Mobile Sat. System	IRIDIUM	GLOBALSTAR
Organization	Motorola	Loral/Qualcomm
Services	Voice, Data	Voice, Data, Paging
Coverage	Global	Global
Initial Service	1998	1998
Voice Coding Rate	2.4/4.8 Kbps VSELP	2.4/4.8/9.6 Kbps
Data Rate	2.4 Kbps	9.6 Kbps
Modulation	QPSK	
Channel Spacing	2 KHz	
Multiple Access	FDMA/TDMA	FD-CDMA
Mobile Terminal Power	600 mW	
Mobile Link		L/S-band
Forward(Tx)	S-band	2483.5~2500.0 MHz
Return(Rx)	L-band	1610.0~1626.5 MHz
Bandwidth		16.5 MHz
Feeder Link		6484~6541.5/5158.5~5216
Frequency	Ka-band	C-band
Bandwidth		57.5 MHz
Polarization		Circular
Spacecraft		
Altitude	780 Km	1389 Km
Inclination	86.4 Degree	52 Degree
Orbital Plane	6	8
Constellation	66(6x11)	48(8x6)
Min. El. Angle	10 Degree	10 Degree
Orbital Period	100.13 min	113.53 min
Service Life		7.5 Years
Weight	750 Kg	230 Kg(Dry)
Spot Beam	48	6(Elliptical)
Antenna	Phased Array(6 feet)	3 feet
Inter-satellite Link	O	X
On-board Processing	O	X

Mobile Sat. System	ARIES	TELEDESIC
Organization	Constellation Comm. Inc.	Microsoft/McCaw
Services	Voice, Data	Voice, Data, Position
Coverage	Global	Global
Initial Service		2001
Voice Coding Rate	4.8 Kbps	
Data Rate	2.4 Kbps	16/2048 Kbps
Modulation		
Channel Spacing		
Multiple Access		FDMA(up)/ATDMA(down)
Mobile Link		
Frequency		
Forward(Tx)	S-band	Ka-band
Return(Rx)	L-band	Ka-band
Bandwidth		200 MHz
EIRP		
G/T		
HPA		
Feeder Link		
Frequency	C-band	Ka-band
Bandwidth		
Polarization		
HPA		
Spacecraft		
Altitude	1018 Km	700 Km
Inclination	90 Degree	98.2 Degree(Sun Sync.)
Orbital Plane	4	21
Constellation	48(4x12)	840(21x40)
Min. El. Angle		40 Degree
Orbital Period	105.5 min	98.77 min
Service Life		10 Years
Spot Beam	7	64(Scanning)
Antenna		El. St. Active Phased Array
Inter-satellite Link		O
On-board Processing		O

Mobile Sat. System	BOPSAT	MOBILESATCOM
Organization	CNES/CNET	Mitre Co.
Initial Service	1995~2000	
Voice Coding Rate		2.4 Kbps
Modulation		8FSK
Channel Spacing		2.625 KHz
Multiple Access		CDMA(PN/FH)
Mobile Terminal		
Antenna		5/19.1 dBi(UHF/SHF)
EIRP		0.8/6.2 dBW
G/T	-21 dB/K	-26/-10 dB/K
Power		1.2 W
Mobile Link		
Frequency	S/L-band	
Forward(Tx)	2483.5~2500.0 MHz	UHF/7 GHz
Return(Rx)	1610.0~1626.5 MHz	UHF/8 GHz
Bandwidth	16.5 MHz	
EIRP	30 dBW	14.4 dBW
G/T	5 dB/K	
HPA	SSPA	SSPA(28 W)
Feeder Link		
Frequency	C-band	
Bandwidth	145 MHz	
Polarization	Circular	
HPA	SSPA	
Spacecraft		
Altitude	1400 Km	1000 Km
Inclination	52 Degree	
Orbital Plane	8	16
Constellation	48(8x6)	192(16x12)
Service Life	7.5 Years	
Weight	500 Kg	400 Lbs
Power	1500 W(EOL)	160 W
Spot Beam	8(Elliptical)	
Antenna		
L-band	Active Phased Array	4/5.5 dBi(UHF/SHF)
S-band	Active Phased Array	
Inter-satellite Link	X	
On-board Processing	X	

APPENDIX D

PARAMETERS OF THE LITTLE LEO SYSTEMS

Mobile Sat. System	ORBCOMM	STARSYS
Organization	Orbcomm/Teleglobe	Starsys
Services	Data Messaging	Data Message, Position
Coverage	Global	Global
Initial Service	1994	
Data Rate	2.4/4.8 Kbps	4.8/9.6 Kbps
Modulation	DPSK	
Channel Spacing		
Multiple Access		FDMA/CDMA
Mobile Terminal		256 bits
Antenna	Omni-directional	
EIRP		
G/T	28 dB/K	
Power	5 W	
Mobile Link		
Frequency	VHF	VHF
Forward(Tx)	137.0~138.0 MHz	400.15~401 MHz
Return(Rx)	148.0~150.5 MHz	148~149.9 MHz
Feeder Link		
Frequency	VHF(56 Kbps)	VHF
Forward(Rx)		149.9~150.05 MHz
Return(Tx)		137.0~138.0 MHz
Spacecraft		
Altitude	785 Km	1300 Km
Inclination	45/90 Degree	60 Degree
Orbital Plane	5	4
Constellation	26(3x8+2)	24(4x6)
Min. El. Angle	5 Degree	
Orbital Period	104.47 min	111.59 min
Service Life	4 Years	5 Years
Weight	85 Lbs	100 Kg
Power	160 W	

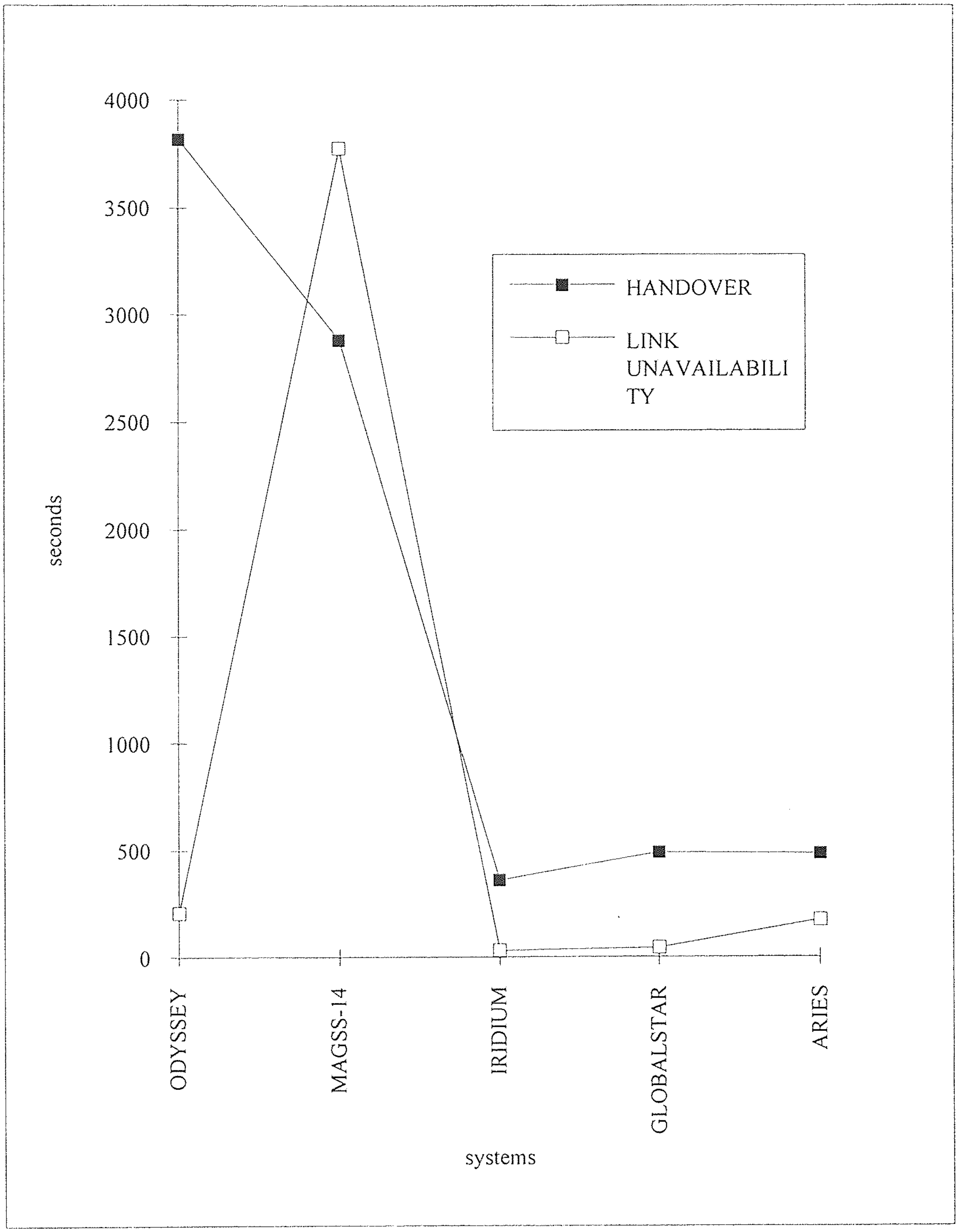
APPENDIX E

PARAMETERS OF THE HEO SYSTEMS

Mobile Sat. System	ELLIPSO	LOOPUS-MOBILE-D
Organization	Ellipsat Co.	MBB
Services	Voice, Position Information	Voice, Data, Paging Position, Broadcasting
Coverage	Global	Nothern Hemisphere
Initial Service		1996
Voice Coding Rate	4.8 Kbps	13.5/6.5 Kbps LRC
Modulation	BPSK	BPSK/QPSK
Multiple Access	FDMA/CDMA	TDMA
Mobile Link	L/S-band	Ku-band
Forward(Tx)	2483.5~2500.0 MHz	12.1~12.2 GHz
Return(Rx)	1610.0~1626.5 MHz	14.0~14.1 GHz
Bandwidth	16.5 MHz	100 MHz
EIRP(Up/Down)	13/35 dBW	
G/T	-17 dB/K	
Polarization	Circular	
Feeder Link	L/S-band	Ku-band
Forward(Rx)	1610.0~1626.5 MHz	14.15~14.25 GHz
Return(Tx)	2483.5~2500.0 MHz	11.2~11.3 GHz
Bandwidth	16.5 MHz	
EIRP, G/T	-17 dBW, -3 dB/K	
Polarization(Rx/Tx)	RHCP/LHCP	
Spacecraft		
Altitude	426/2903 Km	5784/41449 Km
Inclination	63.4 Degree North(116.5)	63.4 Degree
Orbital Plane	4	5
Constellation	24(3x5+9)	9
Orbital Period	2 Hours	14.4 Hours
Service Life	5 Years	10~15 Years
Weight	380 Lbs	1000 Kg
Spot Beam	4(Elliptical)	75

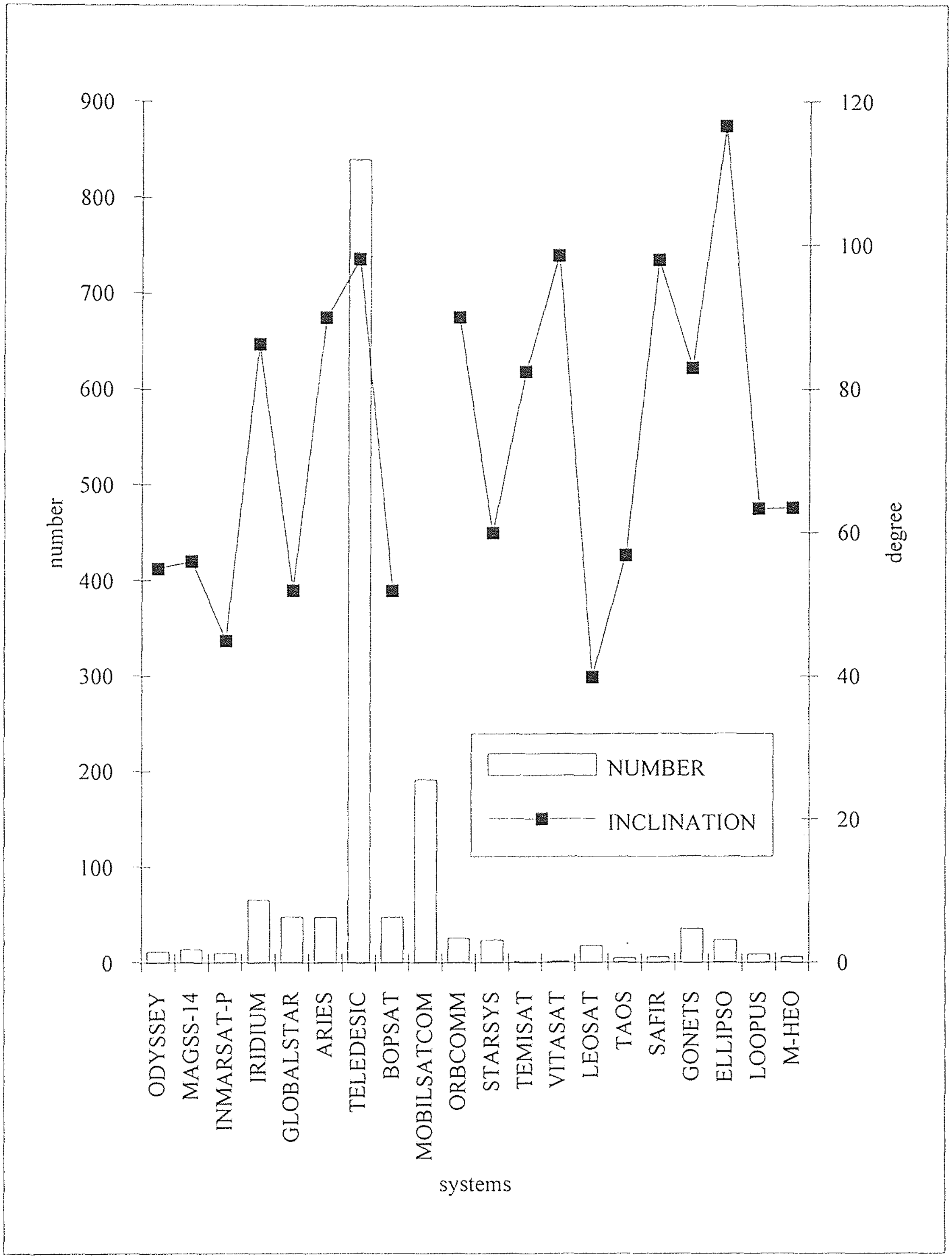
APPENDIX F

HANDOVER AND LINK UNAVAILABILITY COMPARISON



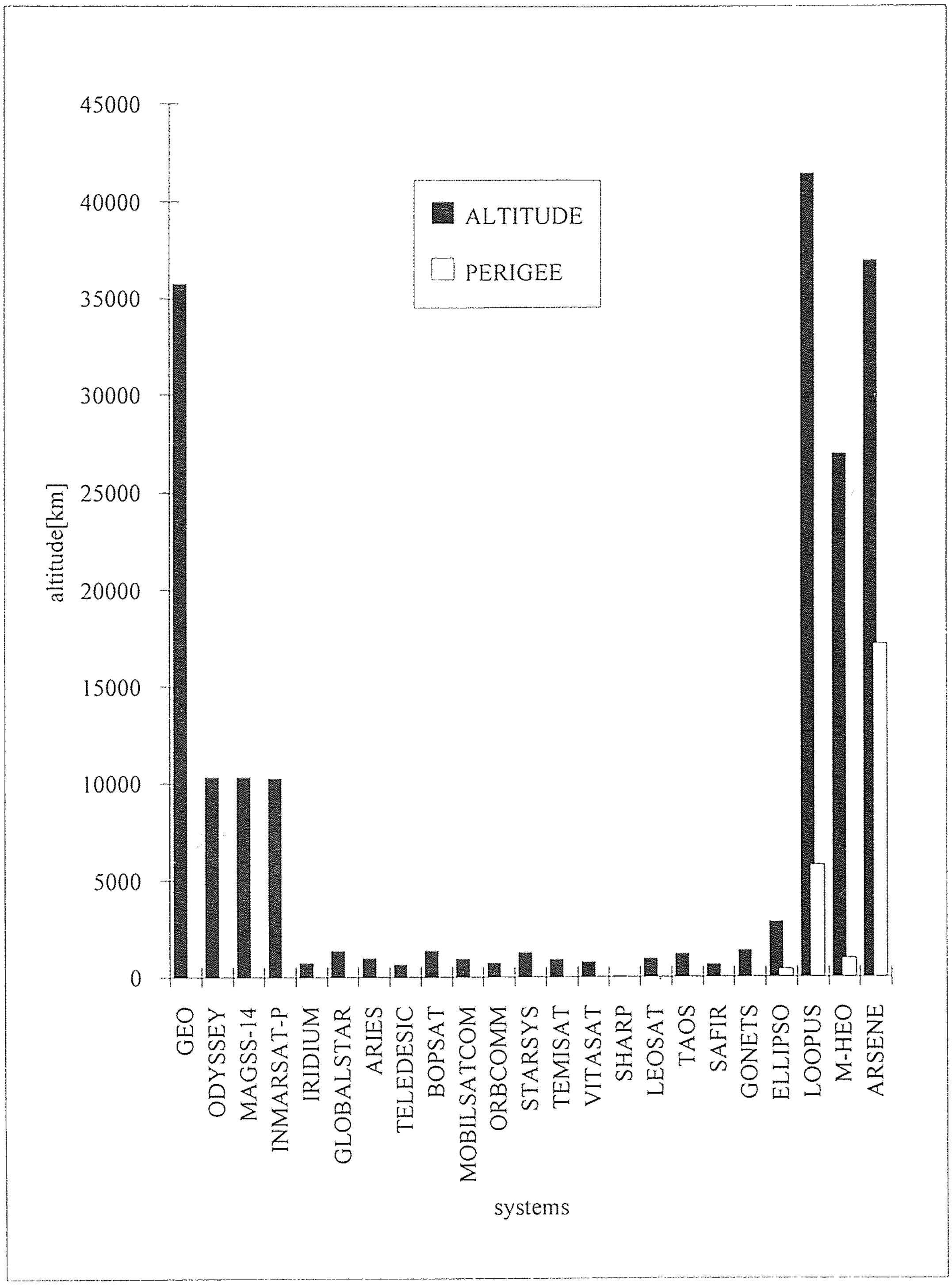
APPENDIX G

CONSTELLATION COMPARISON



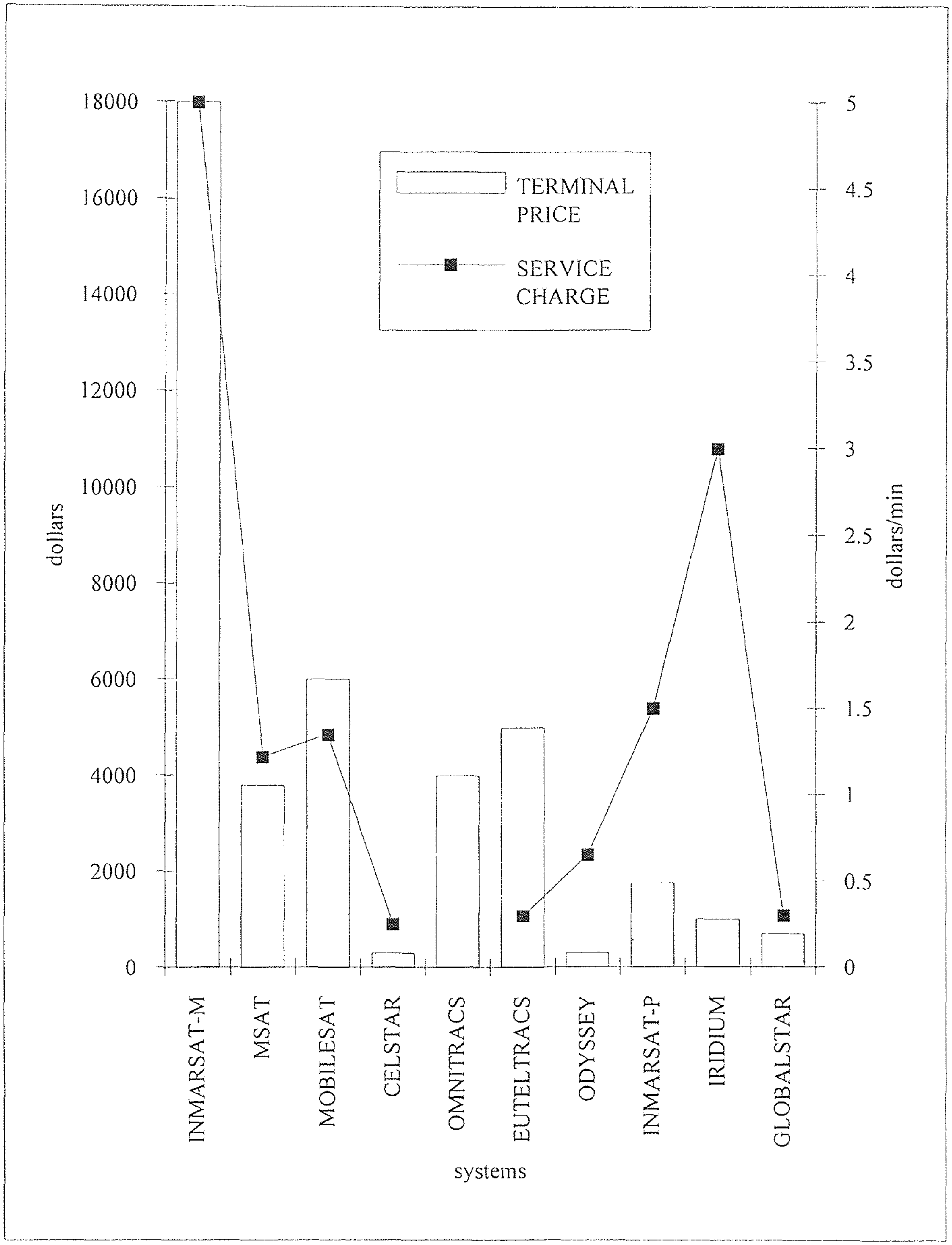
APPENDIX H

ORBITAL ALTITUDE COMPARISON



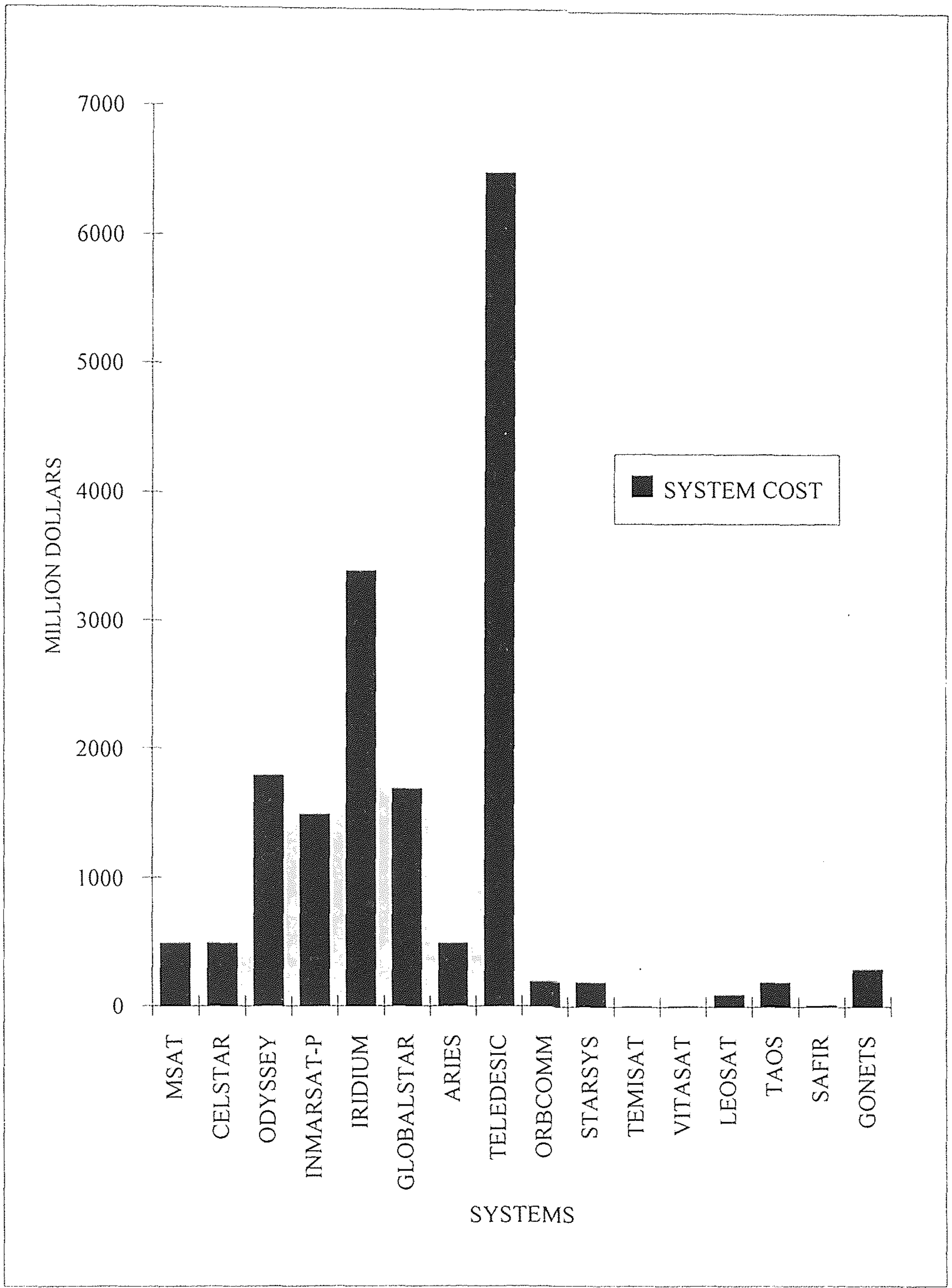
APPENDIX I

TERMINAL PRICE AND SERVICE CHARGE COMPARISON



APPENDIX J

TOTAL SYSTEM COST COMPARISON



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