REPORT 1180

DESIGN OF MOBILE SATELLITE SYSTEMS PROVIDING AERONAUTICAL, LAND AND MARITIME SERVICES USING SHARED RESOURCES

(Question 82/8)

(1990)

1. INTRODUCTION

1.1 Terrestrial radio communications systems enable communications of various types between mobile units and fixed points (usually a radio tower). For some systems, the service range will be within the radio line-of-sight to the fixed tower. There are significant limitations of these terrestrial systems regarding coverage over wide areas, oceanic areas, economical coverage in areas of sparse population or geographical areas where there is small communications demand, and in the provision of worldwide services. The use of satellite techniques can overcome these problems.

1.2 There are three services which can be served by mobile satellite systems, aeronautical, land, and maritime. While these services are diverse, there are common aspects. Mobile satellite systems that provide services in each of the three broad categories may offer possibilities for improved efficiency in the use of the radio spectrum and more economical services.

1.3 This report discusses user requirements and the design characteristics of mobile satellite systems that provide aeronautical, land and maritime services.

Appended are five annexes on:

Annex I: INMARSAT systems overview

Annex II: Proposed domestic mobile satellite systems in North America

Annex III Preliminary outline of technical conditions for transponder sharing

Annex IV: A network control and signalling system for the North American MSS

Annex V: Possible framework for a future Recommendation on mobile satellite service system design concepts

2. SERVICE REQUIREMENTS

2.1 Aeronautical Mobile Satellite Services

2.1.1 The requirements for aeronautical mobile satellite services are discussed in Report 1173.

For Air Traffic Service (ATS) and Aeronautical Operational Control (AOC) these may be described as follows:

a) because of the world-wide nature of civil aviation where the same aircraft can appear in widely different parts of the world within hours, international standards (both technical and operational) are required for aeronautical safety and regularity of flight communications.

b) communication system parameters and practices must assure a very high level of performance, integrity, reliability and availability. International air traffic movements are conducted predominantly on the basis of instrument flying and are subject to ground control. Accordingly, communications are required day by day, minute by minute to assure that aircraft are safely separated while achieving regular and economic operation. Virtually immediate access is required while ensuring that messages are not subject to misunderstandings, since only seconds may be available to avoid an accident.

c) the high standards imposed in b) above make it essential that these services be protected from harmful interference in accordance with Radio Regulation 953.

d) the long-life-cycle characteristic of aircraft and aeronautical communication system ownership make it imperative that adequate spectrum be available to implement near term services and to accommodate future world-wide plans for evolutionary growth while maintaining as a minimum, the current high level of safety.

2.1.2 The aeronautical mobile-satellite service has a number of distinctive features which are brought about by the following requirements:

a) the time taken to establish a connection must be extremely short, not more than 2 to 5 s; this is related to the need to ensure flight safety;

b) the need to transmit large volumes of high priority information (ATS, AOC);

c) the low EIRP of aircraft satellite communications stations; and

d) substantial limitations with respect to the weight and over-all dimensions of aircraft satellite communications stations, etc.

2.1.3 Where ATS and AOC communications are separated in frequency from Aeronautical Public Correspondence (APC) (Aeronautical Administrative Communications (AAC) and passenger communications) aviation will lose the operational flexibility to put all categories of AMSS communications on the same RF channel. The provision of ATS, AOC, AAC and passenger communications services on the same RF channel may support operational flexibility and user equipment economies.

2.2 Land Mobile Satellite Service Requirements

The requirements of the land mobile satellite service are under development. An outline of these requirements is in Report 1183.

2.3 Maritime Mobile Satellite Service Requirements

The requirements of the Maritime Mobile Satellite Service are discussed in Reports 920, 918 and 761 among others.

2.4 Special Provisions for Safety Services in the Mobile Satellite Services

No. 953 of the Radio Regulations indicates that special measures are required to ensure that all safety services are protected from harmful interference. ICAO is currently reviewing Report 927 for application to aeronautical mobile satellite service. Special provisions for maritime distress and safety communications and for land mobile satellite uses involving safety of life and property must also be taken into account. (see Para 4.2.5) Further study is required to specify provisions to protect safety services provided in mobile satellite systems.

3. SCENARIOS FOR SHARING RESOURCES

3.1 Sharing is the joint use of one or more system resources among aeronautical mobile-satellite service (AMSS), land mobile-satellite service (LMSS) and/or maritime mobile-satellite service (MMSS). Three sharing scenarios are identified:

a) Share satellite, separate transponders. A satellite would carry numerous transponders, an appropriate number of which would be dedicated to each service and would use frequency bands dedicated to the appropriate service. All operations within these dedicated frequency bands would be in accordance with requirements and standards of the appropriate service.

b) Share satellite, share transponder. Any transponder may carry more than one service. The allocated spectrum would be divided between the services by electrical partitions which may be fixed or dynamically variable. With variable partitioning, the position of the partition(s) would need to be under central control.

c) Share satellite, share transponder, share spectrum. Any communication channel within the allocated spectrum would be dynamically assigned to any of the services for the period necessary to complete a message transaction.

4. SYSTEM DESIGN CONSIDERATIONS

4.1 General Considerations

4.1.1 In order to safeguard the relevant safety services, and to meet the technical and operational requirements, in the sharing scenarios described in Section 3 above the following general considerations need to be taken into account when designing a shared system.

4.1.2 Aeronautical Mobile Satellite Service

4.1.2.1 The stringent demands of safety and regularity of flight require standards and adequate spectrum to be applied and available on a world-wide basis. From an operational point of view it would be desirable for aviation authorities to operate a family of dedicated satellites. However economic considerations prohibit this solution at this time and therefore some form of sharing has to be considered.

4.1.2.2 The sharing scenario which involves shared satellites with separate transponders requires:

a) that the shared satellites are positioned and other satellite system parameters are appropriate to give the desired aeronautical coverage and system performance; and

b) arrangements are made that under satellite malfunction conditions the aeronautical transponders required for safety communications are among the last to be shed.

4.1.2.3 The sharing scenario which involves shared satellites and shared transponders raises a number of technical complexities.

a) **Fixed partitioning**

While the LMSS/MMSS units serviced by the shared transponder would operate in a frequency band separate from AMS(R)S, these mobile units could interfere with AMS(R)S communications if they are not appropriately designed and controlled. In particular, transponder power is shared among the services and effects such as intermodulation and small signal suppression could arise from the operation of the LMSS/MMSS units and could appear in the AMS(R)S band. It may be necessary therefore, for the mobile units of the LMSS/MMSS to comply with certain technical conditions established by ICAO to avoid harmful interference with AMS(R)S communications. These technical conditions would affect the design, certification and operation of LMSS/MMSS units. ICAO is developing the necessary technical conditions which it believes should be met by mobile units of LMSS/MMSS sharing satellite transponders with AMS(R)S. A preliminary outline of technical conditions for transponder sharing is shown in Annex III.

b) Variable partitioning

The technical complexities that arise with variable partitioning are somewhat greater than those associated with a fixed partition. In particular, the mobile satellite system, including the mobile units of the LMSS/MMSS would need to include technical conditions to assure that the partition can be adjusted in real time to provide the AMS(R)S spectrum required.

4.1.2.4 The sharing scenario that involves the fully shared use of any frequency in the shared band is the most complex because operation of the other mobile units interspersed among AMS(R)S channels could provide the greatest potential for interference with AMS(R)S communications. Priority access is discussed in Para 4.2.5.

4.1.3 Land mobile satellite service (LMSS)

4.1.3.1 The wide range of land mobile applications requires some protection from other shared services in order to guarantee the communications quality and integrity.

4.1.3.2 Sharing scenarios possibilities

a) Fixed partitioning

The shared mobile satellite system should operate through a transponder operating in a linear mode to minimize the effects of small signal suppression and prevent intermodulation products from appearing undesirably in other frequency bands.

A set of minimum technical conditions should be established to limit intra-system interference which can be maintained under acceptable limits.

b) Variable partitioning

The complexity of the variable partitioning is increased by the need, if applicable, to interconnect individual control centres with adequate protocol that would define the priority for bandwidth allocation. Under this scenario the mobile terminals need to include technical characteristics that assure the adjustment of partition under control of the control centres.

The fully shared use of available bandwidth would impose an additional complexity in the protocol that defines the frequency allocation for the different services sharing the same bandwidth.

4.1.4 Maritime Mobile Satellite Service

To be developed.

4.2 Detailed Considerations

4.2.1 Introduction

The design of mobile satellite systems capable of meeting the diverse user requirements in the mobile satellite services presents special problems. In this context the most demanding of the requirements of each of the services must be accommodated. Described below are some of the important design considerations for mobile satellite systems. These considerations form part of the basis for development of a draft Recommendation (see Annex V).

4.2.2 Access techniques

Different service requirements may dictate the need for separate multiple access schemes. Initial work has indicated that either frequency division or code division multiple access may generally be the most appropriate schemes for the land mobile-satellite service, at least for return links. Large groups of users with low duty cycle data requirements may dictate the need for different access schemes for voice and data in order to improve spectrum and system efficiencies.

4.2.3 Channel Assignment

Demand assigned multiple access to channels contributes to efficient spectrum use. Low data rate, narrow bandwidth channels will serve the needs of many users. Close channel spacing will increase the number of channels within the available bandwidth. A common system reference for control of mobile receive and transmit frequencies can minimize the width of guard bands between channels and serve as a reference for doppler shift due to high speed vehicle motion. Tuning increments of 500 Hz, or integral multiples thereof, should be considered.

In a power limited environment the control of a two or more satellite mobile network could be done by a common network control centre in order to improve the usage of the spectrum, which would, otherwise, have its efficiency affected by interference problems due to the reduced discrimination of a large number of mobile units.

4.2.4 Availability/reliability

The application that has the most stringent demand for service availability determines the level of reliability which must be met. However the less rigorous requirements for other applications should also be taken into consideration to avoid excessive cost penalties to the overall satellite system viability. Aviation safety related communications require exceptional availability of the satellite communications system (see Report 1173). Redundancy, load detection and switching or rerouting and load shedding can be used to achieve a high degree of availability.

For individual satellites, availability is generally specified in terms of the probability that a given fraction of the satellite capacity is available at the end of life. A typical objective is that there is at least a 75 percent probability that 85 percent or more of the rated capacity is available at the end of life. Backup capacity on other satellites is employed to restore service in case of a failure that cannot be repaired by switching in redundant units or redistributing traffic to unaffected portions of the spacecraft. Experience has shown that outright failures are extremely rare with overall commercial space segment availability better than 0.9999. Specific availability requirements for future systems still have to be quantified.

See also Report 918.

4.2.5 Priority Access

Article 51 of the Radio Regulations defines priorities for aeronautical mobile-satellite service communications and Article 61 defines priorities for the maritime mobile-satellite service communications. The Radio Regulations do not specifically include an order of priority of communications for the land mobile-satellite services although the general priority of Distress, Urgency and Safety communications should be observed. A future competent WARC would need to develop interservice priorities.

Within the shared bands aeronautical mobile-satellite (R) requirements need priority access for communications in the mobile-satellite service taking into account other safety related communications in the mobile-satellite service.

To fulfill this requires a mechanism to implement priority and preemptive access in the mobile-satellite service as needed. Priority and preemptive access can be activated by a single point control center if the mobiles are immediately responsive to control signals from the center.

Where one or more control centres are used separately for land, aeronautical and maritime communications a well-defined priority protocol must be implemented.

4.2.6 System Capacity

To be developed.

4.2.7 <u>Interworking among mobile satellite systems</u>

Some mobiles will routinely move through areas served by more than one mobile satellite system. Aviation is one of the applications that requires service availability, using a single aircraft earth station, in all the areas served by systems. Interworking among mobile satellite systems for aviation is assured by compliance with ICAO standards and recommended practices (SARPs).

When beam footprints of independent satellite systems overlap, frequency coordination will be necessary when common frequency bands are used.

In systems where communications can be scheduled the coordination process between networks could be facilitated if these schedules are used as a tool to reduce potential interference between these networks.

4.2.8 Interworking with Terrestrial Systems

To be developed.

4.2.9 Need for Flexibility in Order to Accommodate Diverse Uses

A mobile satellite system may at one time serve a variety of mobiles with diverse requirements for channel bandwidth, signal power, priorities, and network interfaces. The mix of user characteristics will change continuously.

Satellite transponder characteristics and the control means of the network operating center should enable the assignment of appropriate bandwidth and power to each mobile terminal in accordance with its needs.

4.2.10 <u>Satellite transponder requirements</u>

Under a shared transponder environment, the flexibility requirements may best be met with satellite transponders that have the full allocation bandwidth and are sufficiently linear to accommodate the large number and diversity of independent user signals without excessive interference due to intermodulation. A range of transponder gain settings might be required to accommodate the variety of mobile users and the effects of interference between networks. Up-link power control in mobile units would also help in improving performance of services under shared transponder operations. This would be essential for any sharing with the aeronautical safety service.

4.2.11 Feeder link considerations

To be developed.

(Information to complete this section is needed to identify advantages or disadvantages of frequency sharing, including integrity considerations.)

4.2.12 System Control

Systems that share power and/or bandwidth on a variable basis amongst aeronautical, land and maritime users need to have a capability for immediate preemption of the bandwidth and power for high priority uses. Single point control of all mobile terminals in the shared part of the system is essential to the priority assignment of satellite capacity. The single-point control will need to be exercised by a network operating centre. The centre should have a physical backup at a different geographical location. The centre must have immediate access to all terminals operating in the shared capacity portion for the purpose of reassigning communications channels or, if necessary, turning off lower priority users when satellite capacity is needed for high priority uses.

This centre also needs to have the capability to remotely control faulty mobile terminals which could be causing excessive interference into the system.

4.2.13 User Terminal Considerations

One useful feature is for the terminal to have a signalling channel incorporated so that the terminal will receive the signalling channel at all times.

4.2.14 Earth Station Considerations

To be developed.

4.2.15 Need for Orbit Reuse/Multi-beam Satellites

To be developed.

4.2.16 The Effects of Preemption by Priority Users

Further studies are needed to investigate consequences of preempting channels with lower priority, taking also into account the possible use of queueing systems for the lower priorities.

4.3 Economic Considerations

4.3.1 Aircraft equipment is designed to meet very high standards of performance, integrity and reliability and to operate in severe environmental conditions. This leads to relatively high unit costs. In a shared system all mobile terminals should meet additional requirements to ensure that one service will not degrade another.

4.3.2 Some standards and specifications to be met by maritime and land mobile earth stations will not be so demanding as for aircraft earth stations. The use of common equipments or major equipment subassemblies by aeronautical and non-aeronautical mobile earth stations therefore is not envisaged since it would place an unnecessary cost penalty on the non-aeronautical units. As a result, it is unlikely that production of mobile earth stations for LMSS/MMSS will contribute significantly to reduced production costs for aircraft earth stations based on economies of scale.

4.3.3 Multiple space systems providing a service in the same or adjacent geographical areas may lead to frequency coordination problems. Spectrum sharing is likely to compound those problems and to limit the ability of these services to coordinate.

4.3.4 When the combined spectrum requirements of the spectrum sharing services exceed the available spectrum there will be a problem. The dynamic or permanent allocation of extra spectrum to one service at the expense of another may be difficult because of the considerable financial investment made by the disadvantaged service. Thus additional frequency spectrum for all mobile satellite services may be necessary to satisfy future mobile satellite service requirements. Therefore suitable long-term arrangements would need to be made.

4.4 <u>Methods for efficient utilization of the frequency bands allocated to the mobile satellite services</u>

4.4.1 Several principles should be considered in order to obtain efficient utilization of the spectrum and orbit resources by the mobile satellite services. The principles discussed below should be considered for application to new systems and, over time, to existing systems as satellites and mobile earth stations are replaced (or refurbished) and as new capabilities and equipment are developed:

- optimal channel spacing in the frequency sharing environment;

- reuse of frequencies through service area or satellite angular separations;

- modulation and coding methods resistant to interference and minimizing bandwidth consumed;

- dynamically assigning channels for various requirements from pooled system resources.

4.4.2 The minimum possible spacing between channels used in the same beam of a satellite is dependent on factors such as error in Doppler compensation, frequency instabilities, and the tuning increments of earth station frequency synthesizers. Operation with this minimum channel spacing may be less efficient than use of slightly larger separations in many circumstances where frequency reuse is not possible on a co-channel basis. In systems using multiple beam antennas, interleaving channels assigned (i.e. offsetting in frequency) in different beams might increase the level of frequency reuse). However, for some types of carriers, the channel spacing may have to be larger than the minimum value to achieve adequate discrimination. Likewise, interleaving of the channels used in two or more systems might reduce the overall bandwidth needed by those systems, as compared with use of non-overlapping channels. See Report 1172.

4.4.3 As discussed in Report 1172, geographic separation of service areas and spatial separation of satellites can facilitate frequency sharing. When advantage is taken of these principles through the designs of satellite antennas and mobile earth station antennas, the spectrum required among the systems can be greatly reduced. Report 1172 also addresses the principal of increasing spectrum utilization efficiency by reusing frequencies within the same system. This can be accomplished with multiple-beam satellites, which also enhance sharing with other systems thus obtaining enhancements in spectrum utilization efficiency.

4.4.4 Making inflexible, permanent distinctions between the bandwidth that can be used for some mobile-satellite services and not by others can significantly reduce spectrum utilization efficiency. This is true even when the services that would otherwise be segregated require different grades of service [IEEE, 1982]. One approach for avoiding this inefficiency has been contemplated in section 4.1.2.3 b) of this report. Regardless, it is essential that systems implementing pooled resources be carefully engineered to meet all performance requirements.

5. SYSTEM OPERATING CONSIDERATIONS

5.1 Service Coverage Areas

To be developed.

6. CONCLUSIONS

6.1 It is generally accepted that some form of sharing of satellite system resources by the mobile satellite services could lead to overall savings in implementation costs.

6.2 Considering the sharing scenarios listed in Para 3, it is evident that system complexity increases as the level of sharing increases but any additional implementation costs arising from such complexity could be offset by overall operational efficiencies. However, it is equally evident that certain of the spectrum sharing options would require considerable planning, coordination and validation to ensure that the high reliability, integrity and priority required for AMS(R)S communications will be met.

6.3 It is considered that shared mobile satellite systems should, at least initially, employ fixed spectrum partitioning thus allowing sufficient time to further investigate, define and validate technical and operational conditions under which variable partitioning and spectrum sharing could be implemented.

7. References

LUNAYACH, R.S. [November, 1982] - Analysis of a mobile radio communications system with two types of customers and priorities, Transactions on Communications, Volume COM-30, No. 11, IEEE.

ANNEX I

INMARSAT systems overview

	INMARSAT SYSTEM NAME						
	STANDARD A	STANDARD B	STANDARD C	STANDARD-M		AERONAUTICAL VOICE	AERONAUTICAL DATA
SERVICE	MM (LM)	MM (LM)	MM, LM	MM	LM	AM	AM
TYPICAL ANTENNA GAIN	20 dBi	20 dBi	1 dBi	14 dBi	12 dBi	12 dBi	0 dBi
ANTENNA TYPE EXAMPLE	DISH	DISH	QUAD HELIX	SHORT B.F.	LIN ARRAY	PHASED ARRAY	QUAD HELIX
TYPICAL ANTENNA SIZE	1 m DIAM	1 m DIAM	5 cm DIAM	40 cm DIAM	60 x 9 cm	50 x 50 cm	10 x 10 cm
FIGURE OF MERRIT: (G/T)	-4 dB/K	-4 dB/K	-23 dB/K	-10 dB/K	-12 dB/K	-13 dB/K	-26 dB/K
EIRP	36 dBW	33 dBW	13 dBW	24 dBW	22 dBW	26 dBW	14 dBW
SIGNALLING RATE, MOD. TO MES	1200, BPSK	6000, BPSK	1200, BPSK	6000, BPSK	6000, BPSK	600, ABPSK	600, ABPSK
FEC, RATE	NA	CONV, 1/2	CONV, 1/2	CONV, 1/2	CONV, 1/2	CONV, 1/2	CONV, 1/2
SIGNALLING RATE, MOD. FROM MES	4800, BPSK	24000, OQPSK	1200, BPSK	3000, BPSK	3000, BPSK	600, ABPSK	600, ABPSK
FEC, RATE	NA	CONV, 3/4	CONV, 1/2	CONV, 1/2	CONV, 1/2	CONV, 1/2	CONV, 1/2
VOICE CODING	2:1 COMP	16 kb/s APC	NA	TBD (around 5 kb/s)		9.6 kb/s RELP	NA
USER DATA RATE	(4800 b/s)	9.6 Kb/s	600 b/s	2400 b/s	2400 b/s	9.6 Kb/s	300 b/s
COMM. CHANNEL RATE, MOD.	FM,12kHz DEV	24kb/s,OQPSK	1200b/s,BPSK	8kb/s, OQPSK	8kb/s, OQPSK	21kb/s,AQPSK	600, ABPSK
INTERLEAVING TIME	NA	NA	8.64 s	NA	NA	40 ms	0.67 s
TYPICAL C/No	52 dBHz	49 dBHz	37 dBHz	43 dBHz	41 dBHz	48 dBHz	36 dBHz
CHANNEL SPACING	50 kHz	20 kHz	5 kHz	10 kHz	10 kHz	17.5 kHz	2.5 kHz
START CF OPERATIONS	1976	1992	1990	1992	1992	1990	1990

ANNEX II

DOMESTIC MOBILE SATELLITE SYSTEMS IN NORTH AMERICA

1.0 Introduction

Canada and the United States have long recognized the need for reliable mobile communication services to all areas of the continent and for various applications. A growing demand for mobile and transportable voice and data communications services coupled with the cost reducing trends of evolving satellite and communication technologies have provided a strong basis for pursuing operational system development.

The potential user base of a multiple service mobile satellite communication system coupled with the limited area to be covered (i.e., much less than global coverage) will support the cost of providing a satellite system with relatively high gain satellite antennas, thereby providing service cost economies and increased functional capabilities for users with lower gain antennas.

Thus, Canada and the United States have taken initiatives to develop compatible mobile satellite service systems to serve aeronautical, land, and maritime users, i.e., combined services systems. These system developments are being pursued by Telesat Mobile Incorporated (TMI) and the American Mobile Satellite Consortium, Inc. (AMSC) in Canada and the United States, respectively.

The initial implementations will be matched to the expected initial demand for the mobile services. Capacity will grow with increasing demand, first with the addition of satellites in orbit, then with later generation satellites having more beams for greater frequency reuse and more power. The systems will be upward compatible such that no change in user equipment will be necessary when the new satellites become operational.

The WARC-MOB-87 reallocated 1.5/1.6 GHz spectrum to accommodate Land Mobile Satellite Service in addition to Maritime Mobile Satellite Services and Aeronautical Mobile Satellite Services. The North American baseline systems configuration presented below assume that sufficient spectrum at 1.5/1.6 GHz can be coordinated for North America, to establish commercially viable systems in both Canada and the United States.

Canada plans to purchase one satellite for operation at 106.5°W longitude and AMSC plans initially to purchase one satellite for operation near 100°W and later to add two satellites near 60° and 130°W longitudes.

The specifications for the Canadian Mobile Satellite System (MSAT) and AMSC space segments described below are not finalised and could be subject to modifications.

2.0 User Needs and Satellite Service Capabilities

There is an extensive need for improved and additional land mobile satellite service communication capabilities. In both Canada and the United States mobile communications are needed to close the sometimes large gaps between services provided by terrestrial mobile systems. These needs include the Canadian North and the sparsely populated areas outside the 200 to 300 km wide strip along the Canada - United States border. Likewise, many areas in the United States are not within the range of mobile systems. In Canada, for example, there is a drastic contrast between the reliable voice, data, and video communications provided by Anik satellites through fixed facilities which link the country and the HF radio communications which are notoriously unreliable under adverse propagation conditions which prevail in central and the northern parts of Canada.

There are particular needs for improved aeronautical mobile communication services in North America and adjacent over-water areas. These needs extend to both safety and non-safety communications, and are analogous to the land mobile service needs discussed above. In particular, improvements in aeronautical mobile safety communication services can be viewed as near-term and longer-term implementations. In the near-term, satellite service can significantly improve services for all users and airspace applications in the vast interior of Canada. In the United States, satellite services can fill the lower attitude coverage gaps left by the existing terrestrial system (e.g., providing services to medivac helicopters flying to highway accident locations). In the longer term, as envisioned by the ICAO Future Air Navigation Systems (FANS) Committee future system concept, aeronautical mobile safety communication are anticipated to evolve to the use of satellite services to replace rather than supplement terrestrial facilities. This capability would allow a significant reduction of the present ground infrastructure.

Several market studies have been carried out by Telesat, DOC,AMSC, NASA, Woods-Gordon, Telecom Canada, Bell Canada, Radio Common Carriers' Association and others over the past few years to identify what types of services are required and the size of the market for a wide area mobile satellite system. Some of the typical applications identified by the surveys are shown in Figure 1.

These applications may be met by the following services:

(1) Mobile Radio Service (MRS) which provides voice communications between a mobile terminal and a base station or between mobile terminals.

(2) Mobile Telephone Service (MTS) - a full duplex voice communications service which provides direct access for mobile terminals to the Public Switched Telephone Network (PSTN) via SHF Gateway Stations.

(3) Mobile Data Service (MDS) - a service which provides a communications path for the bi-directional transfer of data between a mobile terminal and a data hub station. The data may be circuit-switched or packet-switched.

(4) Data Acquisition and Control Service (DACS) - which provides for the transfer of sensor data information from data collection platforms to base stations and the transmission of control messages in the opposite direction.

(5) Aeronautical Service -although this may be provided by some of the above categories, it is considered unique enough to be categorized separately. See Report 1173. Applications include:

- Air Traffic Services (ATS), in accordance with ICAO specifications,

- Aeronautical Operational Communications (AOC), in accordance with ICAO specifications, and

- Aeronautical Public Correspondence (APC) including Aeronautical Administrative Communications (AAC).

(6) Other services, such as Position Location Service, Wide Area Paging and Transportable Communications Services, depending on demand for them.

Several factors influence the development of the market. A forecast showing the Canadian growth of terminal sales in 1990s is shown in Figure 2. The forecast predicts a rapid growth of the market during the service life of the first generation MSAT system. TMI and the AMSC will jointly procure two satellites, one for TMI and the other for AMSC's initial operations. Each satellite will act as a back-up for the other in the event of a catastrophic failure of one. The launch of the satellites may be phased to match the market build up. In that case, initially the capacity of the first satellite , which may be Canadian or U.S.-owned, would be shared with the other partner. A second satellite,owned by the other partner,would then be launched a few months later, and the two satellites would carry traffic and also provide mutual in-orbit back-up protection to each other. In so far as the United States requirements are extensive, AMSC plans to launch two additional satellites in pace with the initial increase in demand. As demand further escalates, a second generation system with greater frequency reuse will have to be implemented.

The above strategy necessitates full compatibility of service between the Canadian and the U.S. mobile satellite systems. Although compatibility of service does not necessarily mean identical spacecraft, procurement of two very similar initial satellites would obviously offer economic advantages by sharing the non-recurring costs of the space segment between the two operators.

2.1 Priority Services

Some services, such as those pertaining to safety of life and regularity of flight for aeronautical services or distress and safety for maritime services, require higher priority than other communication services. Examples of these are Air Traffic Services (ATS) and Aeronautical Operational Control (AOC). Specific capacity will be made available on the system for AMS(R)S services which can only be used by aeronautical safety services or other aeronautical services that comply with the ICAO FANS architecture. The AMSC/MSAT systems will have "variable dynamic partitioning". That is the specific capacity and power reserved for AMS(R)S will be varied depending on need. In the event that peak AMS(R)S safety traffic is anticipated to exceed the allocated capacity, additional bandwidth and power will be made available on a realtime preemptive basis. The capacity available in the first and successive system generations is expected to exceed the AMS(R)S peak traffic load, so that lower priority users will not be unduly disrupted.

3.0 SYSTEM CONFIGURATION

The satellite resources (channels) are best utilized by assigning them on a demand basis. The demand access capability is satisfied by a Priority Demand Assignment Multiple Access (PDAMA) system residing in the Network Control Centre (NCC). Many mobile terminals can be connected to other mobile terminals, base stations, PSTN or data networks (via a gateway station), hence providing a flexible communication network.

The NCC can allocate circuit capacity on a per call basis for voice and circuit-switched data. It can allocate a channel (or channels) to be used for packet-switched data under the control of the data hub. A mobile terminal typically places a call on a signalling channel (request channel). The NCC uses a signalling channel (assignment or control channel) to assign that terminal and feederlink earth station to a free communication channel. At the termination of the call the terminal relinquishes the communication channel which then becomes free for reassignment by the NCC to another call. For AMS(R)S service, frequency and power capacity will be allocated to aviation PDAMA system elements in distinct portions which will be used in channels consistent with ICAO SARPS.

The systems will have multiple spot beams in order to increase the satellite EIRP, and allow for frequency reuse since the available spectrum is limited.

Communications to and from the mobile terminals will use the 1.5/1.6 GHz band, with uplinks in the 1626.5-1660.5 MHz band and downlinks in the 1530-1559 MHz band. Transmission to and from the network control center, gateways and base stations will use SHF (near 13/11 GHz) uplinks and downlinks. Transmission paths from these stations to the satellite, and from the satellite to the mobile terminals are designated as Forward Links. Transmission paths in the opposite direction are called Reverse(or Return) Links.

The main elements of the system are:

(1) The space segment which includes the satellite and the Satellite Control Centre (SCC).

(2) The ground segment consisting of:
- gateway stations
- base stations and data hub stations
- mobile terminals.

(3) The Network Control Center (NCC) which includes
- the Network Management System (NMS)
- the PDAMA Control System (DCS).

(4) The Aviation PDAMA Control System.

(5) A Signalling system to interconnect the elements of the system

The system configuration is shown in Figure 3.

4.0 HOW SERVICES ARE PROVIDED

The system operators have the capability to operate as common carriers, owning and operating the satellites and NCCs that provide priority demand assigned multiple access to satellite power and spectrum resources as explained below. End users could obtain service from service providers who may be institutionally independent of the space system operator.

The satellite systems will have a variable dynamic spectrum partitioning capability which will allow flexibility in assigning spectrum to different services. This capability will allow the assignment of exclusive spectrum for aeronautical safety communication services. The NCC used in conjunction with an Aviation-PDAMA (AV-PDAMA) will provide for priority and immediate preemptive access to up to all the spectrum and power of the system that is required at any time for aeronautical safety communication services.

The NCC will operate as the single point switching and control center for the flexible assignment of spacecraft spectrum and power to the multiplicity of users. As part of its function, the NCC will assign spectrum and power for aeronautical safety communication services in response to requests from the AV-PDAMA(s), which will be under the control of appropriate aviation authorities.

There must be a systematic, evolutionary approach to the provision of aeronautical safety communications by satellite. The development and implementation of the approach must demonstrate to the aeronautical community in a highly credible manner that spectrum sharing does not compromise the reliability or integrity of aeronautical safety communications. The system must have the capability for future growth sufficient to meet all AMS(R)S needs.

Air Traffic Services (ATS) which includes air traffic control, and Aeronautical Operational Control (AOC) are the only communications functions that comprise AMSS(R) with the right of priority and immediate preemptive access. Other aeronautical communications, Aeronautical Administrative Communications and Aeronautical Public Correspondence have the same status as similar non-aeronautical communications. The control capability of the NCCs will enable priority access for non-aeronautical safety and emergency communications.

Communications other than aeronautical safety communication services will be provided to end users through a variety of service provider arrangements under the control of the NCCs.

A government agency, utility or large trucking company may lease satellite capacity and set up its own network of feeder link earth stations for its direct call setup and communications with its vehicles. Operation of the network will require lock to the control channels of the NCCs in order to comply with the requirement for priority and preemptive access for essential safety communication services.

5.0 SYSTEM PERFORMANCE REQUIREMENTS

For optimum utilization of the spectrum, most communications will be established using Single-Channel-Per-Carrier (SCPC), Frequency Division Multiple Access (FDMA) with nominal 5 kHz channel spacing as compared with the wider 30 kHz channels adopted for the 800 MHz terrestrial cellular systems. This 5 kHz channel requirement places a constraint on the possible speech coding/modulation techniques that can be used in MSAT. The basic analog voice modulation scheme considered is Amplitude Companded Single Sideband (ACSSB) while the basic digital version is 4.8 kbps Linear Predictive Coding (LPC) using Trellis Coded Modulation (TCM) with 8-PSK. Other suitable coding/modifications techniques may be employed such as 8 kbps Codebook-Excited LPC (CELP) with Differential Minimum Shift Keying (DMSK). Techniques suitable for aeronautical users for conformance with ICAO Specifications are given in Report 1173.

Voice performance is dependent on the inherent performance of the modulation schemes used, propagation characteristics of the links, noise and interference, the practical limits of the satellite RF power per voice channel as well as the practical limit of the earth terminal G/T's that can be achieved considering the dimensions of the vehicular antenna. Mobile Radio Service (MRS) voice channels will be designed to operate with an unfaded carrier-to-noise density (C/No) of 52.3 dB-Hz at the 1.5/1.6 GHz band.

For mobile telephone users where higher subjective quality has to be provided, the C/No is expected to be about 55 dB-Hz. For aeronautical and marine applications which do not experience shadowing, the C/No requirements would be relaxed by about 3 dB.

For an MRS terminal using a 10 dBi gain mobile antenna, these voice channel performance requirements translate into a satellite EIRP of 32.3 dBW per voice channel for ACSSB, as shown in Table 1.

The system will have the following modes of operation for voice communication:

(1) MRS mobile-to-SHF base station;

(2) MRS mobile-to-mobile in the same beam; and

(3) MRS mobile-to-mobile in a different beam.

The same types of connections will be available for MTS terminals except that they will interface with the gateway station rather than a base station. Similar connections can be defined for circuit, packet and message switched data communications.

In the normal mode of operation, the uplink signals from 1.6 GHz band beams will have their frequencies translated at the satellite into the SHF downlink beam.

Similarly, the uplink SHF channels will be translated in frequency to the 1.5 GHz band downlink. As well, a segment of these SHF channels will be cross-strapped to form a direct SHF-SHF link. These SHF-SHF links are intended mainly for signalling, data exchanges among gateways, and for NCC communication purposes. Typical system connectivity links are shown in Figure 4.

Capacity of a first generation system should be high enough to serve, during the peak traffic period, at least 50 to 60 thousand equivalent voice users. Assuming voice activation with an activity factor of 0.4 (i.e. assuming that an assigned channel will be actively transmitting only 40 percent of the time), and further assuming that the average user generates a traffic of 0.0106 Erlang and the system is designed for a blocking rate of 15 percent, 60,000 users translate into approximately 570 to 580 assigned channels, for voice traffic. Of course, the traffic will not be homogeneous, with various channels and blocking rates being used.

An additional requirement is to be able to accommodate a concentration of users in some parts of Canada and the United States since a uniform distribution of users across the country is not likely. The actual distribution may not be known until some considerable time after the start of service. The space segment will therefore have the capability to redistribute system capacity under ground command.

With respect to the voice land mobile channel performance requirements, some tests have indicated that the 52.3 dB-Hz may degrade to 45 dB-Hz before the MRS channel becomes unusable. With the given noise budget, this translates into a downlink margin of about 10 dB. Signal level degradation for mobile terminals operating in the 1.5/1.6 GHz band is mostly due to multi-path and blocking by obstacles, such as trees, and a full characterization of these will not be available until some time after the start of the service. The link margin required for a given grade of service may therefore have to be modified after the launch of the satellite to accommodate the blockage characteristics of a particular service area. Hence the space segment design will permit operation with large level differences among the active channels.

6.0 SPACE SEGMENT DESCRIPTION

The size, power, and configuration of the MSAT/AMSC satellites are determined by the performance requirements of the system. There are several design solutions, and the decision for the technical implementation must be left to the eventual spacecraft contractor.

The spacecraft outlined in the following paragraphs is only one of several possible configurations; it has been chosen to provide a basis for system capacity. In this section, a brief outline of the conceptual design of the satellite is given, and the estimated system capacity is discussed.

Coverage of the Canadian service area at 1.5/1.6 GHz is provided by four circular spot beams with an Edge Of Coverage (EOC) gain of 33 dBi. A five beam configuration covers the continental U.S. (including Alaska). Figure 5 a) shows the resulting nine beam configuration. An option is left open to provide an extra two beams to cover Mexico if it opts for joint service on either the Canadian or the U.S. satellite. Other areas that may be provided coverage include Puerto Rico, the U.S. Virgin-Islands, and Hawaii.

A single SHF transmit/receive beam serves to cover the combined Canadian-U.S. service area, with an EOC gain of 25 dBi (Figure 5 b)).

In order to accommodate a variety of users with different requirements, hence different modulations, power levels, etc., the satellite will have wideband linear transponders i.e. there will be no channelization at the satellite. Because the same 1.5/1.6 GHz spectrum is sought by many administrations and international organizations, there is no guarantee that the system will have a contiguous chunk of spectrum to meet its needs. It is most likely that several pieces of spectrum will be available all across the band after coordination with other users of the band. Requirements, therefore, call for enough flexibility such that any piece of spectrum in the band can be switched into any beam. This permits an assignment of system capacity in multiples of a basic unit of spectrum among the four Canadian and five U.S. beams, by means of a ground commandable switching network, as shown in Figure 6, which also illustrates the payload functional block diagram.

The main space segment characteristics are shown in Table 2.

The channel capacity of the space segment is limited by the available payload power and the spectrum. Most of the payload power will be used by the 1.5 GHz RF power amplifiers. Assuming a 2 dB output loss, the 32.3 dBW EIRP will require 1.35 W RF power per active channel, for a 33 dBi EOC antenna gain. Based on these figures, the estimated channel capacity of the system will be roughly 860 assignable equivalent voice channels.

Some places in the coverage area enjoy relatively high elevation angles and/or have little or no shadowing. For these areas, the link margin requirements would be reduced, hence lower satellite EIRP per channel would be needed. Further, other modulations requiring less EIRP's may be developed in the future. All this would increase the satellite capacity beyond the 860 equivalent voice channels stated above.

The satellite separations are anticipated to be favorable for radio determination by range measurements from the satellites. As an example of performance that could be provided, previous tone code ranging technique —————————— (Brisken et al, 1979) achieved position locations accurate to about 400 m throughout the latitudes of North America with quarter-second digital transmissions at 2.4 kilobits per second data rate. Higher accuracy could be achieved with greater bandwidth or longer transmission time throughout the latitudes of North America.

7.0 GROUND SEGMENT DESCRIPTION

The major components of the ground segment are the Gateway Stations, Base Stations, Data Hub Stations and the Mobile terminals.

7.1 The Gateway Stations will interface with the PSTN to allow for communication between users and the PSTN subscribers. The gateway will support voice and data transmissions. For PSTN data services, such as Data-Route and Datapac, protocol translators will be required at the gateways. The gateways will operate in the SHF band and they will be located at sites across Canada and the United States to ensure optimum usage of the terrestrial and satellite networks.

7.2 The Base Stations are defined as the dispatch centers or private fixed earth stations for user groups subscribing to MRS or other private services. It is assumed that every MRS user group will consist of at least one Base Station and a number of mobile users. It is expected that up to 95 percent of MRS traffic will be between Base Stations and mobile terminals.

The ratio of mobile users to Base Stations will vary significantly between various mobile communities (the average ratio is estimated to be 250 to 1). However, on average, the total traffic offered to the system from all the Base Stations is assumed to be equal to that from all mobile users. This will affect the required number of 1.5/1.6 GHz and SHF signalling channels. The ratio of the voice/data traffic from Base Stations to that which originates from mobile terminals is a critical parameter which will have a direct impact on the required onboard satellite power.

The base stations will transmit to the satellite in the SHF uplink band and receive in the SHF downlink band.

7.3 Mobile Terminals
Mobile radio terminals will be under complete control by the NCC. They may operate in half-duplex or full-duplex mode, and both transmitter and receiver will have a frequency agile design. Terminals will operate in the 1.5/1.6 GHz band. They will have a DAMA processor which will enable it to receive and respond to instructions from the NCC communicated via the signalling channels. One positive control technique is for the terminals to have a signalling channel receiver (SCR) separate from the main communication channel receiver so that they will receive the signalling channel at all times (even when transmitting). This offers several advantages including:

- access denial for terminals not meeting performance specifications;
- the means to continuously control the mobile terminals e.g. for preempting or reassigning to open channels;
- positive derivation of frequency from a common frequency reference; and
- the availability of a continuous signal for mobile antenna tracking and power control.

The user equipment will not be able to transmit unless it is locked to the control channel. An option that may be required of some classes of user equipments will be the incorporation of built in sensors that measure key performance parameters that could be read out on command over the control channel by the NCC.

The mobile telephone terminal will be similar in operation to the mobile radio terminal except that it will interface with the PSTN via a gateway. It will operate in a full-duplex mode.

A large percentage of terminals in the system are expected to be mobile data terminals. They will be offered in a variety of configurations with various capabilities depending on the type of data services offered, such as two-way interactive data terminals, one-way data terminals, paging units, position determination terminals, etc.

8.0 NETWORK CONTROL CENTRE

The Network Control Centre will be the single point control station for all system operating functions except aviation safety. The functions include:

System frequency reference
Communication channel assignment
Priority assignment of channels
Preemption of bandwidth needed for safety reassignment
Network performance monitoring
User equipment performance monitoring
Turn-off of malfunctioning user equipments
Recording of time, bandwidth and power used per call
Recordkeeping and billing.

The two main elements of the Network Control Center are the Network Management System (NMS) and the DAMA Control System (DCS). Figure 7 shows the block diagram of the Network Control Centre. Aviation PDAMA interfaces are omitted for clarity.

8.1 The Network Management System will be responsible for overall supervision, maintenance and long-term resource planning of the system. It will communicate directly with the DCS and the AV-PDAMAS in order to receive information concerning traffic statistics and AMS(R)S needs. The NMS will compute the partition between voice, data, and signalling channels to optimize performance and will execute the partitioning required by the aviation safety PDAMA system. Furthermore, it will be responsible for optimizing the routing tables used by the DCS to route the MTS calls to the proper gateway stations. This information will be transmitted to the DCS. The NMS will also gather billing information from the DCS and the gateways. This information will be collected regularly, during off-peak hours, via SHF signalling channels. The NMS is also responsible for discouraging unauthorized users.

8.2 The DAMA Control System coordinates, controls, and maintains the activities within different earth segment components, with particular emphasis on the short-term activities and events. The principal objectives of the DCS are to achieve maximum channel availability in performing these functions, and in conjunction with the NMS, to make the best use of the system resources. An efficient signalling system is required which can use the minimum number of channels while still providing an acceptable performance, such as call set up times. The DCS will also transmit frequency and timing information to other network entities.

The Canadian DCS will operate a network consisting of approximately 80,000 to 120,000 users at the point of system saturation for the first generation system. It will be connected to all base stations, gateway stations, and user terminals via packet-switched data links called "signalling channels". The United States DCS must accommodate an even larger number of users and will have functionally similar signalling channels.

All communication control functions associated with the network, such as call processing, must be performed by a set of highly reliable computers compatible with the other network elements to ensure maximum system reliability. The reliability and integrity must be at least as great as that required for AMS(R)S.

9.0 KEY TECHNOLOGY ITEMS

The equipment procurement and system development program presents a challenge to equipment manufacturers as well as system designers. Both the space segment and the ground segment contain components which have a major influence on the cost-effectiveness of the system and have to meet demanding performance requirements. The main areas of concern include the development of an efficient satellite 1.5 GHz RF Solid State Power Amplifier (SSPA), the design and qualification of large (approximately 5 m) satellite antennas, retention of flexibility to accommodate aviation needs which are not yet fully specified, and the availability and performance of cost-effective, high gain vehicular antennas.

SSPAs must be able to operate with high DC to RF Power conversion efficiency and acceptable intermodulation, over a wide range of output power levels, while carrying a varying number of active channels. They also have to demonstrate high reliability over a long (>10 years) service life in an adverse radiation environment, without a heavy mass penalty. Development of high power 1.5 GHz SSPAs is in progress. Breadboard measurements indicate that efficiencies in excess of 25% may be achieved with a carrier-to-intermod ratio of 22 dB, at power levels of up to 50 to 60 Watts RF. Higher carrier-to-intermod ratios are achieved at lower efficiency levels.

Large diameter spacecraft antennas require sophisticated deployment mechanisms since launch vehicle payload envelope restrictions necessitate folded or unfurlable reflectors beyond a reflector diameter of about 3m. Performance verification of these antennas on the ground also presents a problem since the in-orbit mechanical shapes are difficult to reproduce accurately in a 1g environment.

Several companies are designing spacecraft antennas in the 5 m range. Although the deployment mechanisms are generally much more complex than those of the durable, solid reflectors, the achievable surface accuracies promise high reflector efficiencies.

The use of mesh reflectors increases the chances of Passive Inter-Modulation (PIM). Contamination from the spacecraft thrusters may contribute to this problem, particularly since the high transponder gains of the mobile satellites (>150 dB) and the frequency separation between the transmit and receive 1.5/1.6 GHz frequencies make this system sensitive to passive intermodulation. Maximum separation of the transmit and receive paths, and extensive use of PIM reducing techniques (such as soldered connections rather than connectors, avoidance of braided cables, etc.) will have to be employed in order to contain the risk of performance degradation.

Antenna gain of the mobile terminals has a direct effect on one of the most cost-sensitive parameters of the system - the downlink(satellite) EIRP. Design and qualification of a cost-effective high gain vehicular antenna which is acceptable by the user community from a cost, performance, and an esthetic point of view is therefore of considerable importance.

High gain vehicular antennas must be steered to keep pointing toward the satellite as the vehicle changes direction. The design of a suitable pointing mechanism presents a considerable challenge to the designer.

There are several high gain 1.5/1.6 GHz mobile antennas in various stages of development. Electronically steered, phased array antennas have been built, with a gain in excess of 10 dBi but a significant amount of development work is still required before they become commercially available.

References:

(1) Brisken A. F. et al, "Land Mobile Communications and Position Fixing Using Satellites" IEEE Transactions on Vehicular Technology, Vol. VT-28, No. 3, August, 1979.

Table 1 MRS 1.5/1.6 GHZ and SHF Link Budgets
ACSSB VOICE

PARAMETER	UNIT	FORWARD LINK	REVERSE LINK
UPLINK		3.5m SHF ANT. to Mobile	Mobile to 3.5m SHF Ant.
Frequency	MHz	13200	1650
Uplink EIRP/Voice Act. Carr.	dBW	45.1	16.2
Path Loss	dB	206.8	188.7
Satellite G/T	dB/K	- 3	2.8
Total IPBO/Transp. (Av.Pwr.)	dB	N/A	12
Req'd Flux Density/Voice Carr.	dBW/m2	-117.8	-146.7
C/No Thermal	dB-Hz	63.9	58.9
Noise Bandwidth	kHz	3	3
C/N Thermal	dB	29.2	24.1
DOWNLINK			
Frequency	MHz	1545	11300
Req'd EIRP/Voice Act. Carr.	dBW	32.3	10.6
Req'd Total OPBO	dB	N/A	7
Path Loss	dB	188.1	205.4
Receive Terminal G/T	dB/K	-17.5	25.9
C/No Thermal	dB-Hz	55.2	59.7
INTERFERENCE (C/I)			
Intermod & Energy Spread			
Uplink	dB	32	25
Downlink	dB	22	25
Other Sources			
Uplink	dB	32	40
Downlink	dB	40	29
Total Interference	dB	21.2	21.1
Total C/Io	dB-Hz	55.9	55.9
Total Unfaded C/No+Io	dB-Hz	52.3	53.1

TABLE 2: SPACE SEGMENT CHARACTERISTICS

Orbit location	106.5°W, Canadian near 60°W, 100°W, 130°W U.S.
Satellite class	2,500 kg
Payload mass	350 kg
Payload power	2.5 kW
Frequency bands	RX 1626.5-1660.5 MHz TX 1530-1559 MHz
Transponder bandwidth	29 MHz
Number of beams	4 Can+ 5 US at 1.5/1.6 GHz (+option 2 Mexico) 1 North American SHF
Polarization	RHCP for 1.5/1.6 GHz band linear VP Receive HP Transmit for SHF
Antenna size	two 4.9m reflectors
EOC G/T	2.8 dB/K 1.6 GHz -3 dB/K SHF
Eclipse protection	25% of busy-hour traffic
Service life	10 years

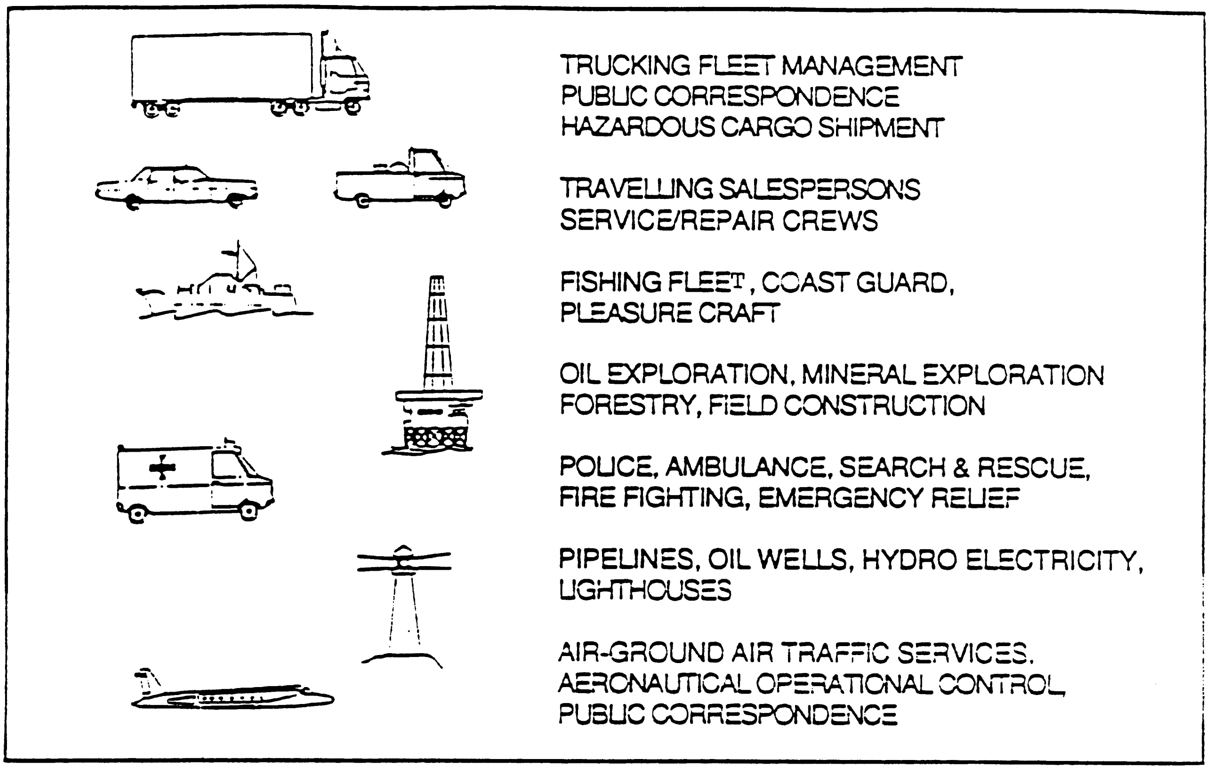

Figure 1 Typical Applications

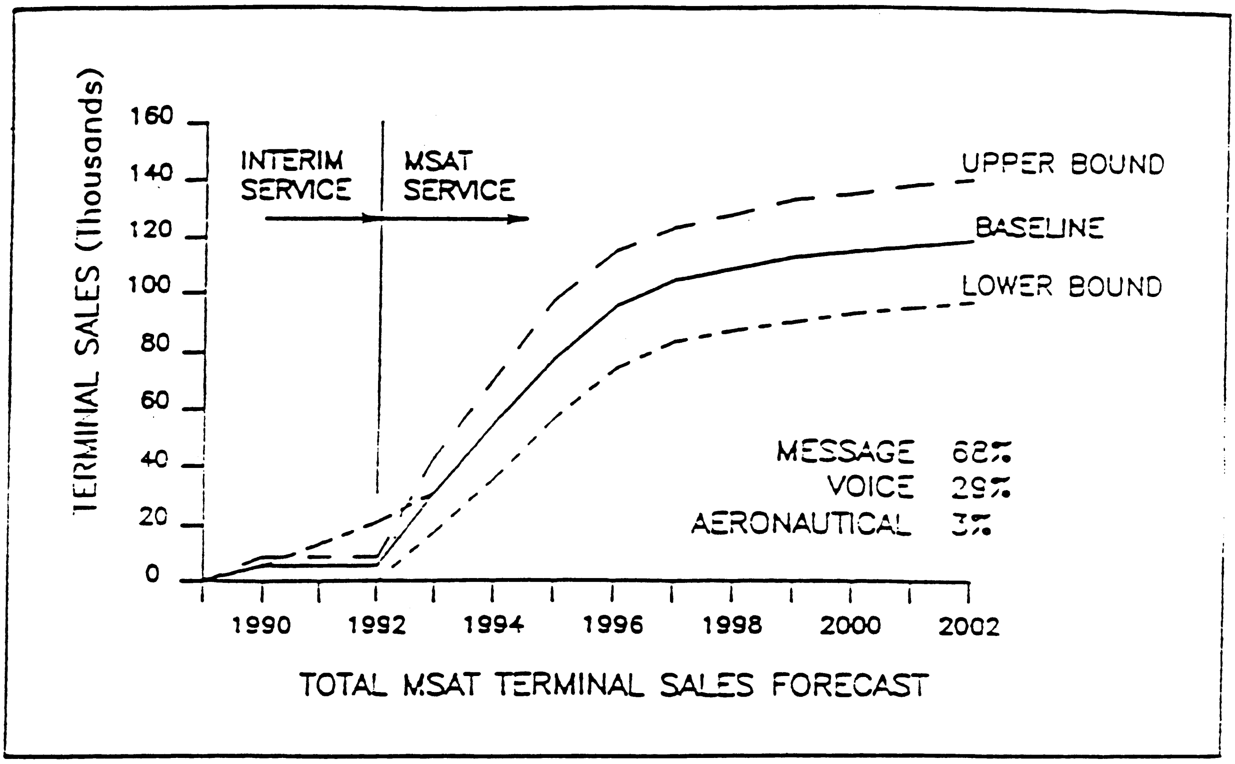

Figure 2 Total Canadian Terminal Sales Forecast

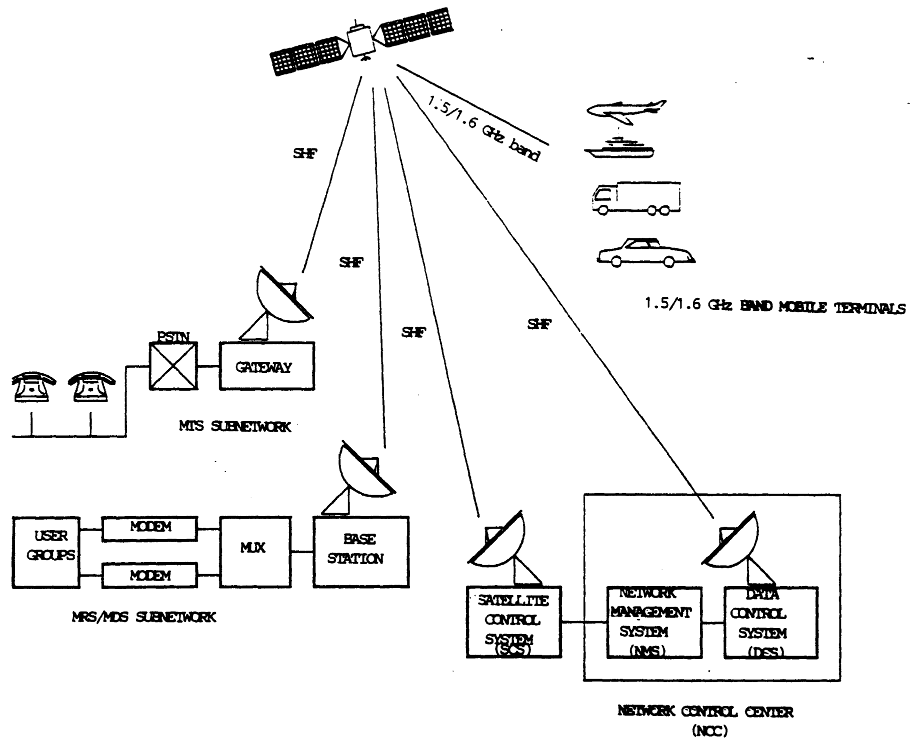

Figure 3 System Configuration

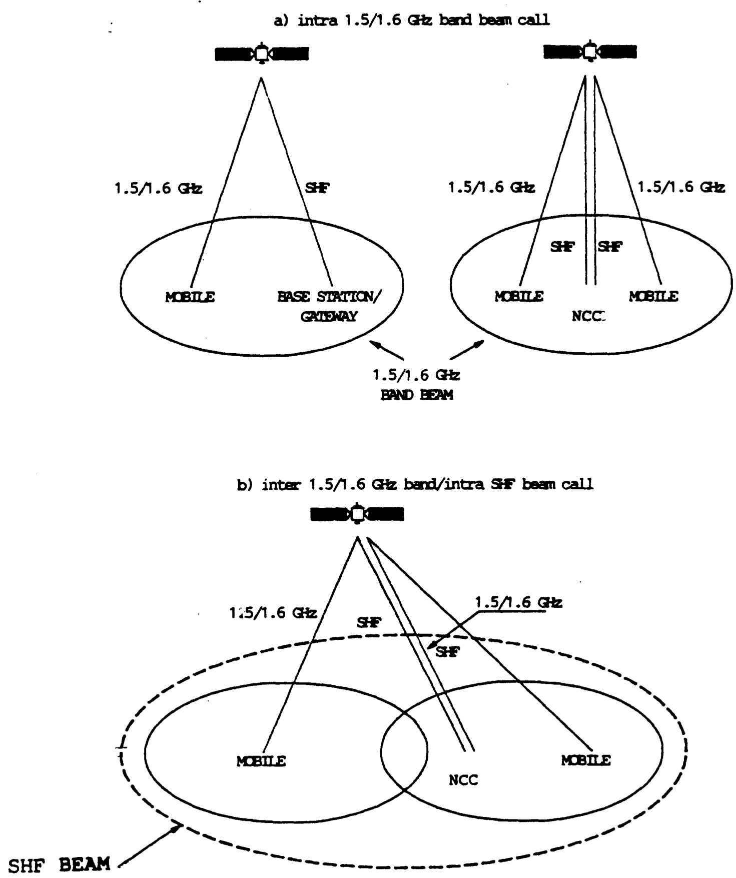

Figure 4 System Link Connectivities

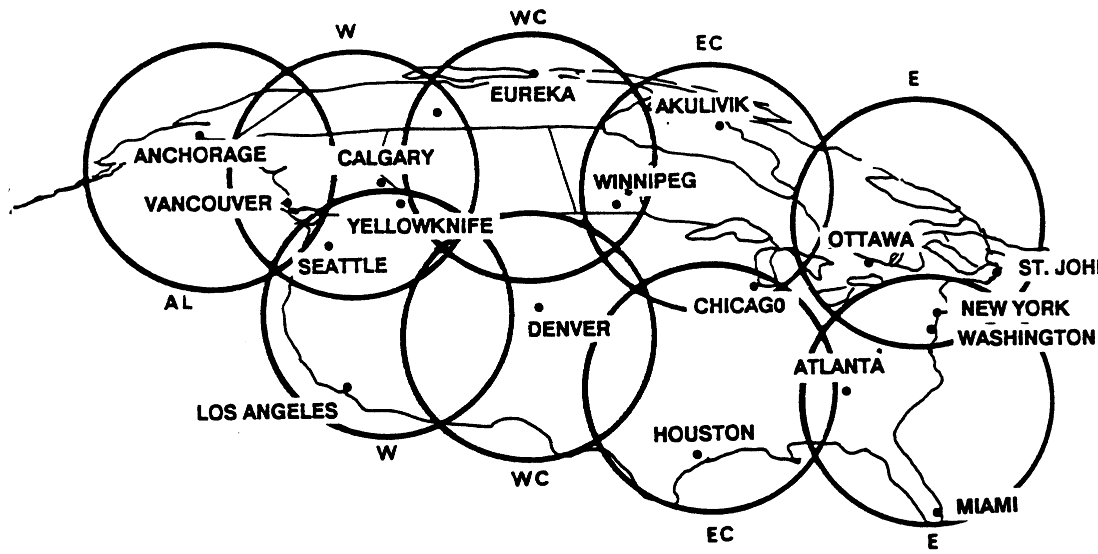

Figure 5 a) 1.5/1.6 GHz Nine Beam Coverage

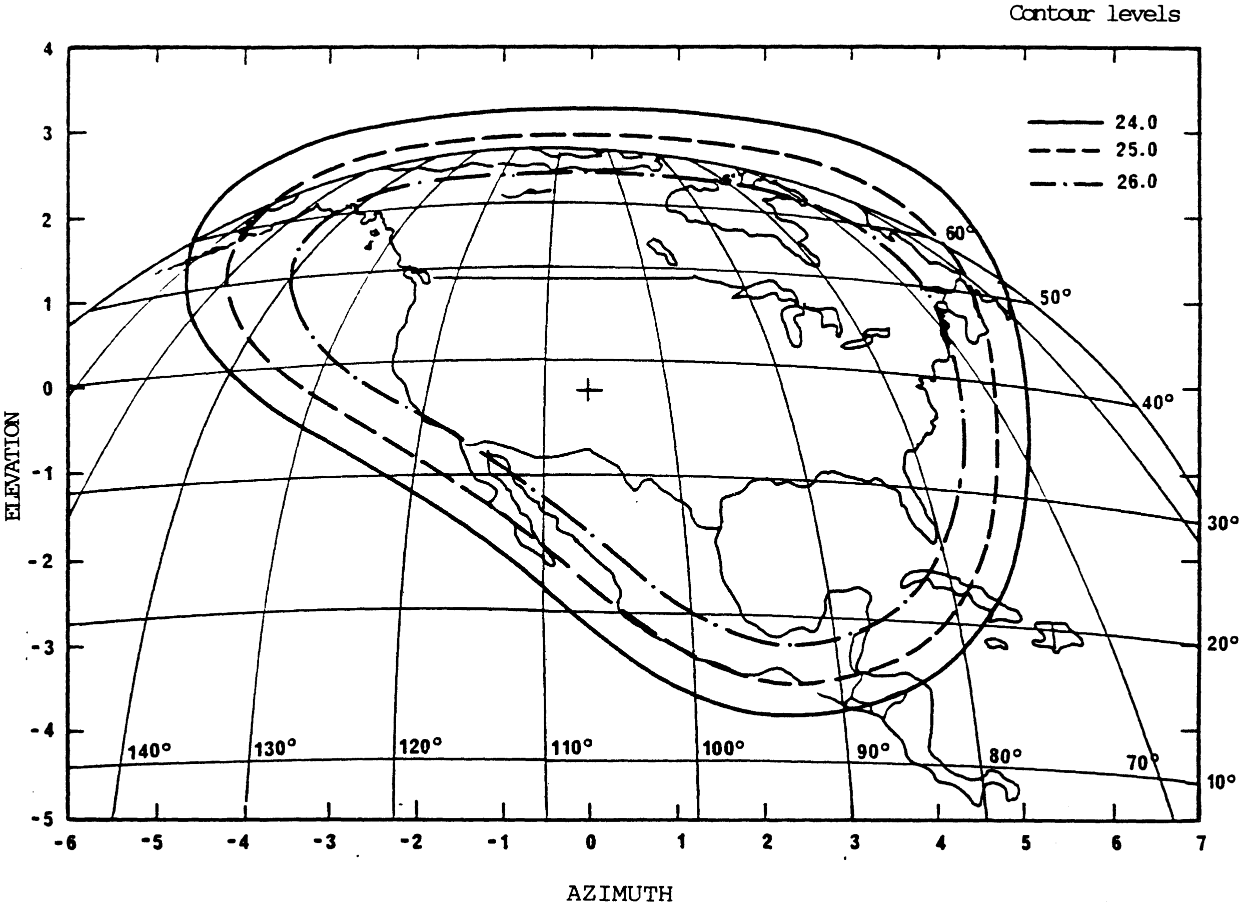

Figure 5 b) SHF Coverage Pattern

Orbit location: 108° W

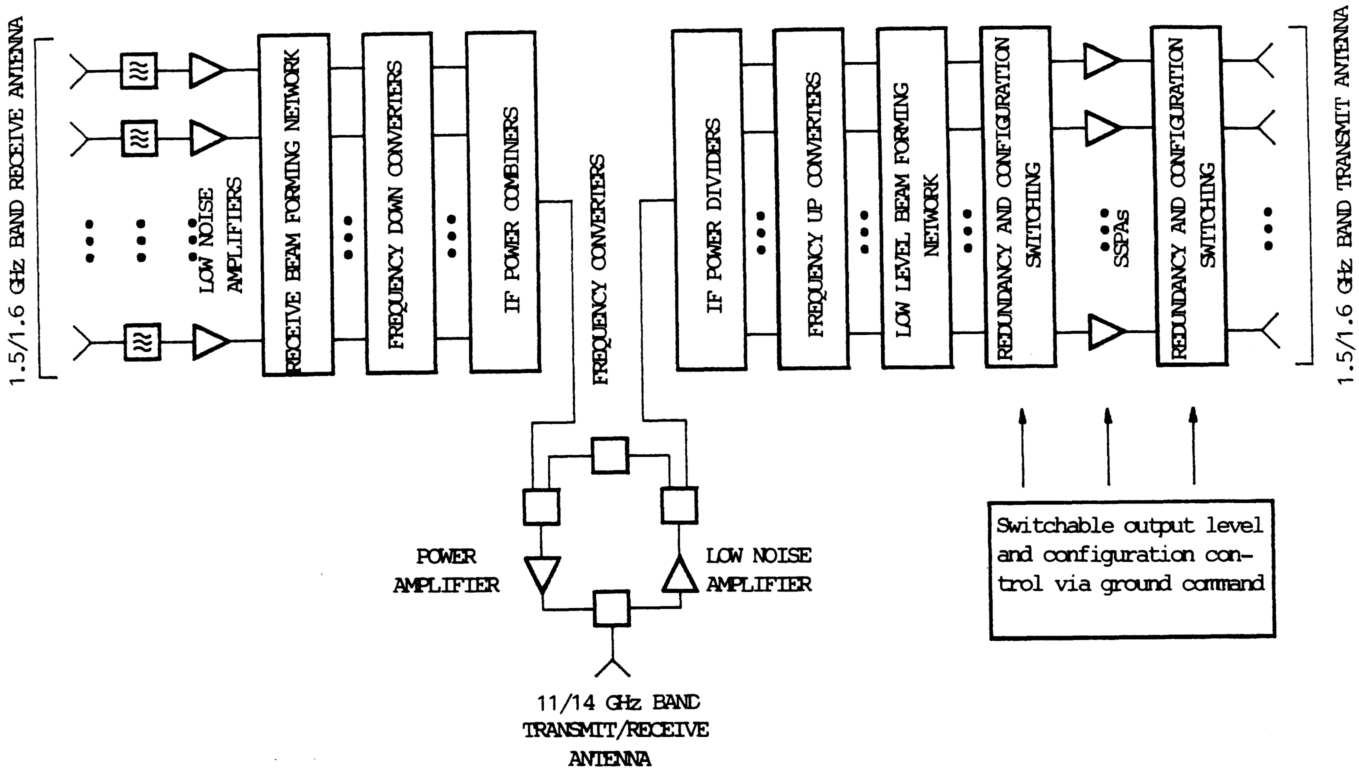

Figure 6 Satellite Transponder Functional Block Diagram

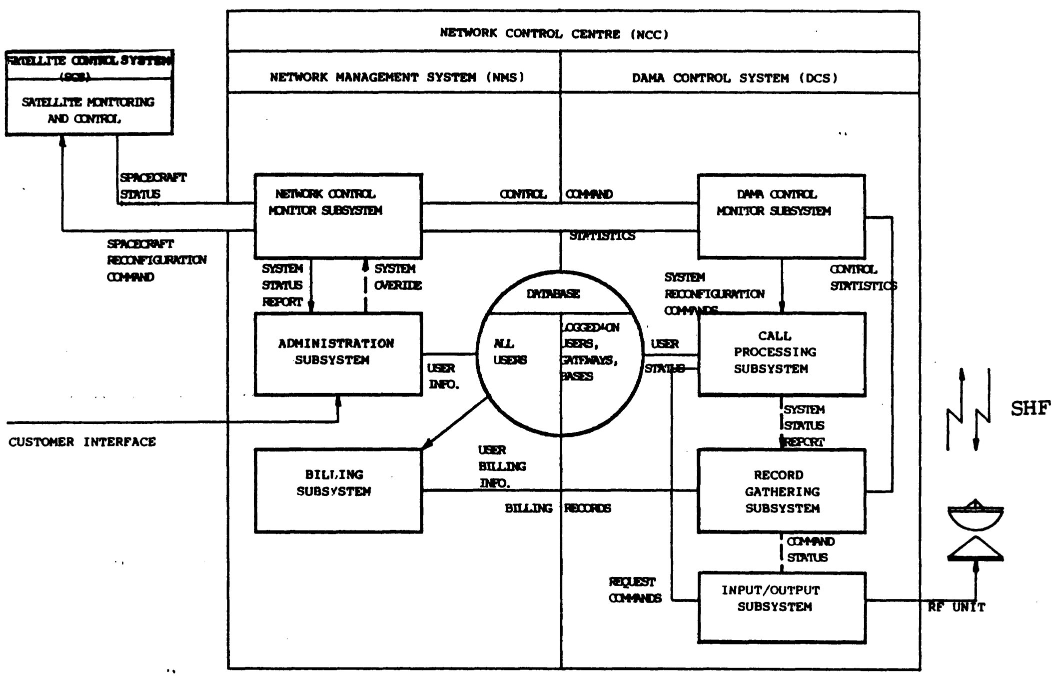

Figure 7 Network Control Centre Block Diagram

ANNEX III

PRELIMINARY OUTLINE OF TECHNICAL CONDITIONS FOR TRANSPONDER SHARING

Mobile equipment

- radiated power and power density not to exceed agreed limits under any circumstances;

- transmissions not possible unless receiver is locked to a receive channel from which the equipment is subject to system control;

- acceptable type approval procedures focusing in particular on:

  a) antenna radiation pattern;
  b) frequency stability and control;
  c) spurious emissions;
  d) access control functions;
  e) reliability in intended environment; and
  f) power control

- obligation on users not to modify equipment or use it for other than intended purposes and the obligation to maintain the equipment to a prescribed standard; and

- each installation to be tested upon entry to the satellite network.

Satellite provider/service provider

- registration of every mobile station and responsible owner/operator;

- provision of acceptable system monitoring;

- connections to air traffic control (ATC) centre: acceptance of priority rules for the allocation of satellite power;

- procedures for identifying "rogue" terminals;

- implementation of acceptable approval and testing procedures for all equipment sharing transponders;

- guarantee of transponder performance:

  a) noise floor;
  b) gain; and
  c) carrier to intermodulation ratio.

ICAO declaration of performance requirements

Interference Criteria

RF channel type	Carrier to total interference (minimum)
P (600)	(To be developed)
P (1 200)	(To be developed)
R	(To be developed)
T	(To be developed)
C	(To be developed)

Rules for the allocation of satellite power

(X per cent) extra power capacity shall be provided when any of the following message delivery times are exceeded.

Message priority	Average delay
15	(To be developed)
14	(To be developed)
13	(To be developed)
.	.
.	.
.	.
2	(To be developed)
1	(To be developed)
0	(To be developed)

System monitoring rules

- identify presence of a carrier having (X dB) excess power.

ANNEX IV

A NETWORK CONTROL AND SIGNALLING SYSTEM
FOR THE NORTH AMERICAN MSS

1.0 INTRODUCTION

In designing a suitable signalling system for the North American Mobile Satellite Service, flexibility is of paramount importance. In order to satisfy the disparate demands of up to one million users in the initial system, the system must be easily expandable and be able to incorporate new technologies without the whole system being reconfigured. Equally important is the ability to pre-empt portions of the spectrum for aeronautical safety and regularity of flight use on a real-time basis.Another key feature of the signalling design is that it be robust under the sometimes harsh multipath and fading conditions. As most of the signalling is non-revenue bearing traffic, the system must be as efficient as possible in order to reduce this overhead. Finally, in designing the system the needs and expectations of the end-users play a critical role, especially in the areas of call set-up times and grades of service.

The concept for a baseline signalling system will support the categories of service defined in Annex II to this report. Mobile Radio Service (MRS) and Mobile Telephone Service (MTS) will be circuit switched, while the Mobile Data Service (MDS) will be packet switched. The voice services may use analogue or digital techniques. Mobile terminals with a range of G/Ts and e.i.r.p.s may be adopted. Thus the signalling system must be capable of supporting different modulation types as well as mobile terminal e.i.r.p.s without being wasteful of limited satellite resources.

The overall system architecture consists of a centralized Network Operating Centre (NOC) and one or more Network Control Centres (NCC) (which have the functions of Network Administration, Network Management and DAMA Control), numerous Gateway and Base Stations (or Feeder-link Earth Stations (FES)), and the Mobile Earth Terminals (MET).

Ongoing work on propagation conditions will ensure that the signalling system, whose design is continuing, will meet the requirements under the various propagation conditions experienced in North America.

2.0 MSAT NETWORK CONTROL

A NOC will have overall control of the allocation of all resources within the MSS system. This system may involve one or more satellites. The NOC will exercise control over the assignment of capacity on a particular satellite, and this assignment will be implemented by an associated NCC. The NCC will have active control of all METs and FESs in its network. The control by an NCC will be effected using the signalling capabilities described in the following sections.

The NOC will interface with all external networks or organizations (e.g. a private network) which may lease bandwidth and power on any satellite for which the NOC has control. It will also interface with Aviation PDAMA(s) (see § 8 of Annex II) which will be owned by an operator providing AMS(R)S service to the aeronautical community. The NOC will maintain a database which defines the frequency bands which have been coordinated for use or reuse in any beam of a multi-beam system. The associated NCCs will operate within these definitions.

This arrangement provides for the dynamic allocation of spectrum to any beam to satisfy requirements for service. The system will also have variable dynamic partitioning of channels among services according to need.. This arrangement also provides for the dynamic preemption of channels in case of increased demand for spectrum for aeronautical safety services. When the spectrum is reallocated, the NCCs immediately react by assigning channels within each beam in accordance with the revised allocation. By requiring the use of common signalling channels, which METs must receive in order to operate, positive control of all METs (which may be required, for example, to control potential sources of interference in the case of misfunctioning METs) and positive real-time pre-emption of frequency channels can always be effected.

The system will be designed to permit orderly partitioning of frequencies, with the capability to dynamically change the partitions under normal operating conditions and also in the case of emergencies Through appropriate forward planning between MSS and AMSS(R) operators, and appropriate look-ahead capability of AMS(R)S operators to estimate increased needs for spectrum,the NCC can reserve channels for AMS(R)S use and make sure that they are available when needed. This way, other services will never have to be preempted except in unforeseen extreme emergency situations.

3.0 PERFORMANCE OBJECTIVES

The ability to establish connections between a MET and a feederlink earth station is dependent upon the conditions of the propagation path. The following are provisional objectives for channel connect times and probabilities:

Performance Objectives	Degree of Shadowing None	Light	Moderate	Heavy
Mean Connect Time (s)	2.0	3.0	4.0	5.0
90% Connect Time (s)	5.0	6.0	8.0	10.0

Where light shadowing refers to less than 15% of the travel distance shadowed, moderate is 15% to 40% shadowing, and heavy is greater than 40% of the travel distance is shadowed. Connect time is measured from the time a station initiates a call until the assignment is acknowledged to the NCC by both the FES and the MET. The connect time does not include the time for direct FES-MET connect establishment. It is recognized that a more rigorous definition of the shadowing statistics is required, but it is beyond the scope of this paper.

4.0 CHANNEL CONFIGURATION

Figure 1 shows the channel configuration between the Network Control Centre (NCC), Feederlink Earth Stations (FES, i.e. gateways and base stations), and Mobile Earth Terminals (MET). The nominal channel bandwidth is 5 kHz, although other channel band widths are possible (in 2.5 kHz steps). Six different channel types have been defined:

NCC-I Interstation signalling channel originating from the NCC going to an FES.

FES-I	Interstation signalling channel from a Feederlink Earth Station to the NCC.
NCC-T	Outbound signalling channel from the NCC to the MET.
MET-R	Inbound random access (slotted Aloha) channel from the MET to the NCC.
FES-C	Outbound communications channel from a base or gateway station to a MET.
MET-C	Inbound communications channel from a MET to an FES.

The following table shows the characteristics of these channels:

Channel	Link	Characteristics
NCC-I	SHF-SHF	TDM, data rate TBD
FES-I	SHF-SHF	TDMA, data rate TBD
NCC-T	SHF-1.5 GHz	TDM at 1200 and 2400 bps
MET-R	1.6 GHz-SHF	Slotted Aloha at 1200 and 2400 bps
FES-C	SHF-1.5 GHz	Selectable communications channel
MET-C	1.6 GHz-SHF	Selectable communications channel

5.0 MODULATION AND CODING

The parameters of the interstation signalling channels (NCC-I and FES-I) have not yet been determined. The communications channels (MET-C and FES-C) will have many possible choices for providing voice and/or data. This is described in greater detail in a later section.

The MET-R and NCC-T channels will use the same modulation and coding. There will be two choices (at least in the initial system) of modulation and data rates. This will accommodate different values of MET G/Ts and EIRPs and METs which may also be operating under vastly different propagation conditions.

The lower rate channel may transmit at 2400 sps using aviation BPSK (A-BPSK), while the higher channel rate may transmit at 4800 sps using QPSK. Both will operate within a 5 kHz channel and may use rate 1/2 convolutional coding (constraint length 7) thus giving information throughputs of 1200 bps and 2400 bps respectively. Other forms of coding are being investigated. The structure of the NCC-T and the MET-R channels will be described in a later section.

6.0 SIGNALLING CHANNEL STRUCTURE

In order to ensure orderly packet transmission in TDM, TDMA, and Slotted Aloha modes it is vital that all packets be of the same length. Thus a common signalling unit size must be chosen which is large enough to handle most of the information that needs to be sent without wasting satellite resources on excessive filler bits. The signalling unit (SU) structure that INMARSAT has developed (see Report 1173) also meets the North American requirements. The 96-bit SU includes a CCITT recommended 16-bit CRC for error checking.

6.1 Signalling unit structure

The signalling system is designed to transmit a wide variety of information concerning the MSAT network and user needs. For example, the signalling packets will convey, among other information, the following: message type, MET unique ID (factory preset), whether a user is Canadian or American, priority and grade of service requested, modulation type for MTS and MRS, the base station ID, the PSTN called party ID, and bandwidth and satellite e.i.r.p. requested.

Figure 2 shows the structure of a type SU for an MTS call request. In this case, it can handle up to eight message types, a 24-bit ID allowing 8 million subscribers each in the United States and Canada, 10 digit dialling of PSTN subscribers, up to eight levels of priority, and eight modulation types. The modulation types could include ACSSB, 8 kbit/s CELP with QPSK, 16 kbit/s (8 kbit/s CELP, rate 1/2 coded) with TCM and 4.8 kbit/s CELP with QPSK. The 8 spare bits in Figure 2 allow for future services to be added. For circuit-switched services, the MET will need to originate SU packets such as Log-On/Log-Off, MTS/MRS Call Request, various Acknowledgements, Call Forward/Unforward, Call Hold/Unhold, etc. The NCC will originate SU packets such as MTS/MRS Call Indicator, various Acknowledgements, Call Termination/Abort, Call Waiting, etc.

In addition to the circuit switched services there is also the packet switched MDS, which has not yet been defined.

6.2 NCC-T CHANNEL FRAME STRUCTURE

Figure 3 shows a proposed frame structure for the NCC-T channel. The frame length is 0.5 second or 1 second long for the 4800 sps and 2400 sps channels respectively. Thus each frame is 2400 symbols long regardless of the data rate. The frame header and unique word are used for synchronization purposes and to identify the channel and frame number. Each frame contains 12 SUs that are rate 1/2 coded and block interleaved, and 12 flush symbols.

Each MET will continuously monitor the NCC-T channel even while engaged in communications on the MET-C and FES-C channels. This will allow additional services to the MET, such as Call Waiting and Hold, and any required real time pre-emption. Monitoring the NCC-T channel will also enable the MET to track the satellite with a directional antenna, as well as use the channel for a frequency and timing reference.

6.3 MET-R CHANNEL STRUCTURE AND BURST FORMAT

Figure 4 shows the in-bound slotted Aloha MET-R channel structure and burst format for the 2400 sps channel. The NCC-T channel is used to provide the timing information, thus the MET-R channel is divided into frames of 2400 symbols each with 8 slots per frame. Again, each 96 bit SU is rate 1/2 coded to give a 204 symbol packet (including flush bits). A 15 bit unique word is used at the NCC for automatic frequency compensation and bit timing recovery. The 81 symbols at 2400 sps provides for 35 msec (total) of guard time for each packet which should be sufficient given the MSAT beam size. For the 4800 sps MET-R channel, the same guard time must be provided, thus giving a proportionately larger number of symbols (not shown).

The number and spacing of retransmissions on the MET-R channel will be variable and will change according to the traffic loading. The NCC will communicate this information to all mobiles on a channel when they log on and when the traffic situation changes.

7.0 MET-C AND FES-C CHANNELS

The communications channels can be any one of up to eight different types for an MTS call to a gateway, or up to sixteen types for MRS mobile-base communications. The reason for the greater number of modulation types for MRS is that it is anticipated that the capacity for different types of circuit switched data will be possible. Also, it is possible that each base station could have a different choice of sixteen call types, e.g. ranging from 2.4 kbit/s CELP, BPSK to 32 kbit/s ADPCM, TCM. While it is unlikely that there will be a great variety of voice coding options for the initial implementation of MSAT, one must keep in mind that the signalling system must be able to accommodate new technologies and services as they arise without forcing the whole network to change.

It is also possible that different service providers will want different modulations in order to distinguish their product from the rest and to meet the needs of specific groups of users.

8. Summary

A signalling system is currently being designed in order to satisfy the unique requirements of a North American Mobile Satellite System. Not only does the system have to be flexible for incorporating new technologies, but it must also be able to share the limited available spectrum with other users.

The signalling system described here is expected to be diverse enough to handle the widely varying needs of users across North America. The system will be able to evolve in an expeditious manner without the obsolescence of older technologies or the need to re-design the entire infrastructure.

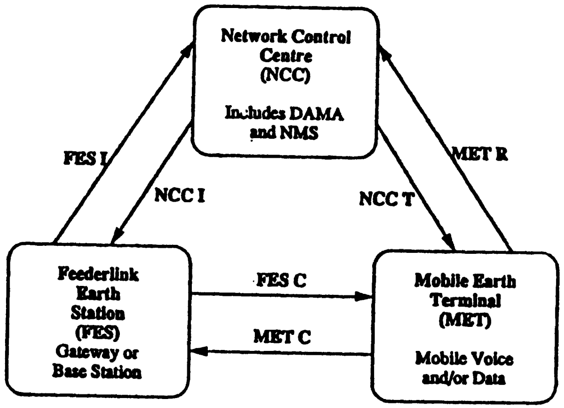

Figure 1. MSAT Signalling Channel Configuration

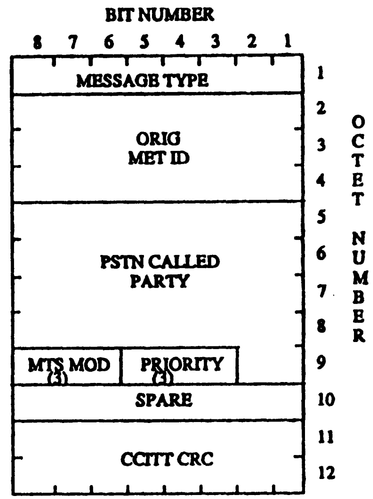

Figure 2. MTS Call Request SU

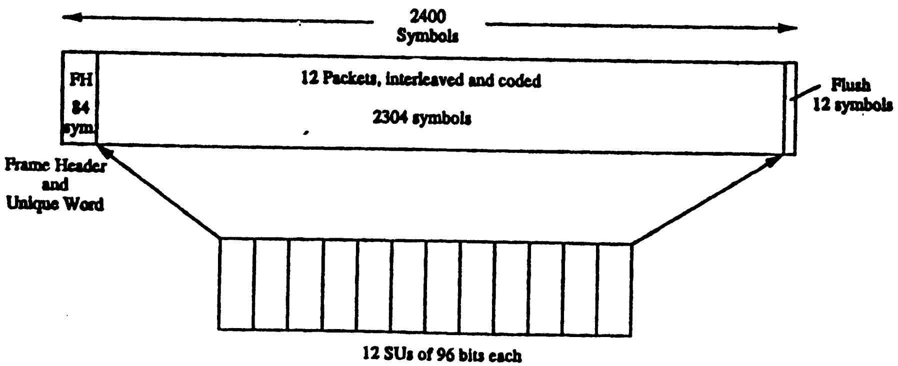

Figure 3. NCC T Channel Format

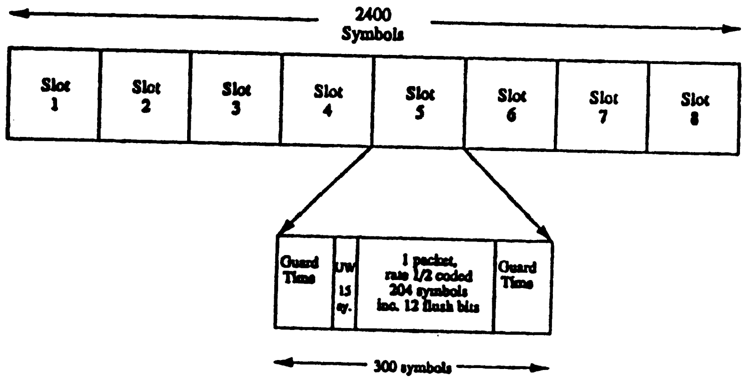

Figure 4. MET R Channel Burst Format at 2400 sps

ANNEX V

POSSIBLE FRAMEWORK FOR A FUTURE RECOMMENDATION ON MOBILE SATELLITE SERVICE SYSTEM DESIGN CONCEPTS

(Question 82/8)

The CCIR,

CONSIDERING

(a) that there is a need for more reliable long distance communication between existing terrestrial networks and mobile earth stations in the maritime, aeronautical and land mobile satellite services;

(b) that international connectivity among mobile earth stations using the various mobile-satellite services may be desirable;

(c) that integration of the various mobile-satellite services is now being planned to allow economical systems, to provide all users with similar services and to share the limited frequency resources effectively;

(d) that in the interests of promoting development of the most efficient and effective services throughout the world, guidelines for mobile-satellite service system design concepts should be available;

(e) Recommendation No. 405 of the World Administrative Radio Conference (Geneva, 1979), and Recommendations Nos. 313 (Rev. Mob-83) and 312 (Rev. Mob-87);

RECOMMENDS

1. That administrations and system designers adopt system concepts for the mobile-satellite services operating in bands around 1.5/1.6 GHz such that standards can be developed for interoperability between user equipments and any compatible mobile-satellite communication system;

2. that the following network characteristics should be included in mobile-satellite systems in the 1.5/1.6 GHz bands:

2.1 Each satellite or group of satellites shall be easily identifiable to its users. Identification of individual beams in multiple beam satellites may also be necessary.

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*The Director, CCIR, is requested to bring this Recommendation to the attention of the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO), and the Director, CCITT.

2.2 Assigned channel bandwidths and frequency synthesis techniques shall take account of Doppler shift due to expected vehicle speeds relative to the satellite. For high speed vehicles, e.g. aircraft, Doppler compensation may be necessary.

2.3 All signals radiated by satellites to mobile earth stations shall have high frequency stability and accuracy [requiring further study].

2.4 Mobile earth stations may use the control and/or pilot frequencies radiated by the satellite as a reference to synthesize the frequencies required by its equipment and/or to calibrate the frequency determining equipment of the mobile earth station.

2.5 Mobile earth stations shall be able to operate in a network with dynamic assignment of channels and bandwidths. Efficiency of power usage is important and use of power control may be desirable.

2.6 A tuning increment of [500 Hz or integral multiples thereof] starting from [an agreed reference point] shall be available.

2.7 A standard protocol should be developed to allow mobile earth stations to communicate with the satellite network control station; in particular this protocol should make provision for an internationally recognized code as a unique mobile earth station identification.

2.8 Mobile earth stations shall be able to select the satellite (or satellite group) required and, where appropriate, the type of service needed.

2.9 Satellite antennas in the mobile-satellite bands shall be circularly polarized.

2.10 A scheme to identify and give priority handling to distress and safety communications consistent with Articles 51 and 61 of the Radio Regulations shall be included if appropriate in the system design.

2.11 Systems requiring interconnection with public networks shall comply with CCITT Recommendations.