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# SYSTEM ARCHITECTURE FOR THE CANADIAN INTERIM MOBILE SATELLITE SYSTEM

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## ABSTRACT

This paper reviews the system architecture for the Canadian Interim Mobile Satellite Service (IMSS) which is planned for commencement of commercial service in late 1989. It also discusses the results of an associated field trial program which has been carried out to determine the limits of coverage and the preliminary performance characteristics of the system.

## 1.0 INTRODUCTION

In Canada, there is considerable momentum and commitment building towards a Mobile Satellite System (MSAT) implementation program; however there still remains a significant period of time before MSAT becomes a service reality. Since an immediate need exists amongst various industries for the types of services that are best delivered by mobile satellite technology, Telesat Canada is cooperating with specific user groups to develop a portfolio of mobile satellite services whose initial implementation will use the Inmarsat MARECS-B satellite and could last until the launch of a dedicated MSAT.

To this end, Telesat issued a Request for Proposal in July, 1987 which called for a complete hub messaging facility and an initial consignment of fifteen mobile data terminals which were intended to prove the IMSS concept prior to making available for procurement additional volume quantities of mobile terminals to offer commercial service in 1989. This service would permit fleet dispatchers to have regular updates of location and vehicle status information as well as the flexibility of transmitting and receiving general messages. This paper describes the IMSS system concept and architecture, and outlines the anticipated range of services and applications, systems design parameters, and projected system capacity. It also discusses the results of a pre-implementation field trial program which involved monitoring the reception of data transmission from the Inmarsat satellite in Eastern Canada during the fall of 1987.

## 2.0 SYSTEM CONCEPT

The IMSS uses a star network configuration to provide low-rate data satellite communication services to the mobile user community as illustrated in Figure 1. The initial coverage of this system is in Eastern Canada from 30° to 15° elevation angle as shown in Figure 2. The frequency of operation covers the entire WARC-87 allocation, i.e., 1626.5-1660.5 MHz for transmit and 1530-1559 MHz for receive with 5 kHz channel spacing.

In a configuration of over 4,000 mobile terminals, six 5 kHz satellite channels over the INMARSAT MARECS-B satellite are shared by the mobile terminals in the IMSS network. One of these channels, the outbound, is used by the hub to send network control information, signalling messages, and traffic information to all mobile terminals. Of the remaining five inbound channels, three channels are used to send position reports, one channel for two-way messaging and request, and one for text transfer.

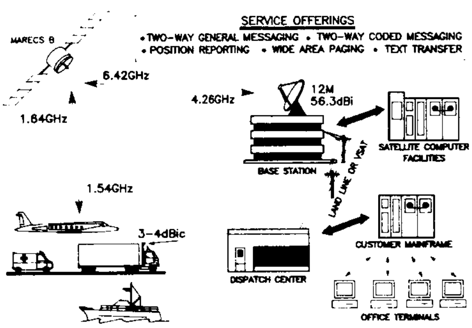


Figure 1: IMSS Service Illustration

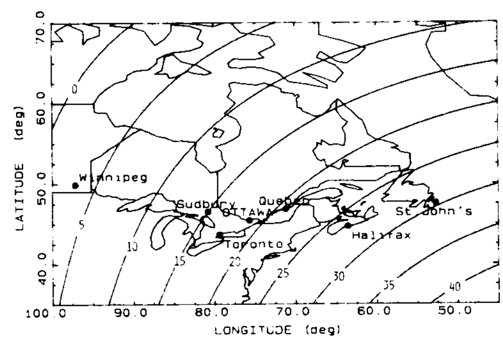


Figure 2: Canadian Coverage by MAREC-B

## 3.0 SERVICES

Three distinct services are planned for IMSS network which are explained in terms of the type of information, length of messages and traffic capacity objectives.

Vehicle location is the primary service planned for the system and is characterized by 7-character messages, representing vehicle position in terms of longitude and latitude to the second of degree plus a coded message, sent at periodic intervals of 15 minutes or multiples, from a population of over 4,000 mobile terminals. Vehicle position information is determined via the Loran-C receiver which is integrated with the mobile terminal. A mobile terminal failing to report its position on the scheduled slot or those whose transmission is lost due to fading conditions will repeat its transmission on a contention basis after being polled by the hub. This channel has a capacity of about 4000 position reports per hour.

Two-way general messaging is characterized by the transfer of messages of variable length with an average length of 32 bytes and maximum of up to 128 bytes, either from the hub to a particular mobile terminal or from a mobile terminal to the hub. In the mobile-to-hub direction, the messages are transmitted on the request/messaging channel on a reservation basis, where the first packet of each message is handled with a random access mechanism over the availible unreserved capacity of that channel. Subsequent packets, each containing 10 bytes of information, are sent over reserved slots on the same channel. An estimated 330 messages per hour with the average length of 32 characters can be accommodated on one channel.

Text transfer is characterized by transfer of relatively long messages in the order of 4,000 characters long. This service will be offered on a demand assignment basis by allocation of a dedicated inbound channel carrying consecutive 127 byte packets. This channel has a capacity of about 32.9 characters/second.

## 4.0 SYSTEM DESIGN PARAMETERS

Communication Modes: The key system parameters are summarized in Table 1 below. Eight communication modes are used in the system to provide high system throughput and efficient channel assignment. For example: (i) the inbound multi-packet modes provide the concatenation of several fixed length packets into a single message transmission by combining random and reserved slots in the request/messaging channel; (ii) the inbound scheduled mode is a low overhead method to send short messages from mobile terminals to the hub at periodic intervals and is used for the vehicle location service. Recovery from errors is performed by the inbound polling mode where a new polling command from the hub is sent to the mobiles after the expiration of a time out period.

| SYSTEM PARAMETER | Values & Applications |
|---|---|
| Modulation | BPSK |
| Symbol Rate | 1200 & 600 bps |
| Interleaving | (64 R X 162 C) |
| FEC Encoding | Rate 1/2 Viterbi , K=7 |
| Multiplexing | TDM,TDMA,S&R-ALOHA |
| Communication Modes: | |
| 1-Inbound Unsolicited | Log on/off & Request |
| 2-Inbound Scheduled | Position Reports |
| 3-Inbound Polling | Lost Position Reports |
| 4-Inbound Multipacket | Two-Way Messaging |
| 5-Inbound Demand Asg. | Text Transfer |
| 6-Outbound Broadcast | Network Control |
| 7-Outbound Unsolicited | Two Way Messaging |
| 8-Outbound Demand Asg. | Text Transfer |

Table 1: IMSS System Parameters

| | | OUTBOUND (1200 bps) | INBOUND (600 bps) |
|---|---|---|---|
| Earth Station EIRP | (dBW) | 60.8 | 16.0 |
| Path & Absorb. Loss | (dB) | 200.7 | 189.0 |
| Satellite G/T | (dB/K) | -15.0 | -10.6 |
| Uplink C/N0 | (dB-Hz) | 73.7 | 45.0 |
| Satellite C/I0 (Inter-Mod) | (dB-Hz) | 55.8 | 53.7 |
| Satellite EIRP | (dBW) | 21.6 | -21.8 |
| Path & Absorb. Loss | (dB) | 188.4 | 197.1 |
| Earth Station G/T | (dB/K) | -22 | 32.0 |
| Downlink C/N0 | (dB-Hz) | 39.8 | 41.7 |
| Nom. Unfaded C/N0+I0 | (dB-Hz) | 39.7 | 39.8 |
| Interference Loss (Adj. Sat.) | (dB) | 0.5 | 0.5 |
| Overall C/N0+I0 | (dB-Hz) | 39.2 | 39.3 |
| Overall Eb/N0+I0 | (dB) | 11.4 | 14.5 |
| Min. Unfaded Eb/N0+I0 | (dB) | 4.6 | 5.5 |
| Modem Implement. Loss | (dB) | 1.0 | 1.0 |
| Fade Margin | (dB) | 5.8 | 8.0 |

Table 2: IMSS Link Budget

Link Budget: With an omni-directional antenna adopted for the mobile terminal and having a minimum effective G/T of -22 dB/K, the link budget, Table 2, provides 5.8 and 8.0 dB margins for the outbound and inbound links, respectively, over the Eb/No needed for a $10^{-5}$ BER considered as the threshold requirement. The lower operation margin adopted for the outbound link is justified by the use of interleaving in this link and is supported by the field trial results to give adequate performance in non shadowed areas. In the inbound links where the relatively short burst transmission makes the use of interleaving ineffective, the higher operation margin of 8.0 dB has been adopted.

Frame Structure: Currently, several frame formats and packet structure options are being considered, of which a potential candidate is shown in Figure 3. The outbound TDM frame contains 639 information bytes which are used for network control, signalling and traffic information from the hub to the mobile terminals. Network control information broadcast by the hub to all mobile terminals is positioned within the first 48 information bytes following the frame synchronization words. The remaining 591 information bytes are available for fixed and variable length outbound packets. The frames for the inbound request/messaging and reporting channels have a period of 8.64 seconds which is divided into 14 slots, each capable of 10 bytes of information.

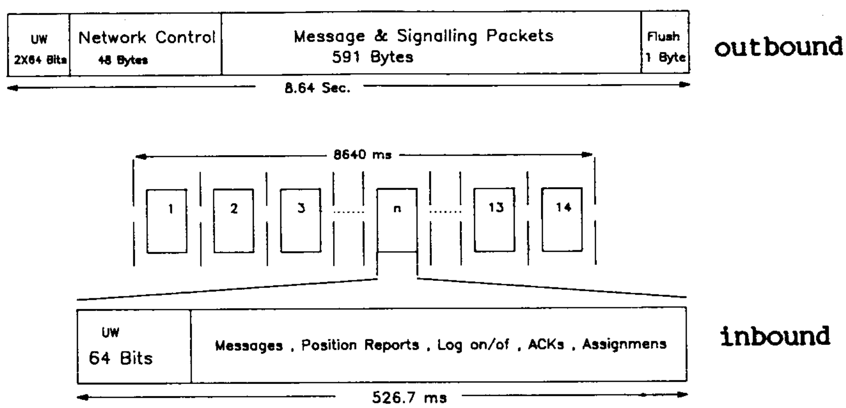


Figure 3: Frame and Packet Structure

## 5.0 SYSTEM CAPACITY

The estimate of system capacity for the IMSS network is shown in Table 3. Because of the nature of frame and packet structure, the capacities are expressed in terms of: (a) reports/second for the position reporting channel; (b) 10-byte packets/second for the messaging and request channel; and (c) bytes/second for the text transfer channel.

The position reporting channel has an available capacity of 1.62 reports/second which is split into 1.11 reports/second for the TDMA scheduled reports and .51 report/second for the retried reports. Based on this arrangement, the usable capacity of the system, reflected by the reserved capacity, is 4000 position reports per hour per channel.

Similarly, the request/messaging channel has a total capacity of 1.62 ten-byte packets/second but its usable capacity is .45 ten-byte packet/second, of which: (i) 0.09 packet/second is used for the first packet of the message and transmitted on a random access basis, and includes 20% random access and 90% ARQ efficiencies; (ii) 0.2 packet/second is the reserved capacity for subsequent packets of the message and includes only the ARQ efficiency; (iii) the remaining .16 packet/second is used for signalling purposes as part of other functions. These combinations will allow 330 messages with an average length of 32 characters plus 576 ten-byte signalling packets per hour. Should the average message length change, for example, from 32 to 96 characters, one can still accommodate the 330 messages per hour. However, the signalling capacity for other functions will drop to 144 packets per hour. Requirements exceeding the above limits would have to be accommodated by adding more channels to the network.

The text transfer channel is basically a demand assigned channel and can accommodate about 32.9 characters/second.

| Inbound | | | | | | | | | Outbound (Bytes/Sec.) |
|---|---|---|---|---|---|---|---|---|---|
| Request/Messaging (Ten-Byte Packets/Sec.) | | | | | | Position Reports/Sec. | | Text Transfer (Bytes/Sec.) | |
| Reserved | | Unreserved | | | | Reserved (Reports) | Unreserved (Retried) | Assigned | |
| | | Request | | Signalling | | | | | |
| 32 Char. Message | 96 Char. Message | 32 Char. Message | 96 Char. Message | 32 Char. Message | 96 Char. Message | | | | |
| 0.202 | 0.789 | 0.0916 | 0.0916 | 0.16 | 0.04 | 1.11 | 0.51 | 32.95 | 61.5 |

Table 3: System Capacity

## 6.0 FIELD TRIALS

<u>Operating Conditions</u>: To monitor the reception of data transmissions from the Inmarsat MAREC-B satellite in an actual land mobile operating environment, a prototype omni-directional mobile satellite antenna and receiver were procured and fitted into a van along with associated monitoring equipment. Signal reception was recorded as the van was driven along typical commercial routes from Quebec City (20°) to Winnipeg (3°). A personal computer was used to capture system performance data on a frame-by-frame basis directly to disk while a printer displayed any messages received.

Data transmission was from the Inmarsat Enhanced Group Call (EGC) channel which uses coherent BPSK modulation transmitted at 1200 BPS with rate 1/2 convolutional coding and constraint length 7. The frame length is 8.46 seconds long and starts with two packets of 40 and 14 bytes which are used to check channel performance and provide information on the frame, respectively. The rest of the frame capacity is left for messages, when no messages are sent, binary zeroes are transmitted instead.

The link budget for the field trials is similar to Table 2 with the following changes. There is an average gain in the satellite EIRP of 1.5 dB because the satellite was not operating at full capacity between 10 a.m. to 4 p.m. Eastern Canada time when daily field trials were being conducted. Also, there is no interference loss due to adjacent satellites and the antenna G/T was higher by 1 dB due to half duplex mode of operation. These changes result in an overall fade margin of 8.9 dB.

<u>Route Characterization</u>: Figure 4 shows a sample of Frame Success Rate (FSR) from Quebec City to Sudbury in two hour intervals and as such characterizes the typical commercial routes within the coverage limits of the IMSS. The FSR is either 0% or 100% for each frame received. Given the scale of the graph, one frame in error appears as a downward 'spike'. An outage, that is, no frame received, is indicated by the FSR 'disappearing' over the graph and 'reappearing' once reception has resumed. The number to the right of each two hour interval is its average FSR. The results indicate that reception is

very good until Sudbury with 15° elevation. Beyond that (not shown for the sake of brevity), system performance degrades due to the lower elevation angles and the very hilly terrain encountered just past Sudbury until the prairies are reached. The FSR is 94% (98% excluding outages) for greater than 15° elevation angles and 75% (97% excluding outages) for the entire field trials. For greater than 15° elevation, the ratio of the number of frames that were not received, due to outages, to the number received incorrectly was 2.7. For the entire area tested, this ratio was increased to 8. In general, outages were caused by complete blockage of the signal such as by a hill or building. A few more dB in fade margin would probably not improve reception in these areas. After blockage of the signal, it is likely that the receiver loses synchronization with the carrier. This can make the outage time longer than the blockage time. Thus, the length of time the receiver takes to reacquire synchronization is critical.

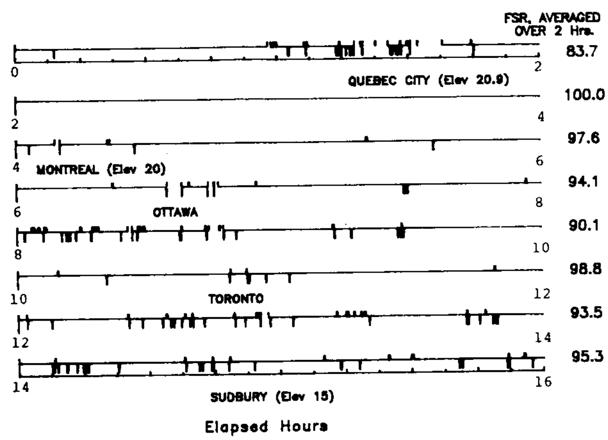


Figure 4: Propagation Measurements in Terms of Frame Success

Multipath Fading: The effects of multipath fading were studied in areas with no shadowing. Figure 5 shows a sample of the relative fade depth for a half-hour period approaching Winnipeg and Quebec City. The fade depth is relative to the fade needed to produce an error in a frame and is not identical to the fade margin because the fade margin is referenced to a BER of $10^{-5}$. Both the prairies and Quebec City fades are drawn to the same scale with the right vertical axis showing the number of renormalizations. This is the actual parameter measured within the decoder and is related to the fade depth in a non-linear fashion. Clearly, multipath was more pronounced at the lower elevation angle and the threshold for producing errors was exceeded a few times. Near Quebec City at 20° elevation, multipath is still present but the overall majority is within 3 dB of the error threshold.

Fade Margin Sensitivity: Given the importance of fade margin in system capacity and performance, the sensitivity of the system to a reduction in fade margin was investigated for elevation angles greater than 15°. Knowing the relative fade depth for every frame, we can simulate a reduction in fade margin (say by X dB) by assuming that any frame with a fade depth of X dB or more would have been received in error. Thus, the total FSR can be calculated for that reduction in fade margin. This is shown graphically in Figure 6.

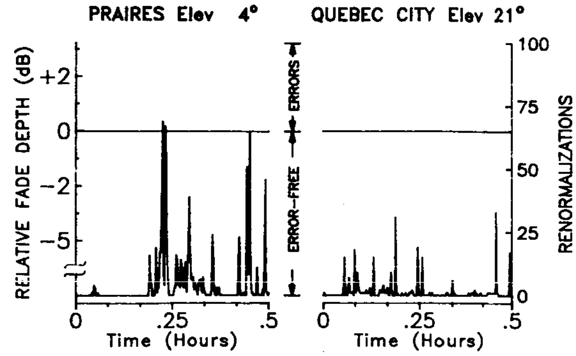


Figure 5: Effects of Multipath Fading Near Winnipeg and Quebec

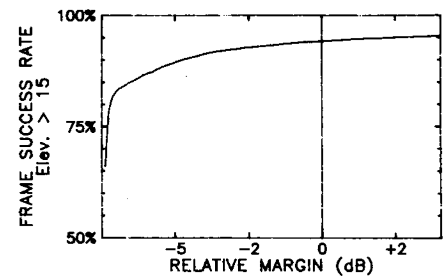


Figure 6: Frame Success Rate Vs. Margin Reduction

This assumes that, when the fade margin is reduced, the fade depth will remain the same. While this is true for shadowing, it is hard to predict for multipath fading because the depth of fade is related to the power of the signal (the exact relationship is dependent on the carrier to multipath ratio as well as the absolute level of the carrier). The worst case scenario is assumed that the fade depth remains the same regardless of a reduction in transmitted power (i.e. fade margin).

Keeping these limitations in mind, the graph shows that a reduction of 3.5 dB will reduce the overall FSR by 3%. This enables us to adopt, for the interim, a fade margin of 5.4 dB for the outbound channel subject to the second phase field trial results in the spring of 1988.

## 7.0 CONCLUSIONS

The interim mobile satellite services are viewed as an important and integral part of the Canadian mobile satellite program and serve a real purpose in achieving an eventual domestic MSAT system. Telesat is currently in the process of securing both space segment and ground segment facilities to meet the requirement of these services.

## 8.0 ACKNOWLEDGEMENT

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