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Telesat Canada

MSAT DAMA SYSTEM STUDY

TASK 19

PREPARED FOR

DEPARTMENT OF COMMUNICATIONS

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Submitted By: Telesat Canada

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TABLE OF CONTENTS

TABLE OF CONTENTS

(Continued)

TABLE OF CONTENTS

(Continued)

Appendices:

ABBREVIATIONS

AFC	Automatic Frequency Correction
ARBS	Active Ranging Burst Synchronization
BTR	Bit Timing Recovery
BH	Busy-Hour
BNR	Bell-Northern Research
CONUS	Continental United States of America
CRC	Communications Research Centre
DAMA	Demand Assignment Multiple Access
DA-TDMA	Demand Assignment Time Division Multiple Access
DS	Data Service
MRS	Mobile Radio Service
MSAT	Mobile Satellite System
MTS	Mobile Telephone Service
NCS	Network Control System
NMS	Network Management System
NPA	Numbering Plan Area
POTS	Plain Old Telephone Service
PSTN	Public Switch Telephone Network
RA	Reservation ALOHA
RAC	Reservation Assignment Channel
RRC	Reservation Request Channel
SA	Slotted ALOHA
SC	Switching Centre
SHF	Super High Frequency
Telco	Telecommunications Company
UHF	Ultra High Frequency
UW	Unique Word

Executive Summary

As part of a series of studies commissioned by the Federal Department of Communications (DOC) towards planning and implementation of a Mobile Satellite System (MSAT), Telesat was tasked to carry out a study on the various aspects of a Demand Assignment Multiple Access (DAMA) based mobile communications system. The present report is intended to describe the major findings of this study.

MSAT is intended to provide cost effective, spectrally efficient mobile services for voice and data communications across Canada. Due to the large number of mobile users characterized by bursty traffic and low activity factor, the system's available spectrum will best be utilized by a DAMA system. Users will request the use of a voice/data channel by communicating with DAMA via the appropriate signalling channels.

The MSAT system will be centrally managed by a Network Control System (NCS). The major constituent elements of the NCS are the DAMA and the Network Management System (NMS). The DAMA is responsible for short term network supervision while the NMS is in charge of the overall control of the MSAT system. The records regarding the usage of system equipments and resources would be gathered by the DAMA and sent to the NMS for billing purposes and to effectively plan long term system modifications and upgrades.

There are three major service categories for MSAT users; namely,

- Mobile Radio (voice) Service (MRS) to mobile communities of various sizes.

- Mobile Telephone (voice) Service (MTS) to mobile users requiring Public Switched Telephone Network (PSTN) interconnection.

- Data Services (DS) for one-way or two-way data transmission between a mobile and, other mobiles, base stations and PSTN subscribers.

To provide these services, four distinct types of channels are required within MSAT system;

- Access request channels
- Assignment channels
- Voice Channels (open-end half or full duplex)
- Data Channels (open-end for long messages and closed-end for packetized transmission)

For maximum system flexibility within and in transition between generations, satellite channel resources would best be utilized through a dynamic channel partitioning scheme. The DAMA will optimally distribute the satellite capacity in a manner consistent with the offered traffic from various user categories over a 24-hour period. This would permit realization of a more stabilized access protocol in the presence of unexpected traffic variations and a more orderly and rapid traffic transfer to a back-up satellite in the event of a catastrophic failure.

The system architecture should allow for modular design of the communication network as a means for timely infusion of new technologies. This will permit a smooth transition to the follow-on generations without requiring an unacceptably large capital outlay for the first generation DAMA.

A centralized DAMA controller colocated with the MRS Switching Centre (SC) is presently viewed to be the preferred approach in conjunction with a distributed structure for the MTS gateway stations. The MRS SC is responsible for channel switching for double-hopped calls, and for monitoring the channels. A similar DAMA architecture for Canada and U.S. is highly desirable to allow sharing a greater portion of the non-recurring engineering and software development costs. However, a joint DAMA back-up capability is a concept which requires further detailed trade-off studies to quantify the real advantages as well as the associated cost implications for both systems.

The numbering plan is one of the major design issues for MSAT system. The MRS and MTS are quite distinct in terms of the type of connections they provide to their respective users. The MRS numbering plan can be an innovative one to connect users within a community. However, the proposed MTS numbering plan should satisfy the following criteria:

- compatibility with the existing PSTN
- minimization of toll charges

The most cost effective solution for MSAT users appears to be a single dedicated area code for MTS services which would be shared with all MSAT operators in North America.

The performance of the signalling channels among the various components of the DAMA has been investigated for two candidate access techniques: namely, Reservation ALOHA and Slotted ALOHA, with Token scheme. The key issues considered in the selection of the most appropriate access scheme are:

- the number of signalling channels to support the expected traffic load
- the delay experienced for a successful call set-up
- stability of the channels
- terminal complexity

The relative performance of the above schemes has been studied under the following operational conditions:

- UHF mobile users in geographical areas limited by 15° elevation angle to the satellite
- UHF mobile users in areas limited by 20° elevation angle
- L-band mobile users in areas limited by 20° elevation angle

The results of these studies indicate that a combination of Slotted ALOHA scheme for call requests and Token scheme for ACK/on-hook/off-hook signalling is the optimum approach as opposed to a combination of Reservation ALOHA and Token schemes.

There are a number of issues to be studied further as the MSAT project progresses. The complete discussion of these issues was not in the scope of this report. The areas to be explored are:

- MTS numbering plan
- statistics regarding the required data services
- trade-offs regarding a joint back-up agreement with U.S. licencee(s)
- DAMA hardware
- NMS characteristics and its role in MSAT system
- billing requirements and regulations
- study of a dual-band DAMA for combination of UHF and L-band services
- study of signalling requirements for SHF signalling channels.

1.0 INTRODUCTION

As part of a series of studies commissioned by the Federal Department of Communications towards planning and implementation of a Mobile Satellite System (MSAT), Telesat was tasked to carry out a study on the various aspects of a Demand Assignment Multiple Access (DAMA) based mobile communications system. While building upon the previous work on the subject matter, the emphasis was to examine the operational facets of DAMA which were deemed to have first order effect on the system's overall efficiency and flexibility. The present report is intended to describe the major findings of this study.

To carry out the task at hand, a detailed review of the background work [Ref. 1 - 2] was conducted as the starting point. The critical assumptions postulated along with the basic data used in these references were carefully scrutinized to ensure their validity and continued relevance to the MSAT System concept as defined today. Areas in need of update or further analysis were identified and followed by appropriate steps to generate updated results or new information.

A sizeable effort was directed toward analysis and quantifying the effectiveness of various access protocols relative to the proposed scheme in [Ref. 1 - 2]. In order to avoid clouding the main issues, detailed description of the interworking of DAMA has not been included here as it could readily be found in the background material. In this report, however, major departing points from Ref [1 - 2] are the areas which have been attended to in detail and are further supported by supplementary analysis and results in the form of a series of appendices.

1.1 Background

Mobile Satellite System (MSAT) is intended to provide cost effective spectrally-efficient mobile services for voice and data communications across Canada. The system is intended to complement terrestrial mobile alternatives (e.g., cellular mobile radio) over the areas which are considered to be beyond their commercial reach. Due to large number of mobile users characterized by bursty traffic and low activity, the satellite capacity will best be managed by a DAMA system. Users will request the use of a voice/data channel by communicating with the DAMA via the appropriate signalling channels.

The DAMA, together with the Network Management System (NMS) will form the major part of the Network Control System (NCS). The DAMA is responsible for short supervision, while the NMS is in charge of the overall control of the MSAT system. The main emphasis of this report is on the DAMA System.

The following major service categories will be supported by the MSAT DAMA System:

Mobile Radio Service (MRS)

This service provides voice communications between mobiles, other mobiles and base stations. The voice channels operate in a half-duplex, push-to-talk mode or a full-duplex mode. Voice activation is assumed. The channels are pooled together and will be assigned to the users on the basis of priority and availability when requested.

Mobile Telephone Service (MTS)

This service provides voice communications between a mobile and, other mobiles and Public Switched Telephone Network (PSTN) subscribers via gateway stations. The voice channels are voice activated full-duplex and will be assigned in the same manner as MRS.

DATA Service (DS)

This service provides data communications between a mobile and, other mobiles, base stations, gateway stations and PSTN subscribers. The data channels operate in one-way or two-way (full-duplex) mode depending on the type of DS required.

The major DAMA system design considerations for MSAT are:

i) Network architecture - centralized or distributed configuration.

ii) Access scheme to the network satisfying the user and system requirements - dynamically assigned or fixed signalling channels.

iii) Call set-up/take-down and communication channel assignment procedures.

2.0 DAMA SYSTEM DESCRIPTION

In this section a brief description of the general DAMA system is presented. The purpose is to outline the various components of the system as well as their intended roles. The traffic statistics and user requirements are introduced in this section.

2.1 System Components

The ground segment facilities of MSAT may be divided into five major categories:

i) The DAMA processor

The DAMA processor is tasked with processing individual calls handled by the system and as such has the following responsibilities:

- Bookkeeping of all the activities of the registered users
- Providing the appropriate communications to those users logged-on to the system at anytime
- Handling and processing any call requests by the system subscribers
- Monitoring and controlling the system resources (communication channels) to ensure an optimized performance
- Collecting billing information
- Providing the overall network activity records to the NMS

ii) MRS Switching Centre

The MRS Switching Centre (SC) is primarily responsible for providing channel switching arrangements for double-hopped calls. The secondary responsibility of SC is to monitor the channels upon DAMA's request and report their activities to the DAMA. The SC would best be colocated with the DAMA processor; an arrangement which permits direct interfacing through a common bus.

iii) MTS Gateway Station

The MTS gateway stations are interfaced with the PSTN to allow for communication between MSAT MTS users and PSTN subscribers. As it will be discussed in the section devoted to numbering plan alternatives, the MTS gateway stations will be distributed across Canada to ensure the optimum usage of the terrestrial links to interface with PSTN.

iv) Mobile Terminals

Mobile users will be equipped with a mobile terminal communicating via 5 kHz channels. There will be three basic types of terminal.

- Mobile radio terminals provide MRS services among mobile users and base stations.

- Mobile telephone terminals provide MTS services among mobile users and PSTN subscribers.

- Mobile Data terminals provide data services among data terminals and base stations.

v) Base Stations

The base stations are defined as the dispatch centres for user groups subscribing to MRS services. It is required that every MRS user group consist of at least one base station and a number of mobile users. It is expected that up to 95% of MRS traffic will be between base stations and mobile terminals.

The ratio of mobile users-to-base stations varies significantly between various mobile communities (current trend is 40 to 1, from [1]). However, the total traffic offered to the system from base stations on the average is assumed to be of the same magnitude as that of the mobile users. The ratio of the offered traffic from base stations is a critical parameter which has a direct impact on the required on-board satellite power. However, based on the limited market information available on the base station traffic statistics, a 50 - 50 aggregate distribution appears to be a reasonable assumption. Another factor which directly affects the DAMA and the required number of signalling channels is the percentage of calls initiated by the mobiles. For the purpose of this study a ratio of 50 - 50 has been assumed.

At the initial stage of studies in [1] two different types of base stations, namely UHF and SHF base stations, were considered due to the projected high cost of SHF base stations. However, as a result of the recent large scale commercial development of the Ku-band transmit receive terminals, the cost of SHF base stations is projected not to be significantly higher than UHF base stations. The drastic cost reduction in the relevant

Ku-band hardware and the resulting savings in the required spacecraft power has led Telesat to baseline a UHF-SHF/L-band-SHF only system. A further advantage to such a payload configuration is the fact that 50% of the total traffic between mobiles and base stations is contributed by the SHF base stations which will access the SHF signalling channels and as such fewer UHF signalling channels would be required.

2.2 System Coverage

The MSAT system is designed to provide Canada-wide coverage, including territorial and coastal waters up to the 200 nautical miles limit. According to the baseline system specifications, this area will be covered by two UHF spot beams and four L-band shaped beams and a single SHF footprint encompassing the entire region. In the subsequent generation systems, multiple SHF beams may be considered to allow for expansion of the system. Figure 2.1 shows MSAT beam coverage at UHF and L-band which is foreseen for the first generation.

2.3 System Channelization

For the baseline system, all UHF uplink channels will be upconverted into SHF downlink channels. For an option under review, a small portion of these UHF uplink channels could be cross-strapped at the satellite to UHF downlink channels and provide UHF-UHF cross-strap within a given UHF spot beam. The majority of SHF uplink channels will be downconverted into UHF downlink channels, while a small portion will be transponded at the satellite to SHF downlink channels.

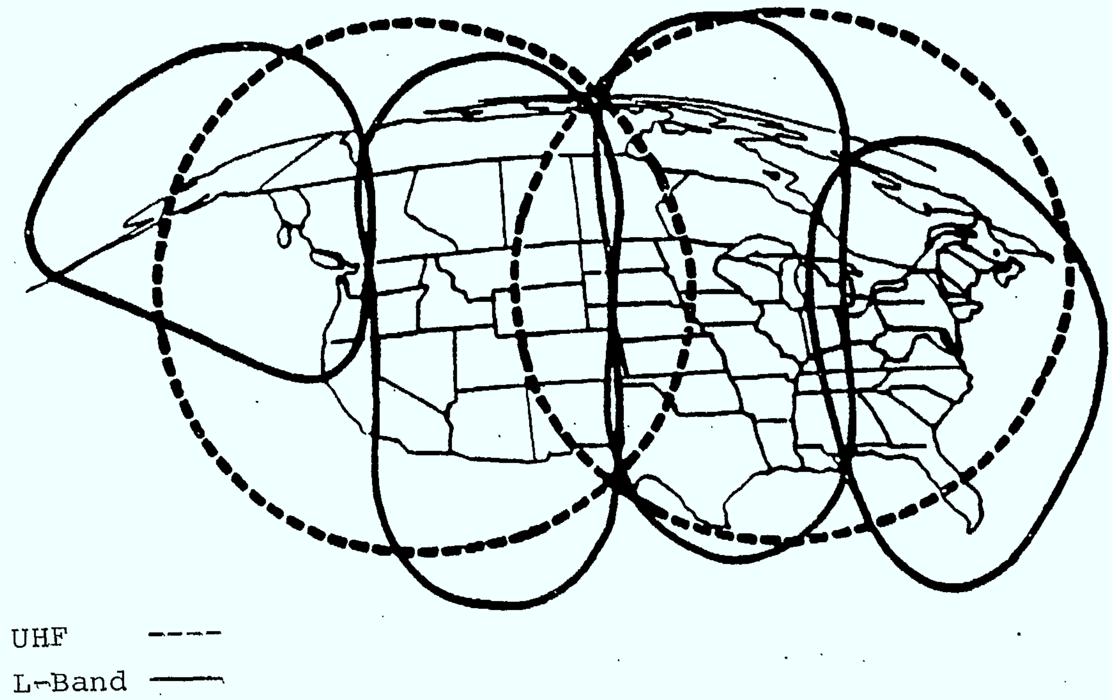


FIG. 2.1 MSAT Beam Coverage

The above channelization would provide three types of link as discussed below.

i) UHF-SHF (and SHF-UHF)

The UHF-SHF/SHF-UHF links would provide direct connection between mobile users and SHF base stations, gateway stations and DAMA processor. The combination of UHF-SHF and SHF-UHF links would result in double-hop connection among mobile users.

ii) SHF-SHF

The SHF-SHF cross-strap is solely provided for signalling and data exchanges (or possibly very limited number of supervisory voice links) among DAMA Centre, gateway stations, NMS and SHF base stations.

iii) UHF-UHF

The UHF-UHF cross-strap is a possible option which would provide direct connection among mobile users within a UHF spot beam. This would provide the user with a shorter delay experienced during the conversation period. However, only 3.38% of traffic is expected at this point in time to involve direct communication between two MRS mobiles within a beam when there are no UHF base stations (figure 2.2). But, due to the half duplex push-to-talk conversation mode envisaged, the difference of delay for single hop and double hop links most likely is undetectable.

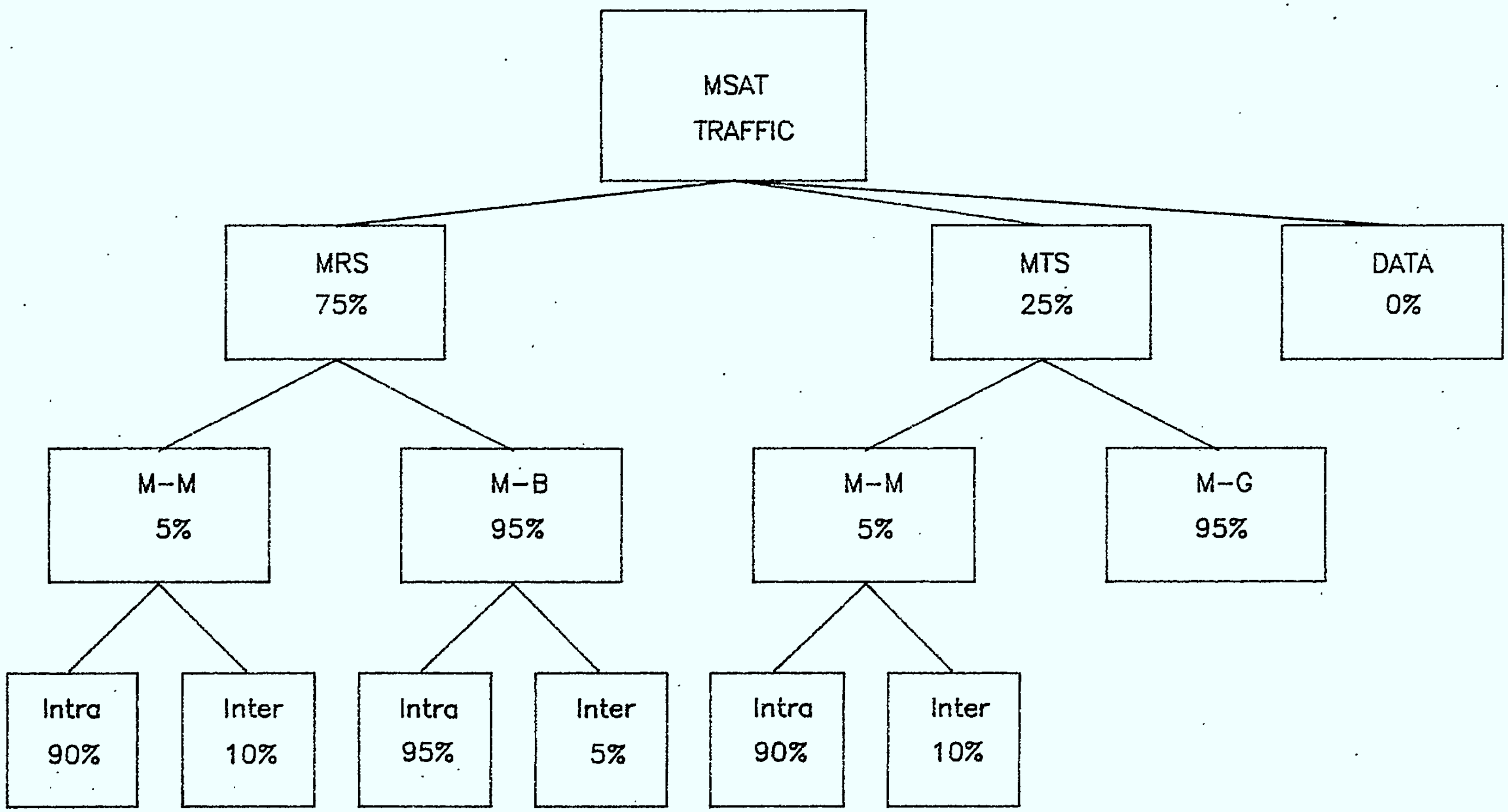
As mentioned previously, the cost of SHF base stations is currently forecasted to be comparable with that of UHF base stations; therefore, the majority of the users would utilize UHF-SHF links which require significantly less satellite power. Moreover, the SHF base stations would access the SHF signalling channel(s), a factor which would contribute further into conserving UHF power and spectrum. The questionable advantage afforded by the possible UHF-UHF option should, therefore, be carefully weighted against its disadvantages in the form of increased satellite resource implications, spacecraft hardware, DAMA complexities and vulnerability to unauthorized access of the satellite.

The above explanation could be applicable to L-band channels when they replace UHF channels.

2.4 Traffic Statistics

The traffic per user is computed according to the analysis given in [2].

The average busy-hour (BH) offered traffic at System saturation is 0.0106 Erlangs/mobile user. The MSAT baseline system will have sufficient capacity to accommodate 35,000 mobile users subscribing to UHF services and 25,000 users subscribing to L-band services at the point of system saturation. Assuming uniform distribution of mobile users among the two UHF beams, there will be 17,500 users/beam. Figure 2.2 describes traffic distribution among various services offered within MSAT. The expected percentage of the traffic generated by UHF and SHF users is included in Figure 2.2, as well as the number of one way UHF voice channels involved in every call scenario.



UHF gen.	100%	100%	50%	50%	100%	100%	75%
SHF gen.	0	0	50%	50%	0	0	25%
No. of voice ch. per call	1	2	1	1	2	2	1

FIGURE 2.2 MSAT TRAFFIC DISTRIBUTION

Assuming MRS average call holding time of 20 seconds and MTS average call holding time of 180 seconds, there will be 6.3 calls per beam per second. It could be broken down to 3.36 UHF originated and 2.94 SHF originated calls per beam per second. The computation analysis is given in Appendix A. The above UHF call generation rate does not include the log-on, log-off and ranging (explained in section 4.5) requests by mobile users. It is assumed that the majority of the log-on and log-off message transmissions will be attempted during the non-BH period. However, the ranging messages are transmitted during the BH period. As discussed in Appendix A, the total number of UHF originated calls and messages on access channels will be 3.97 per beam per second.

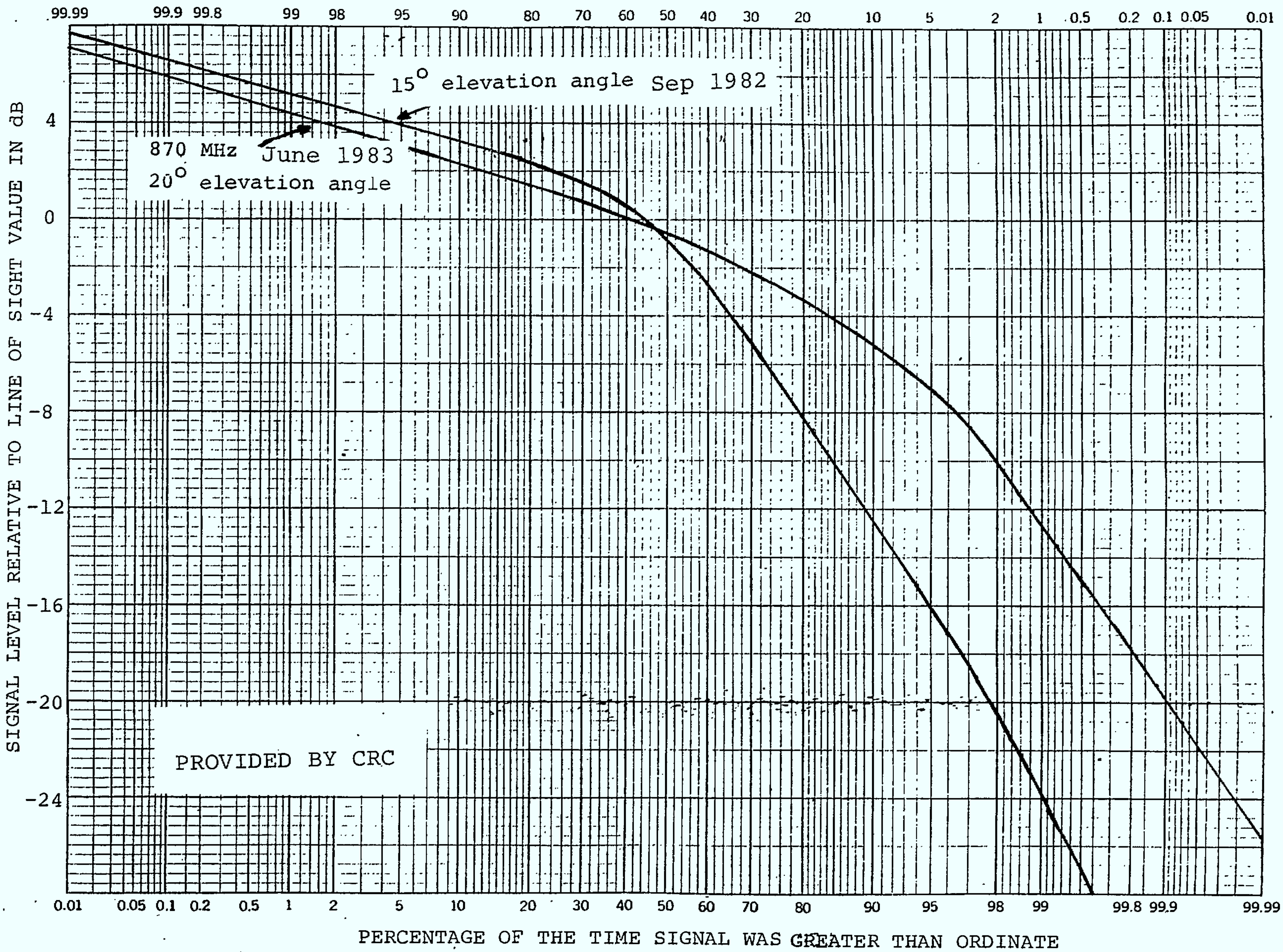
The offered traffic characteristics is assumed to be in accordance with the assumptions of Erlang B (blocked calls cleared) and the grade of service (G.O.S) required at system saturation during BH is to be 15% for the successful call request attempts, p(0.15). It is to be noted that since alternate routing for blocked calls is not available within MSAT, the blocked callers will reattempt. This will result in an effective G.O.S. in the neighbourhood of 20%.

2.5 Propagation And Fade Statistics

Excess path loss in the satellite-to-vehicular terminal link is due mainly to two mechanisms: shadowing by terrain obstacles, and multipath fading. This excess path loss is higher for mobiles at lower elevation angles to the satellite. Communication Research Centre (CRC) has carried out a series of measurements to determine the fade statistics for MSAT at 800 MHz and L-band. The results of these measurements have been presented in reference [3] for 800 MHz, and reference [4] for L-band. The fade statistics at UHF were collected in September 1982 and June 1983. However, some of the measured results of June 1983 did not agree closely with those of the September 1982 results, Figures 22 and 19 of [3] respectively. In the reference, this discrepancy between the two sets of data was attributed to the heading variation of the helicopter used for June 1983 test, and the non constant azimuth pattern of the transmit antenna. As a result, CRC concluded that the fade statistics for 15° elevation angle of June 1983 were in error. Therefore, in this study, the 15° elevation angle fade statistics of September 1982 experiment were used, while for 20° elevation, those of June 1983 were employed. Figure 2.3 shows these fade statistics. Note that their data were collected from routes for which woodland constituted up to 35% of the land area.

A recent subjective test conducted by BNR has indicated that the baseline MSAT link budgets would result in an acceptable performance for the UHF mobile users operating over the areas limited by 20° elevation angle (approximately 70% of the Canadian land area). For regions beyond this limit with similar vegetation characteristics, lower performance should be expected if the link parameters are to be kept unchanged relative to the baseline design. As far as the performance of the signalling channels is concerned, this report will analyze both operational environments characterized by 15° and 20° elevation angles. Given the available measured propagation data, there appears to be 10 - 11 dB more shadowing losses at 15° elevation angle relative to the 20° case for occurrence probabilities in the range of interest.

FIGURE 2.3 Cumulative Probability Distribution Function at UHF



2.6 Billing

In the MSAT system, the information regarding the usage of system equipment and resources would be recorded and then sent to a specific peripheral supervisory unit. These records would be used for billing purposes as well as gathering statistics to effectively plan long term system modifications and upgrades.

The MSAT subscriber bills are expected to be similar in format to North American Telco bills. However, in the absence of location detection capability via MSAT, due to lack of information regarding the mobile users exact geographical location, more detailed billing information may be required to convince users that they are justly charged. The following information list would be suitable:

- Calling and called party's telephone numbers
- Call type (point-to-point, broadcast)
- Call priority
- Call start and stop times (date, hour, minutes, sec)
- Call termination status; if aborted, after how long
- Indication of services provided such as the existing ones within Telco systems. Examples are: collect calls, directory assistance person-to-person calls, etc.
- Indication of services provided for features similar to those of answering service equipments.
- Rates used for every call as well as any discounts where applicable.

The billing information for MRS services would be solely used by the MSAT operator; however, the MTS billing information should consist of the information gathered by the MSAT system and those provided by the interfacing Telco(s). Telco would bill the MSAT operator for the total amount of its resources which have been utilized by MSAT subscribers. Telco will not bill the MSAT subscribers. The bill generated by Telco must include all the information necessary for every individual call to be processed by the MSAT operator towards generation of the individual bills for MSAT subscribers. Similarly, the MSAT services provided to Telco subscribers would be recorded and the Telco would be billed directly with an invoice providing all the necessary information regarding every individual call. Telco would process these records and bill its subscribers accordingly.

2.7 Network Performance Specifications

The network design parameters are taken from Ref [1], but the call set-up response time was modified to reflect the redefinition of this term. Moreover, the required grade of service (G.O.S.) at system saturation during the BH has been changed to 15% (Erlang B) to be in line with the current baseline system specification.

Definition of performance objectives within the context of this report:

- Probability of rejection on request channel:

  A call request packet may be damaged due to collision with another packet, or lost due to multipath and shadowing. The probability of a call request which is unsuccessful after 3 retransmissions and is considered to be rejected.

- Grade of service:
  The probability of a successful call request being blocked due to unavailable communication channels.

- Probability of call missed:
  The probability of a call missed due to a bit error in the unique word portion of a packet.

- Probability of connection to wrong party:
  The probability of wrong connection due to undetected bit errors in a packet.

- Call set-up response time:
  The period starting from the moment that a user finishes dialing and starts transmitting until he receives the final acknowledgment indicating that DAMA has successfully received the call request.

- Log-on response time:
  The period from the moment that the terminal is turned on till reception of log-on response message from the DAMA by the terminal.

Table 2.1 outlines the preliminary values for primary parameters considered in the DAMA system design.

TABLE 2.1 DAMA Network Performance Specifications

Performance Objectives	Specification
Probability of rejection on request channel (after 3 attempts)	≤ 1%
System saturation peak BH overall G.O.S. (Erlang B behavior)	≤ 15%
Probability of call missed due to bit error	≤ 10^{-4}
Probability of connection to wrong party due to undetected error in a packet	≤ 10^{-7}
Call set-up response time	≤ 3 sec
Log-on response time	≤ 10 sec

3.0 System Design

3.1.0 System Architecture

The system architecture has been extensively investigated in previous studies of [Ref. 1-2]. A brief description of the selected architecture will be given here.

As discussed in Section 2.1, there are two types of gateway stations. Since all UHF uplink channels are most likely transponded to SHF downlink channels, one centralized MRS SC would be sufficient to switch the downlink SHF channels to their uplink pairs in the SHF beam. The monitoring procedure could also be handled by the same station. However, the MTS gateway stations are distributed across Canada to provide the shortest terrestrial link to major PSTN subscriber centres and optimize the cost of toll charges against MTS gateway stations cost. The MTS gateway stations could be utilized to concentrate traffic from land linked base stations.

The MRS SC must be equipped with its own built-in backup system. However, the MTS gateway stations must be designed to reroute their traffic to other stations in case of failure, or, handle traffic rerouted from other stations via terrestrial links.

The DAMA controller functions are as outlined in section 2.1 and it is recommended to have a centralized controller which would perform these functions as detailed in Ref [3]. The DAMA controller will be colocated with MRS SC and will have a multi-processor structure internally. The processing of the DAMA functions are divided up into separate groups of activities per beam. Every processor will be in charge of one beam and there will be interconnection among the processors to carry out inter-beam activities. This structure could be easily expanded to provide a dual-band DAMA System.

3.1.1 System Flexibility

In order to facilitate development and expansion of the DAMA associated hardware and software in the course of system evolution, it is prudent to adopt a modular implementation structure from the outset. Such an approach towards implementation of traffic dependent facilities would ensure that planned investment in terms of the required hardware as well as the control software can grow commensurate with the anticipated revenue. Furthermore, timely infusion of new technology could then become feasible without requiring a major redesign of the entire DAMA structure.

3.1.2 System Reliability

Reliability of the DAMA is of paramount importance to the survivability of the MSAT system. As the major coordinating element of the MSAT overall control system, a high availability objective of the order of 99.99% of the time is currently targetted for the DAMA. In order to attain this objective, a highly automated maintenance process must be put in place. The NMS through the use of a number of automated hardware and software maintenance facilities will ensure realization of a rapid and reliable fault recognition, recovery and diagnostics process. Critical units whose operation would directly affect the traffic carrying ability of a major portion of the MSAT system will be duplicated within a highly efficient and mechanized interconnecting redundancy switching network. Dedicated beam processors will control and mediate the signalling and traffic connections within each beam. They will be autonomous in performing certain error-detection, correction and quarantine functions in relation with faulty subsystems. In addition, each beam processor may be assigned the responsibility of monitoring the condition of other processors for failure recovery purposes. A central processor will be responsible for interbeam signalling and interconnection as well as ultimate control and reconfiguration of the system's hardware and associated control software.

In the event that a joint operating agreement can be reached with the U.S. MSAT operator and provided that the two DAMA systems are identical, a higher degree of reliability could be attained by requiring each DAMA centre to be capable of managing the entire spectrum of both systems. However, the increased reliability afforded by such an emergency back-up approach needs to be carefully traded off against the additional cost that would be incurred in provision of two fully interconnected DAMA centres.

3.2.0 Numbering Plan

The MTS and MRS services are quite distinct in terms of the type of connections they provide to their respective users. The MTS numbering plan must be compatible with the PSTN because of interfacing with telephone subscribers. However, the MRS numbering plan can be an innovative one to connect users within a community to each other.

3.2.1 MSAT MRS Numbering Plan

Method 1:

The proposed plan discussed in [1] provides 4,761,180 telephone numbers. The growth of different size communities is restricted to the class they belong to. There are four different classes as described below:

Class	No. of Communities	No. of Terminals
1	90,000	9
2,3	18,000	81
4,5	1,800	729
6,7	180	6561

For example, if a community-of-interest requires 100 terminals, it has to register as a class 4 or 5 and occupy a block of 729 telephone numbers. As a result, 629 numbers would be wasted until this particular group expands and utilizes the block by 100%. Any further expansion of this group would be restricted unless it upgrades its class to 6 or 7. Apart from the problems associated with change of a class, the major disadvantage would be now occupying a block of 6561 telephone numbers (if available). There is no smooth transition, due to expansion, from one class to next and conservation of valuable telephone numbers is not possible.

Method 2:

The other alternative to the above proposal is a method that provides a conservative numbering plan as the group expands. The community sizes are equal to 9n (where n = 1 to 81). A telephone number is defined as:

7 digits = NXX-XNNN

where N = 1 - 9
X = 0 - 9

The possible number of users accommodated within this numbering plan is 6,561,000. A non-uniform numbering scheme is used to accommodate the different size user groups. This scheme would reduce the dialing requirements by allowing the users to dial fewer digits to set up a call with another user within the same group. For example, the users belonging to a group identified by 234-56NN can access any user within their group by dialing only the last two digits (i.e. 11-99 except those numbers ending with 0). The terminal would fill in the rest of digits (234-56) required for the group. The use of 0's in telephone numbers is reserved for the set up of a broadcast call to a subnetwork or community-of-interest. For example, the users in above group can dial any of the following digits to make a broadcast call:

dialed digits	broadcast call to users with last two digit
10	11 to 19
20	21 to 29
.	
.	
.	
00	11 to 99

Table 3.1 explains the assignment of numbers and functions implemented into this method. For the communities of larger than 729 users two alternatives exist.

1) If there are too many of these large communities, then the numbering plan could be modified to NXX-NNNN which allows for groups of larger than 729 users.

2) Otherwise, two blocks of numbers could be assigned to these user groups. As an example, the block of telephone numbers associated to one of these communities would look like 345-6NNN ---345-7NNN. The first block provides 729 telephone numbers and second block can accommodate 9 to 729 additional numbers.

In this numbering plan, the highest most significant number (the seventh number) is 9 rather than 7 as suggested in [1]. As a result, the terminal I.D. sub-frame must be 24-bit long rather than 23-bit. An increase of 1,312,200 telephone numbers is achieved by adding one bit to the terminal I.D. sub-frame.

TABLE 3.1 Terminal Identification Numbers
and
Functions Provided Within Method 2

Telephone Numbers	Size of Community	Call within the Community *	Broadcast Call
3456111 -- 3456119	9	1-9	0
3456111 -- 3456129	18	1-29	0,10,20
3456111 -- 3456139	27	1-39	0,10,20,30
. . .	. . .	. . .	. . .
3456111 -- 3456199	81	1-99	00
3456111 -- 3456999	729	1-999	000

* Except any number used for a broadcast call.

3.2.2.0 MSAT MTS Numbering Plan

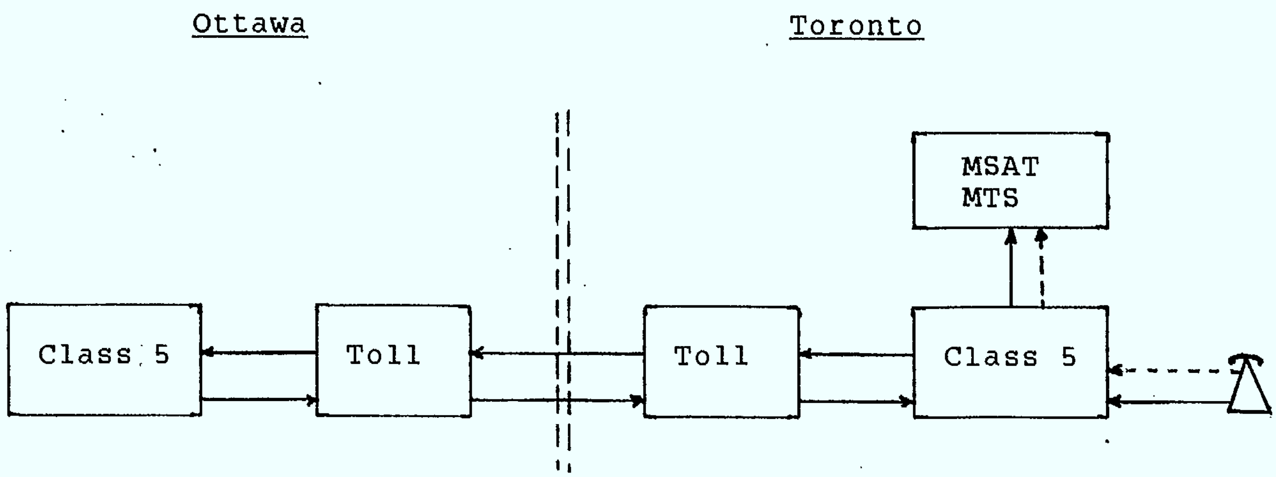
There are several alternatives for assigning numbers to the MTS mobiles that are compatible with the PSTN numbering plan as described below.

i) POTS Numbers

Integrate the MSAT MTS mobile address into the Plain Old Telephone Service (POTS) local telephone numbers for the user's home locality in the PSTN. The user's home location is the geographical home, not the gateway location. It is not practical to assign numbers based on the gateway location, because as gateways are added, the work and customer annoyance caused by changed or rearranged numbers is undesirable. At the same time, the PSTN party would have to pay unnecessary high toll charges if the gateway is in his geographical home while the called party is registered in another NPA and uses the gateway located in call originators area. The following scenario describes the shortcoming of this alternative.

The mobile number would consist of 10 digits made up from the area code and a 7-digit telephone number from the PSTN locality. As a result, the packet size for messages would be 165 bits long. This will have a direct relationship with the increase of generated traffic on signalling channels and require more signalling channels.

Scenario 1: MTS user is registered in Ottawa and the closest gateway is in Toronto. A person in Toronto calls MTS user.



Present Sequence of Events (Solid Line):

1. Toronto originates call through class 5 office to Ottawa.

2. Class 5 office in Ottawa recognizes the call as being to an MSAT user and routes to the MSAT gateway that handles the Ottawa area (Toronto).

3. The call would be routed back to Toronto and then through a class 5 to the MSAT gateway station.

Preferred Sequence of Events (Dash Line):

1. Toronto originates call through a class 5 office in Toronto.

2. Class 5 office recognizes the call as being to an MSAT user and routes the call to MSAT gateway station.

ii) <u>Dedicated NXX</u>

Assign a dedicated central office code (NXX) for each home locality in the MSAT MTS network (where N represents digits 2-9 and X represents digits 0-9). The area code (NPA) would be the PSTN NPA for the MSAT user's home locality. A dedicated NXX for each gateway is not a viable alternative since as gateways are added MSAT MTS numbers would have to be changed and routing would have to be rearranged.

iii) <u>Dedicated NPA</u>

Assign a unique area code (NPA) for MSAT MTS. Mobiles would be assigned 7-digit numbers by the company providing MSAT MTS Services. A new coordination and administration procedure with the existing numbering plan co-ordinators would be required. The required message packet size would be shortened to 150 bits. In addition, less signalling channels would be necessary.

3.2.2.1 <u>Analysis of Above Alternatives</u>

In the following analysis of numbering plan alternatives, several considerations are taken into account: Provision the least expensive terrestrial link cost; growth of MSAT user population; customer needs; efficient use of the NPA (code conservation); ease of implementation; and impact on the existing PSTN.

i) POTS Numbers

Advantages:

- Few changes required in the PSTN equipment.
- Existing billing and routing procedures.
- Makes efficient use of PSTN numbering plan, since MSAT MTS will have few subscribers per locality at the beginning of providing the services.
- No special dialing to reach MSAT mobile.
- Low cost to implement and administer for Telco.

Disadvantages:

- Landline customers have no indication that a call is to an MSAT mobile.
- Landline originated calls must go to the called parties "home" gateway; therefore, unexpected toll charges result if the gateway is far from the call originator. This may be considered by customers as an undesirable penalty.
- The address sub-frame in the packet must accommodate 10 digits (34 bits) rather than 7-digits (24 bits). More signalling channels would be required or the call set-up/take-down delay would be increased.

ii) Dedicated NXX

A dedicated NXX has approximately 10,000 numbers available for assignment to MSAT MTS users.

Advantages:

- MSAT MTS numbers are identifiable in every NPA for special routing.

Disadvantages:

- Rating and routing procedures may be changed in the PSTN.
- Applying for dedicated NXX from numbering plan co-ordinators
- PSTN switching equipment may be modified.
- More costly changes to the PSTN than Case i.
- High toll charges result for PSTN originated calls to a mobile registered in an NPA other than originator's NPA.
- Similar disadvantages to Case i as far as the number of signalling channels are concerned.

iii) <u>Dedicated NPA</u>

The same considerations as in Case ii apply. Considering the relatively few customers (20-40,000), this could be an inefficient use of the PSTN numbering plan at the start of life of MSAT. Therefore, it would be hard to get approval from the numbering plan co-ordinators for this plan. The use of a dedicated NPA would require 10-digit dialing to or from all landline customers. Implementation may be more costly and take longer than the previous alternatives since every switch would have to be modified.

Advantages:

- The toll charges would be decreased extensively.
- There will be no need to modify the system and reassign new numbers to customers in future.
- Call set-up/take-down delays would be decreased.
- The required message packet size would be decreased to 150 bits which results in less number of signalling channels.

3.2.3 Recommendation

Integrating the MSAT MTS mobile numbers into the existing POTS numbering plan (Case i) causes the least impact on the current routing and rating procedures and the least equipment cost, but the toll charges would be high as well as call set-up/take down delays.

Number assignment would be at the discretion of the individual Telcos across Canada, since national coordination is only required for NPA assignment. A dedicated NXX (Case ii) has almost the same disadvantages as Case i.

As a result, Case iii is recommended for the MSAT MTS numbering plan. As the system expands, there would be one gateway in every city. The PSTN originated calls would be routed to the closest gateway, while according to Case i they must be routed to "home central office" of called party, and then routed to "home gateway". Dedicated NPA would involve very low toll charges. The MSAT MTS calls are identifiable and the required number of signalling channels would be reduced. This alternative requires one NPA for both Canada and the US.

3.3.0 Signalling Requirements

So far the various components of the DAMA system have been described. The interconnection among these components is one of the most important issues in optimizing the system design and is defined in this section. The main emphasis is on the interconnection between mobile users and the other segments of the system. Mobile users will communicate via the UHF links. The signalling among the DAMA processor, gateway stations, and base stations is considered to be over the SHF links or in some cases they may interface using land lines.

There are four different types of channels:

- Request Channels used by mobiles to make requests to the DAMA System

- Token channels used by mobiles to transmit OFF-hook/ON-hook signals as well as ACK's to messages received from DAMA.

- Assignment Channels used by the DAMA system to respond to mobile requests or issue commands to mobiles

- Communication Channels used by mobiles to transmit voice or data

The first three channel types are referred to as signalling channels. Two important issues must be resolved before discussing the various possible types of access techniques to be used on request channels.

These issues are:

a) deferred voice channel assignment
b) packet (slot) size

These concepts will effect the behavior of the request channels and the number of channels required to handle the traffic load on the signalling channels.

3.3.1 Deffered Voice Channel Assignment

It is desirable to assign a voice channel when the called party goes off hook. This will allow efficient utilization of voice channels instead of wasting the voice channel capacity by assigning it to a call and waiting for the called party's response. However, this may cause some inconvenience for the called party since there will be no voice channel assigned to the call immediately after he goes off hook. There will be an average delay of one second before a voice channel is assigned to a call from the moment that called party goes off hook.There would also be the probability of no voice channel available at the time. The probability of this undesired behavior could be minimized by introducing an algorithm which accepts call requests only when there is a very high probability of having a voice channel available at the expected reception time of off-hook message . This algorithm would use the system parameters such as length of queue for calls awaiting the called party response and number of idle voice channels.

3.3.2 Packet Size

The packet (slot) size has a direct relationship with the number of signalling (Request/Assignment) channels required to support the traffic load generated by the MSAT users. A packet consists of information, overhead and guard time bits. The overhead includes the preamble and coding bits. The guard time is required for the packets transmitted by the mobile terminals due to the uncertainty of their location with respect to the satellite.

i) Information Bits

The list of messages communicated between mobile users and the DAMA centre is given in Appendix B (a detailed packet structure of these messages is also included). The maximum number of information bits transmitted in a packet by each mobile is 82 bits, while that of a packet transmitted by the DAMA centre is 92 bits.

ii) Overhead Bits

The preamble (UW) is used to assist the AFC and BTR operations. It is concluded in [1] that a 15-bit long unique word can provide the necessary information for AFC and BTR operations. The BCH (15,11) coding scheme capable of correcting one bit in a block of 15 bits was proposed in [1]. This scheme was proven to be suitable for coding the information bits of typical information bit sizes given above.

iii) Guard Time

The packets transmitted by the mobiles on the access channel must take into account propagation delay uncertainties to avoid overlapping into their adjacent slots. In Appendix C, it is shown that a guard time of 48 bits provides sufficient protection for terminals communicating within 5° and 60° elevation angles to satellite when the DAMA centre is located at 35° (most extreme Canadian South point). However, this is a very large overhead for the packet size used for MSAT. This overhead could be reduced by using an Active Ranging Burst Synchronization scheme (ARBS), discussed in [1]. Use of this scheme reduces the guard time to 8 bits where the timing information should be updated every two hours assuming a mobile travels at a speed of 100 km/hour.

The log-on and ranging messages will still require 48 bits of guard time. As it is shown in Appendix B, 60 bits are allowed for guard time within the packet structure of these messages. All the users below 5° elevation angle will be treated as special case to allow for their longer propagation delay (i.e., a manual switch on the terminal).

Considering all the above elements affecting the packet size, the signalling channels will be divided into slots of 150 bits long.

3.3.3.0 Access Scheme

Different access techniques for signalling channels have been investigated during various phases of MSAT studies. The Request and Assignment channels form the major interface between the user and the MSAT DAMA system. As a result, it is critical that their operation satisfy the criteria imposed by both the user and the system requirements. The following are the major conflicting issues to be considered in optimizing the system for any proposed access scheme:

- the number of signalling channels to support the traffic load,
- the delay experienced by a user for a successful call set-up/take-down attempt,
- stability of the channels, and
- terminal complexity.

With the main objectives to reduce the number of signalling channels and to limit the delay experienced by the users, the following access schemes have been considered:

- Slotted ALOHA (SA) for call requests and Token scheme for ACK/on-hook/off-hook signalling

- Reservation ALOHA (RA) for call requests and Token scheme for ACK/on-hook/off-hook signalling

The delay calculations as well as the computation of percentage of successful users after 3 attempts are described in Appendix D. The Slotted ALOHA, Reservation ALOHA and TOKEN schemes are described in the following sections.

3.3.3.1 Slotted ALOHA

In slotted ALOHA scheme the terminal is not permitted to send a packet whenever it has one to send. Instead, it is required to wait for the beginning of the next slot, Figure 3.2.

In case of a collision with another packet, there will be no acknowledgments issued and the terminal will time out and retransmit its packet at random during one of the next K slots (K is chosen to be 6 slots in this study). In order to ensure the stability of the channel, the number of retransmissions allowed by a terminal is restricted to three here, and any unsuccessful attempt during this period will be rejected. The rejected call attempts are proceeded with a busy tone provided by the terminal. The user could re-try immediately or wait for a few minutes.

The channel in slotted ALOHA mode will solely be used for transmission of call request, log-on, log-off and ranging messages. The log-on/log-off message transmissions are expected to occur during the non-busy-hour period. As discussed in Appendix A, the average UHF originated call attempt rate, including ranging messages, is 3.97 messages/sec/beam. The 2400 bps channel is divided into 16 slots of 150-bits long.

Figure 3.1 describes the behavior of a slotted ALOHA channel assuming error free forward and reverse channels. The channel throughput characteristics in presence of packet loss are discussed later.

3.3.3.2 <u>Reservation ALOHA</u>

The reservation ALOHA scheme is based on a random access scheme (slotted ALOHA) to reserve a particular slot for transmitting a call request packet. The Reservation Request Channel (RRC) is divided into two different types of slots:

- Large slots used for transmission of call request, log-on, log-off and ranging messages,

- Mini-slots used to transmit a token in slotted ALOHA mode to reserve one of the large slots for transmitting call request and log-off messages.

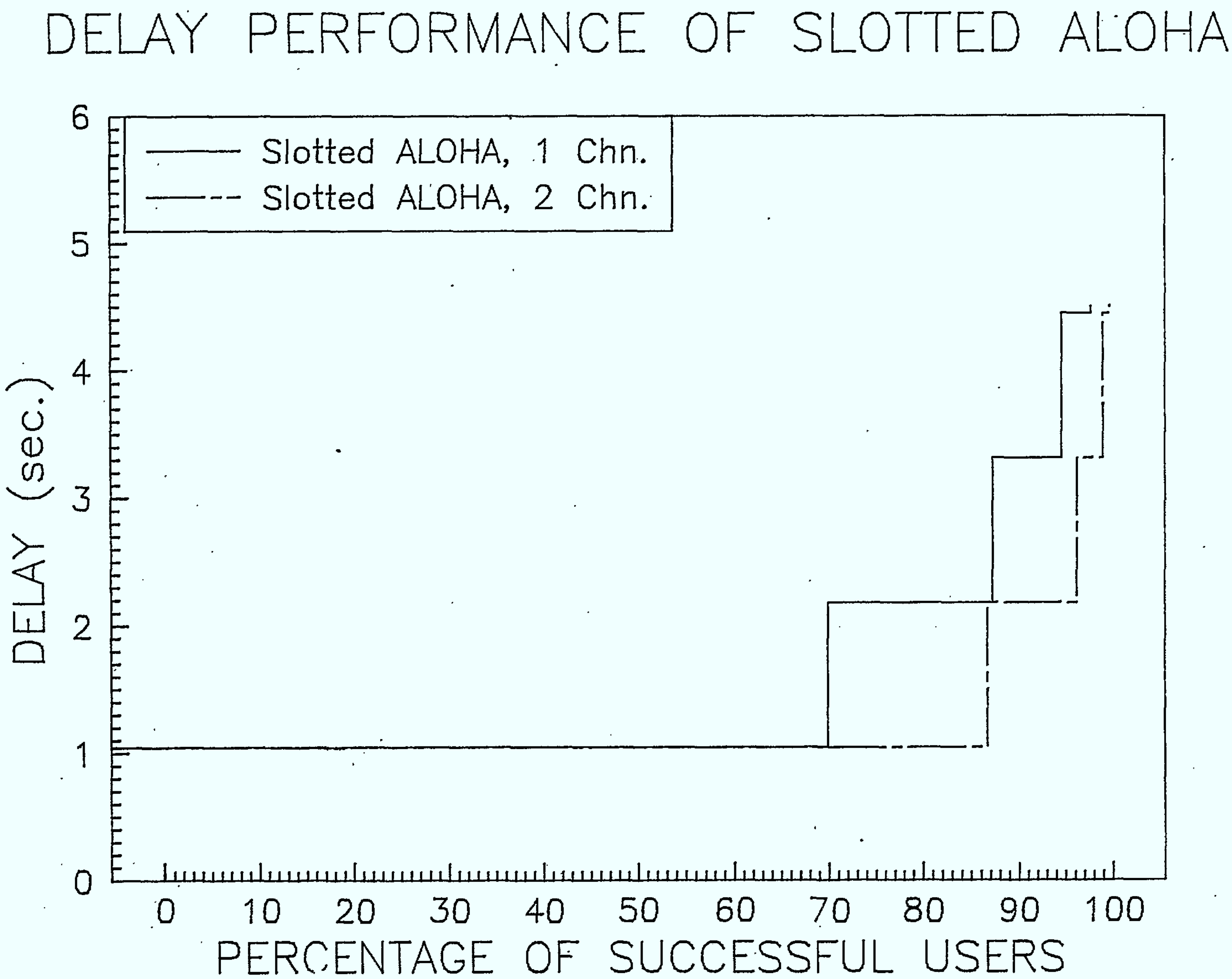
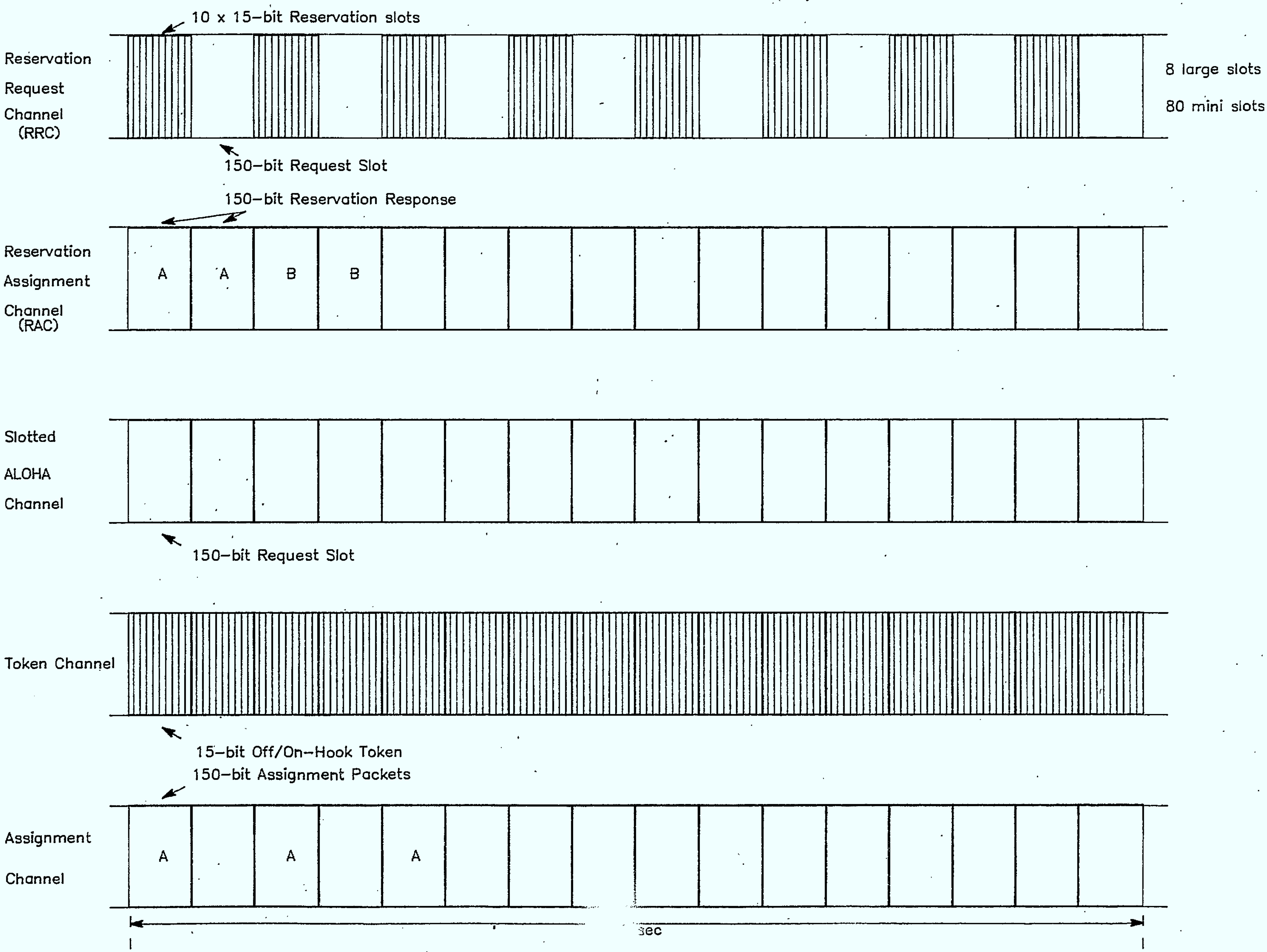


FIGURE 3.1 Delay Performance For Error-free Channels



Figu[illegible] [illegible]nnel Structure

The large slots are 150-bit long while the mini-slots are in groups of ten 15-bit slots as described in Figure 3.2. When a user wishes to make a call, the terminal will send a 4-bit long token in one of the mini-slots (e.g. in mini-slot X). The DAMA centre will detect this burst of energy and transmit a message on the Reservation Assignment channel (RAC) assigning one of the available large slots to whomever transmitted a token in mini-slot X. Due to the small token size, there is no capability of contention detection by DAMA; therefore, the terminals which transmitted their token in the mini-slot X would experience a collision in the large slot and must repeat this procedure. The log-on and ranging messages will be transmitted in one of the empty large slots which should be located by monitoring the messages on RAC for a certain timeperiod. The ranging message transmissions will also occur during the BH; however, their traffic contribution is ignored in channel performance computations since these messages will be transmitted in empty large slots and do not compete with call request attempts for a mini-slot.

The average call rate is 3.36 UHF originated calls/sec/beam. Figure 3.3 describes the behavior of reservation ALOHA channel assuming error-free forward and reverse channels. The channel throughput characteristics in presence of packet loss are discussed later.

The downlink pair of RRC is used to transmit the reservation response messages from the DAMA. Every response is transmitted twice to decrease the probability of packet loss on forward link.

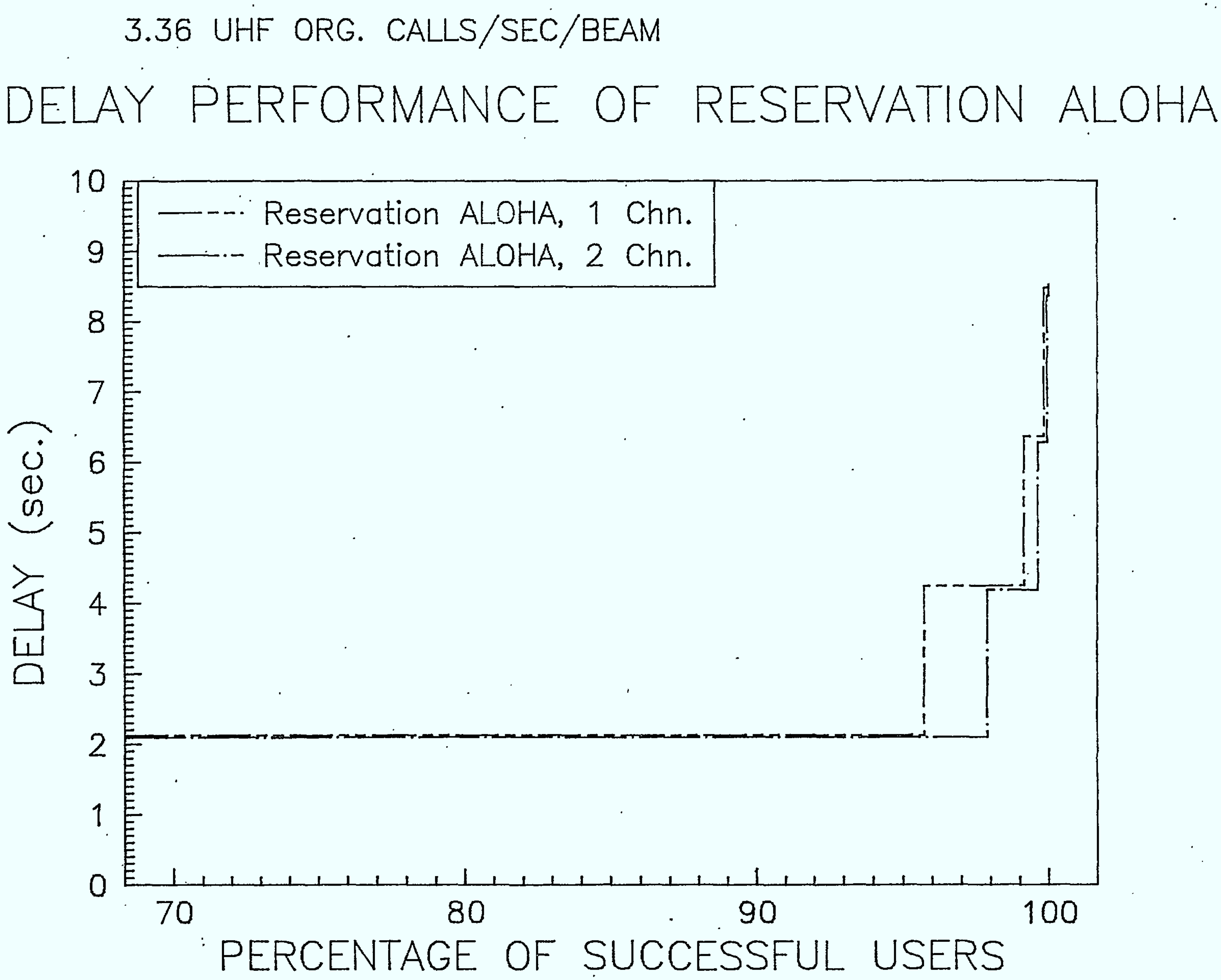


FIGURE 3.3 Delay Performance For Error-free Channels

3.3.3.3 Token Scheme

The 2400 bps channel is divided into 15-bit slots. During the call set-up procedure (after reception of call request) the DAMA will designate one slot to the UHF called party. The user will acknowledge the reception of a ringing message from the DAMA by sending a 4-bit long token in its slot. When the called party goes off-hook, it will transmit an off-hook token in the same slot. The voice channel assignment message transmitted by DAMA will designate another slot to the call initiator. Both parties will acknowledge the reception of this message by inserting a token in their designated slots. After the call termination, another token will be sent by each party as an on-hook signal in their slots. The DAMA will take away and add these to the pool of idle slots for future assignments.

The required number of token slots is dependent upon the number of conversations in progress as well as the number of users awaiting an off-hook signal from the called party. There is a need for approximately 250 tokens which could be accomplished by using two token channels in order to decrease the delay involved in token slot search. The computation of required number of token slots is given in Appendix D.

Figure 3.2 describes the structure of a Token channel. The downlink pairs of these two Token channels will be used by the DAMA to transmit all response messages as well as any commands to the UHF users. The messages will be transmitted three times in alternating slots to decrease the probability of packet loss on forward links for those users located below the 20° elevation angle to the satellite. The average number of messages transmitted by the DAMA via these Assignment Channels is computed to be 6.06 messages/call attempt assuming the requirement of having to transmit every message three times. As it is shown in Appendix A, there is a requirement of three Assignment Channels.

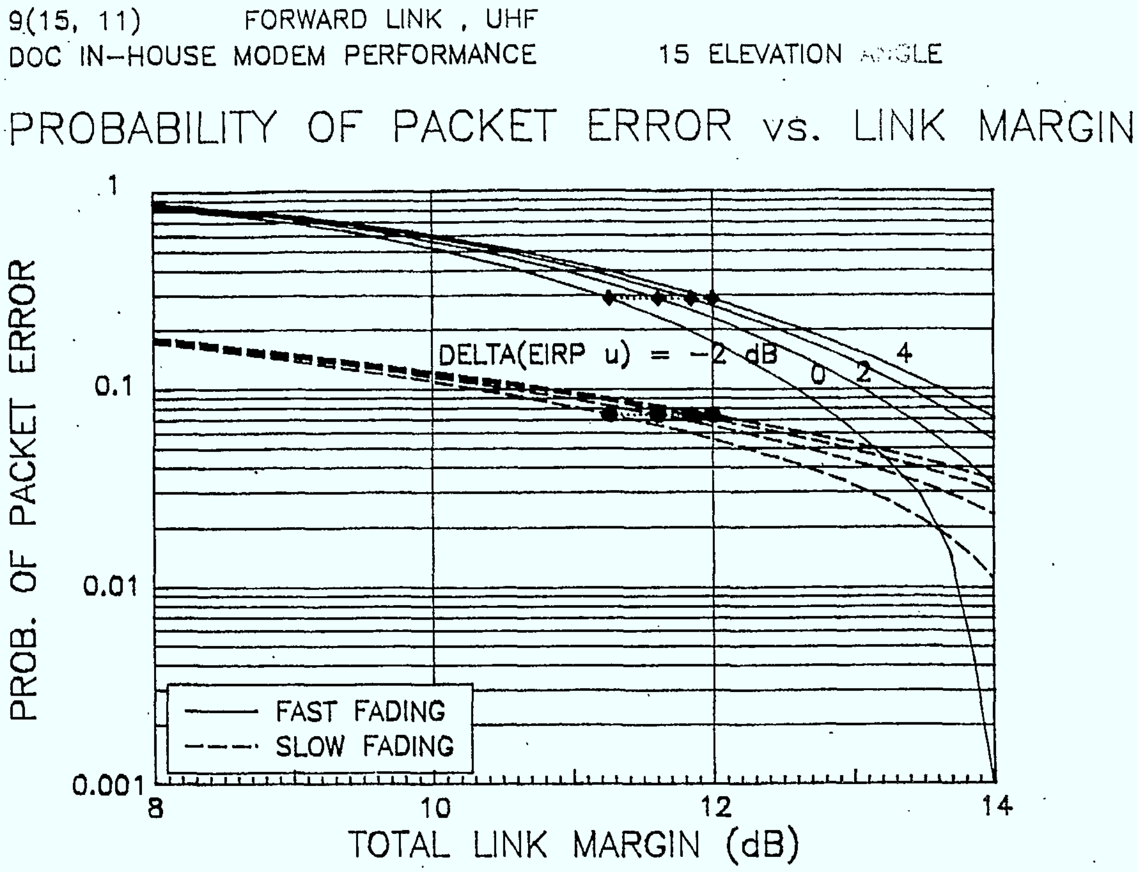
3.3.3.4 Comparison of Access Schemes

The studies presented in [1] are for mobiles located at 15° elevation angle. Service availability will be approximately 93% for these mobiles. However, to obtain 99% service availability, the mobiles must be limited to a minimum elevation angle of 20° to the satellite according to the fade statistics provided by CRC for areas which woodlands constitute up to 35% of the land area.

The performance of signalling channels would be enormously different at various elevation angles due to the propagation effects on these channels. This section is partitioned into two parts, discussing performance of the channels at 15° and 20° elevation angles.

The probability of packet loss on the forward and reverse links for UHF mobiles limited by 15° elevation angle to satellite is given in Figure 3.4 and similarly for UHF mobiles limited by 20° in Figure 3.5. It should be noted that these figures present the probability of packet loss due to uncorrectable errors in coded segment of packet. The total probability of packet error is upper bounded by:

$$\text{total} = P(\text{error in UW}) + P(\text{error in coded segment})$$



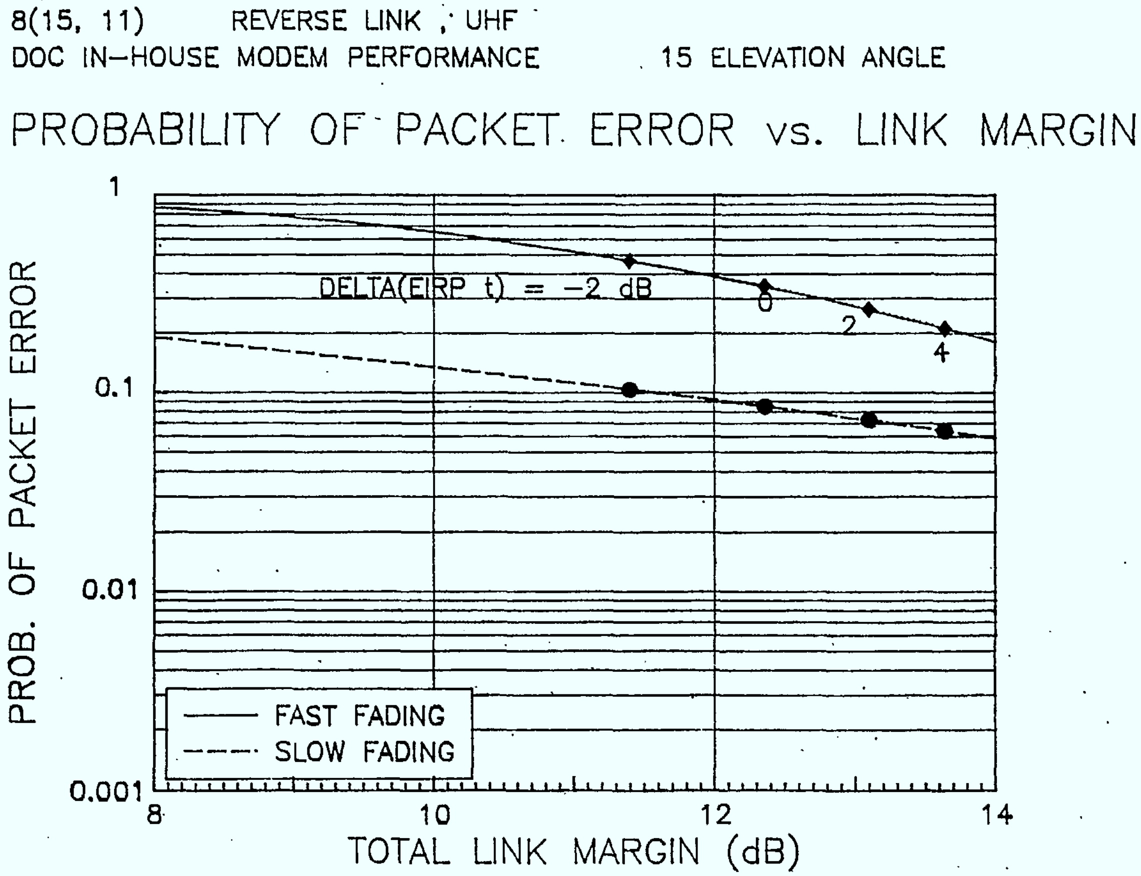
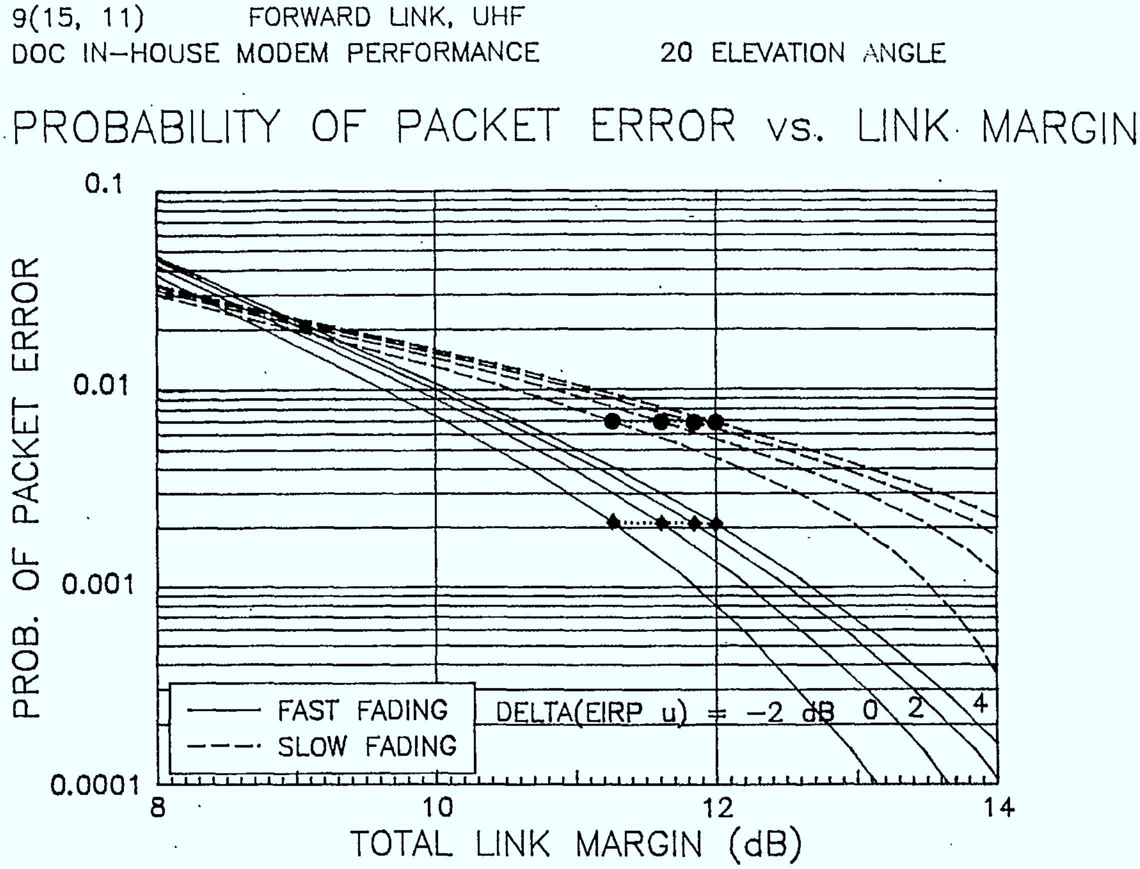


FIGURE 3.4 Probability of packet loss due to error in coded segment of packet versus link margin on forward and reverse links for UHF mobiles limited to 15° elevation angle to satellite



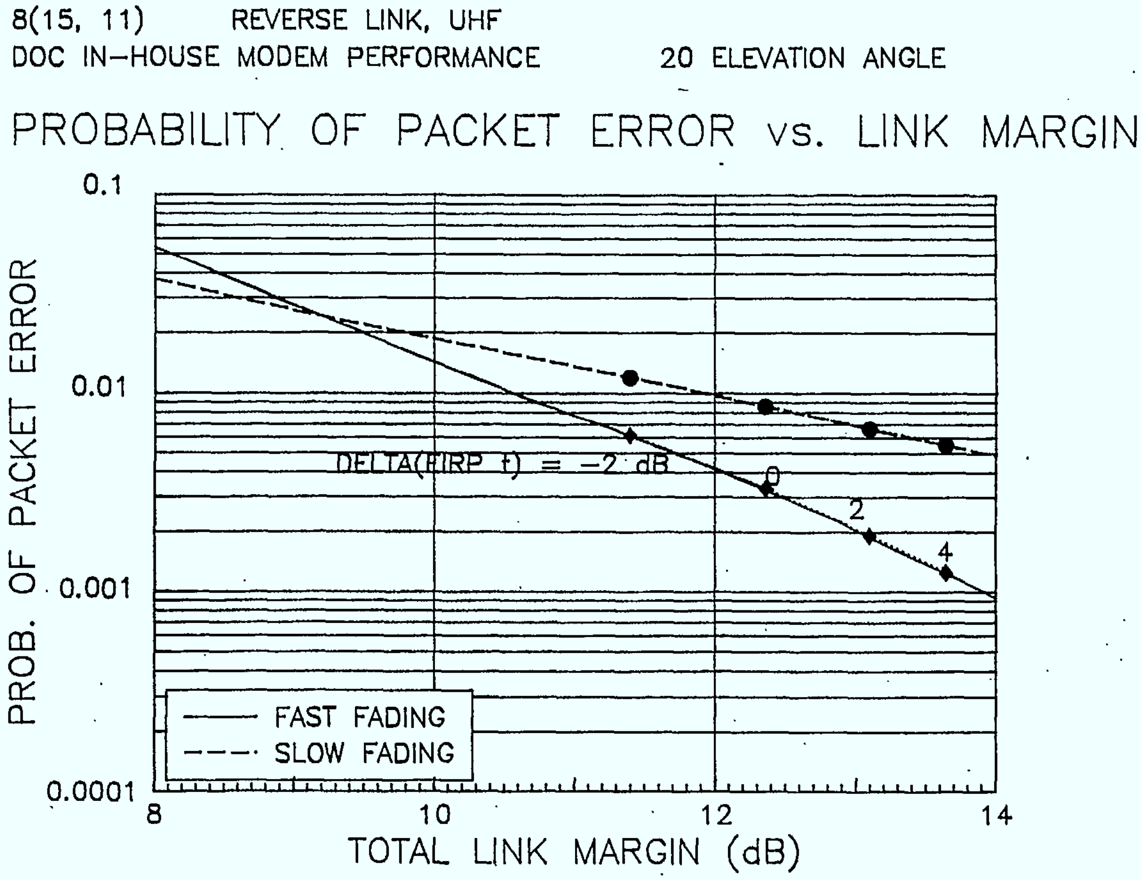


FIGURE 3.5 Probability of packet loss due to error in coded segment of packet versus link margin on forward and reverse links for UHF mobiles limited to 20° elevation angle to satellite

As discussed in Appendix F, this would be true assuming that probability of error occurrence in unique word and coded segment of a packet are independent of each other.

Part A: Users Limited to 15° Elevation Angle

The previous studies discussed in [1] recommends the combination of reservation ALOHA and Token scheme as the access technique to be used for the MSAT MRS DAMA system. Furthermore, it states that the performance of slotted ALOHA scheme is not acceptable due to the relatively slow decay of the tail of the delay distribution. However, by restricting the number of retransmissions in slotted ALOHA to three and using a token scheme for on-hook/off-hook/ACK signalling, a reasonable call set-up delay could be achieved for majority of the users as shown in Figure 3.6. Assuming one signalling channel is slotted ALOHA mode, 52% of call requests would be received by the DAMA centre successfully in the first attempt for a delay of 1.05 seconds. The next 21% would succeed in their first re-attempt with a delay of 2.15 seconds and so on up to the third re-attempt. Under the same traffic conditions, assuming one signalling channel in reservation ALOHA mode, 53% of call requests would be successful in the first attempt with a delay of 2.1 seconds and so on up to the third re-attempt. The major trade-offs between the above schemes are presented in this section.

In the reservation ALOHA scheme due to the nature of the access scheme, two request messages (reservation request and call request) must be transmitted to the DAMA as well as two responses must be received from the DAMA for a successful transmission of a call request. However, in slotted ALOHA, there will be the requirement of one call request transmission to the

DAMA and one response reception from the DAMA. As a result, due to the long propagation delay and processing time involved in coding, decoding and constructing a packet, the delay experienced in the reservation ALOHA for a successful call request will be almost twice of that in slotted ALOHA mode.

A packet received by the DAMA or MSAT terminal with uncorrectable errors is said to be a lost packet. The error occurrence is due to transmission of more than one packet in a slot (collision) or propagation effects on the signalling channel. The performance of the reservation ALOHA scheme compared to slotted ALOHA is significantly more dependent on the propagation characteristics of the channel since two messages are to be transmitted by the terminal as well as the DAMA centre. However, the probability of collision for the request messages in reservation ALOHA is significantly much less than that of slotted ALOHA for the same traffic loads. As a result, two of the solutions to improve the performance of reservation ALOHA scheme, for the environments with fade statistics similar to that of 15° elevation angle provided by CRC, are to increase the EIRP for the signalling channels at the satellite or introduce a better coding scheme to cancel out the propagation effects. As shown in Figure 3.6, increasing the number of signalling channels in reservation ALOHA mode for a constant traffic load generated by mobiles limited by 15° elevation angle does not improve the performance of the channels significantly. However, in slotted ALOHA mode, the performance of the signalling channels could be improved by either increasing the number of signalling channels (as shown in Figure 3.6) or decreasing the probability of packet loss due to propagation effects (i.e. increasing the EIRP at the signalling channels at

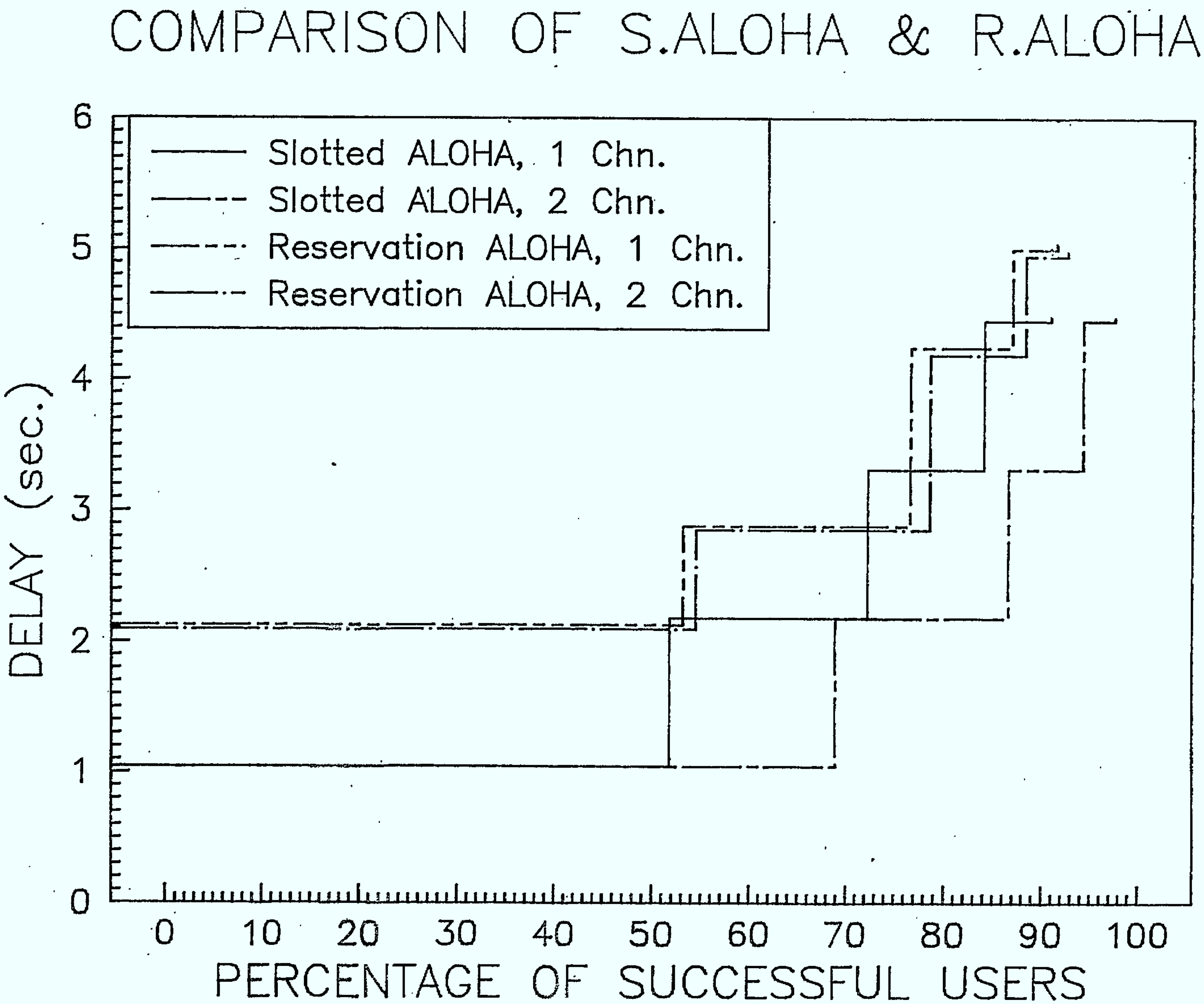


FIGURE 3.6 Delay performan... for users located at 15° elevation angle where Del... (RPs)=0 dB and call attempt has been made unde... shadowing conditions, packets repeated 3 tim... ssignment channel.

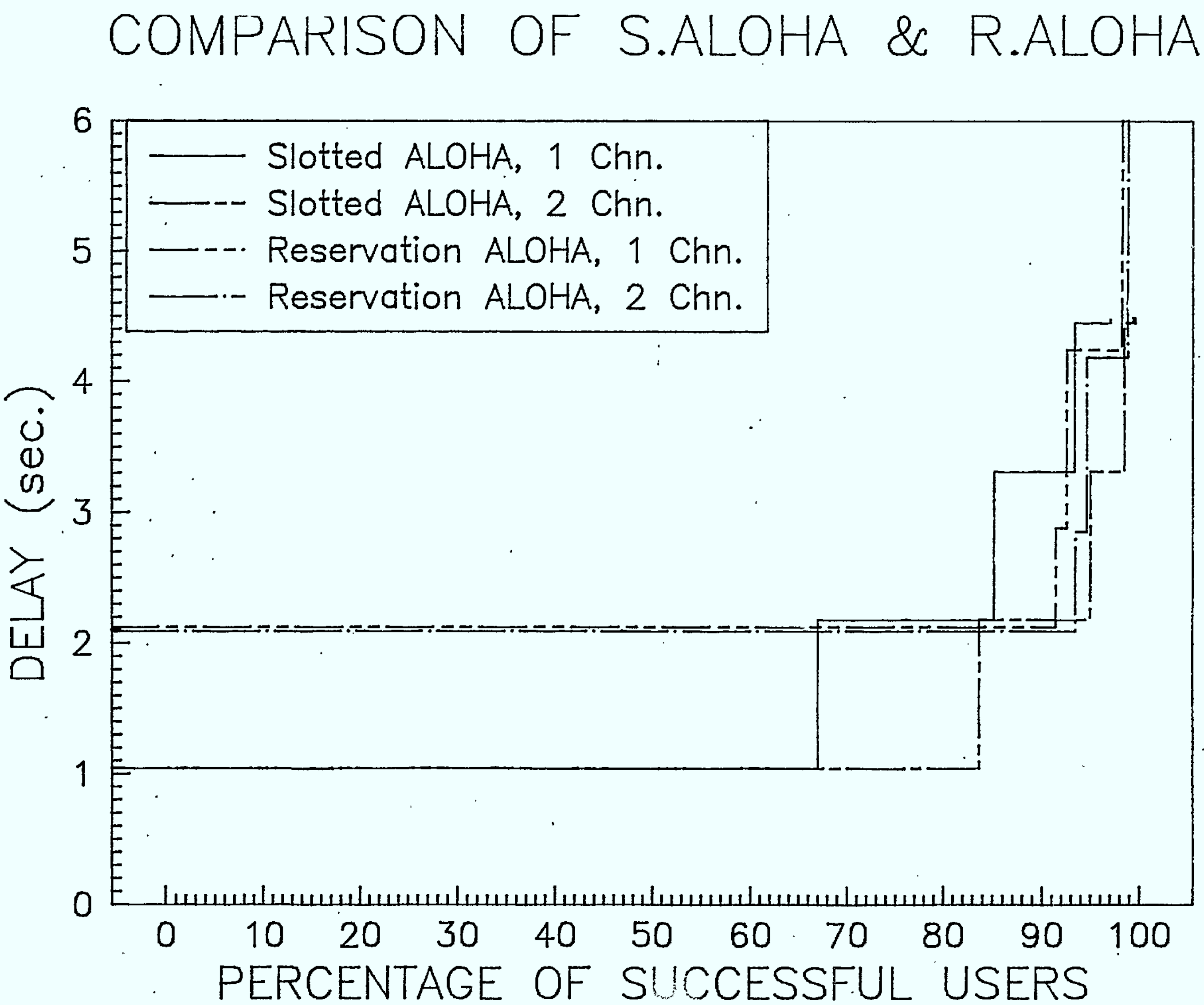


FIGURE 3.7 Delay performance fo: sers located at 15° elevation angle where Delta(EI =6 dB and call attempt under light shadowing con s with packets repeated 3 times on Assignment els.

the satellite, as shown in Figure 3.7). Therefore, the slotted ALOHA scheme is more adaptable and robust to environments with various propagation characteristics compared to reservation ALOHA scheme.

The analysis done in this report does not include any traffic contribution due to log-on, log-off and ranging messages for reservation ALOHA and no log-on/log-off for slotted ALOHA. However, the load due to ranging messages is included in performance analysis of slotted ALOHA scheme. These are valid assumptions as long as these activities occur during non-busy-hour. In case of any traffic contributions due to these messages, the reservation ALOHA scheme is able to handle them without affecting the performance of the channel since they are transmitted in the empty slots. However, the performance of slotted ALOHA will be degraded since any increase of traffic on the channel will increase the probability of collisions among transmitted packets.

The reservation channel has eight large slots available for transmission of messages, Figure 3.2. As indicated in Figure 3.8, due to packet errors in various channels, one RRC channel could handle up to 7 calls/sec for average delay of 4 seconds, while slotted ALHOA in the same environment could handle a maximum of 4 calls/sec for average delay of 2.25 seconds. Meanwhile, for a throughput of 4 calls/sec., the average delay in reservation ALOHA mode is 3.7 seconds.

When the power level of signalling channels is increased by 6 dB (Figure 3.9), an average delay of 2.85 seconds is experienced for 7 Calls/sec. in reservation ALOHA, while the delay is 1.5 seconds for 4 calls/sec in slotted ALOHA mode. The same behavior is also demonstrated in Figure 3.7 for the above discussed channels under the same traffic load and environmental conditions.

As explained before, two Token channels are required to support the traffic load of the system and three assignment channels for the given traffic statistics assuming every message form DAMA is to be repeated three times. Assuming one access channel for either access technique, the required number of uplink/downlink UHF channels will be as follows:

	UHF Uplink	UHF Downlink
Slotted ALOHA	3	3
Reservation ALOHA	3	4

In the reservation ALOHA scheme one extra UHF downlink channel would be required for transmission of reservation responses compared to slotted ALOHA; as a result, four UHF channel pairs are required for this scheme compared to 3 for slotted ALOHA.

Part B: Users Limited to 20° Elevation Angle

As discussed in previous sections, the signalling channels structure were designed to overcome the high probability of packet error (P_{PE}) on both the forward and reverse links. However, the P_{PE} for mobiles limited by 20° elevation angle is quite low as discussed in Appendix I. If the DAMA system were to be designed for mobiles with elevation angles to the satellite greater than 20°, there would be no requirements to repeat packets three times on the forward link and, therefore, the channel performance would be well within the system requirements. The plots of signalling channel performance given in

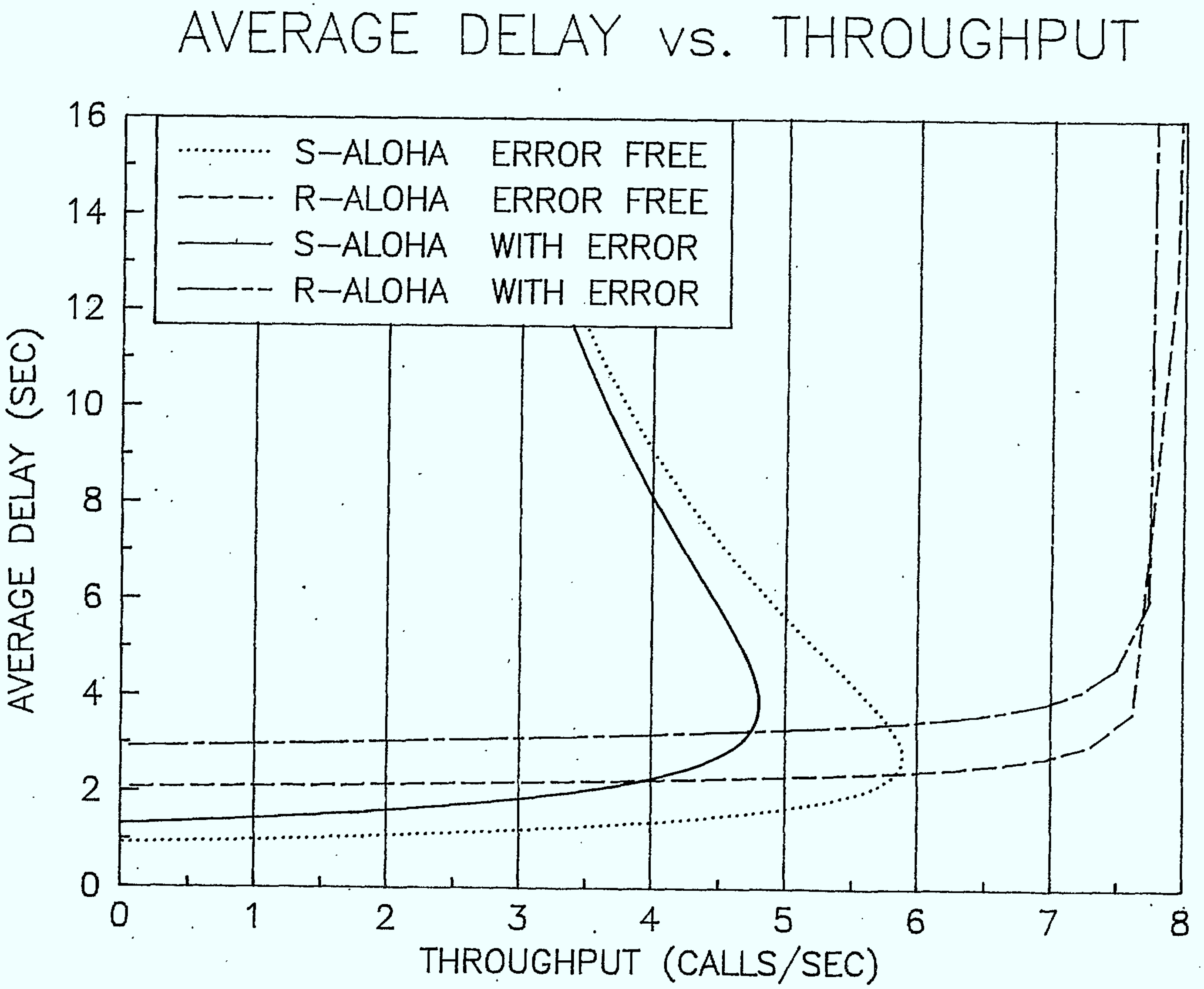


FIGURE 3.8 Average delay performance for error-free channels and channels with er[illegible] for users at 15° elevation angle where Delta(EIR[illegible] 0 dB and call attempt under light shadowing condi[illegible] packets repeated 3 times on Assignment channels.

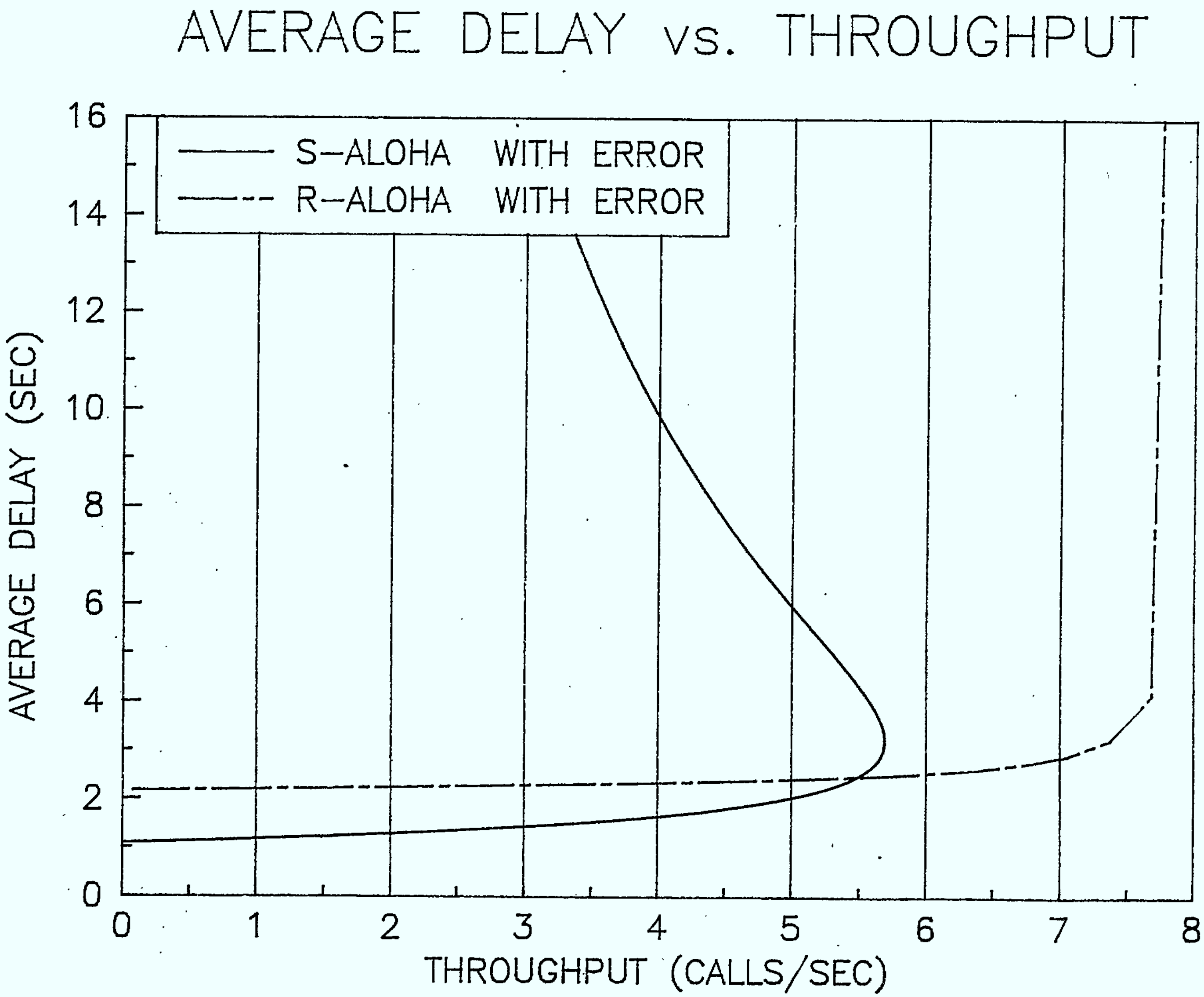


FIGURE 3.9 Average delay performance for users at 15° elevation angle where Delt. ...IRPs)=6 dB and call attempt under light shadowing ...tions with packets repeated 3 times on Assign... ...annels.

Figures 3.10 and 3.11 are based on repetition of messages twice on RAC for reservation ALOHA scheme, and no repetition of messages on Assignment channels for both schemes. As discussed in part a, the delay experienced in slotted ALOHA mode is almost half of the delay for reservation ALOHA. However, due to low P_{PE}, the reservation scheme could operate well and there is no need to increase the power level of the signalling channels over that of the voice channels.

Figures 3.12 and 3.13 illustrate the signalling channel performance for the above channel structure reconfiguration (no repetition on Assignment Channel) for mobiles limited by 15° elevation angle. As it was expected, these mobiles cannot meet the system requirements as far as the call set-up requirements are concerned.

3.3.3.5 Recommendation

The MSAT DAMA system design must be in accordance with the baseline system requirements. In the previous section, two access schemes were analyzed for two different fade propagation statistics. Since Telesat's baseline system design assumes that mobiles are limited to 20° elevation angle, the DAMA system should also be designed in accordance with this assumption. From Figure 3.12, those mobiles operating at 15° elevation angle would suffer significantly more from shadowing losses than for the 20° elevation case mobiles. Thus, it is desirable to have some means to distinguish between users above and below 20° elevation angle to the satellite. With such a mechanism, the DAMA could repeat

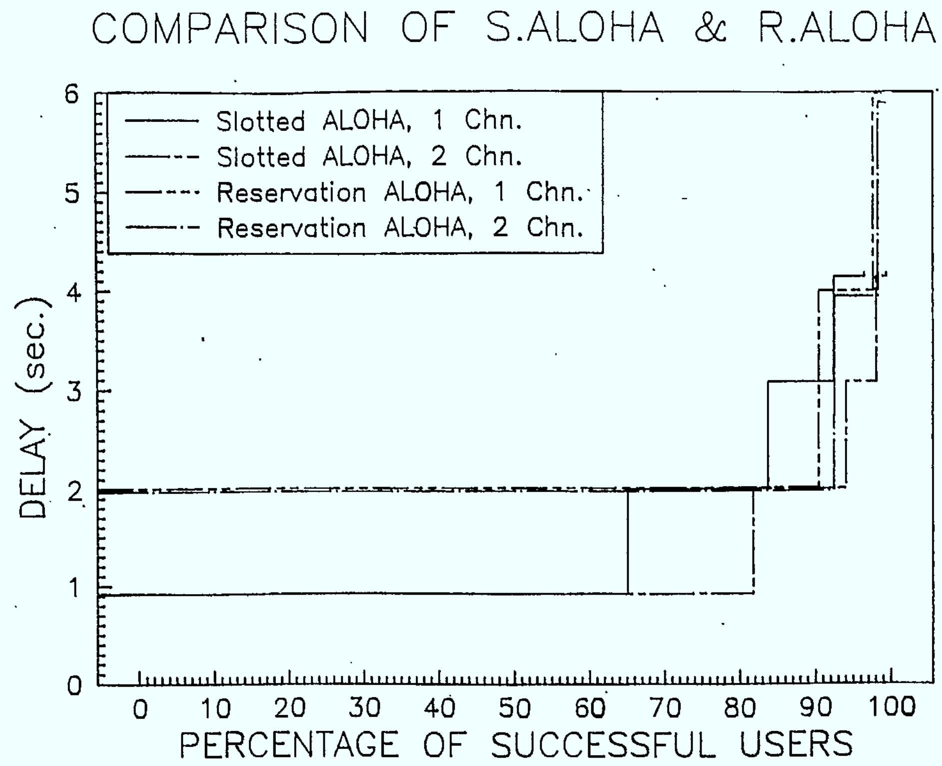


FIGURE 3.10 Delay performance for users located at 20° elevation angle where Delta(EIRPs)=0 dB and packets transmitted once on Assignment channels.

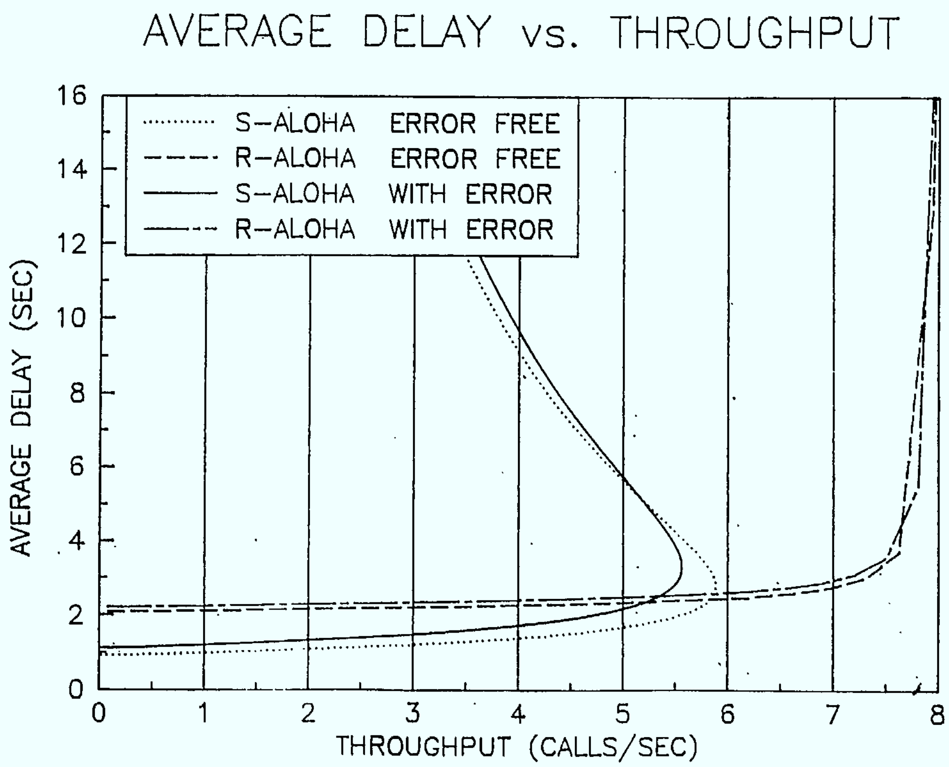


FIGURE 3.11 Average delay performance for error-free channels and channels with errors for users at 20° elevation angle and packets transmitted only once on Assignment channels (Delta(EIRPs)=0 dB).

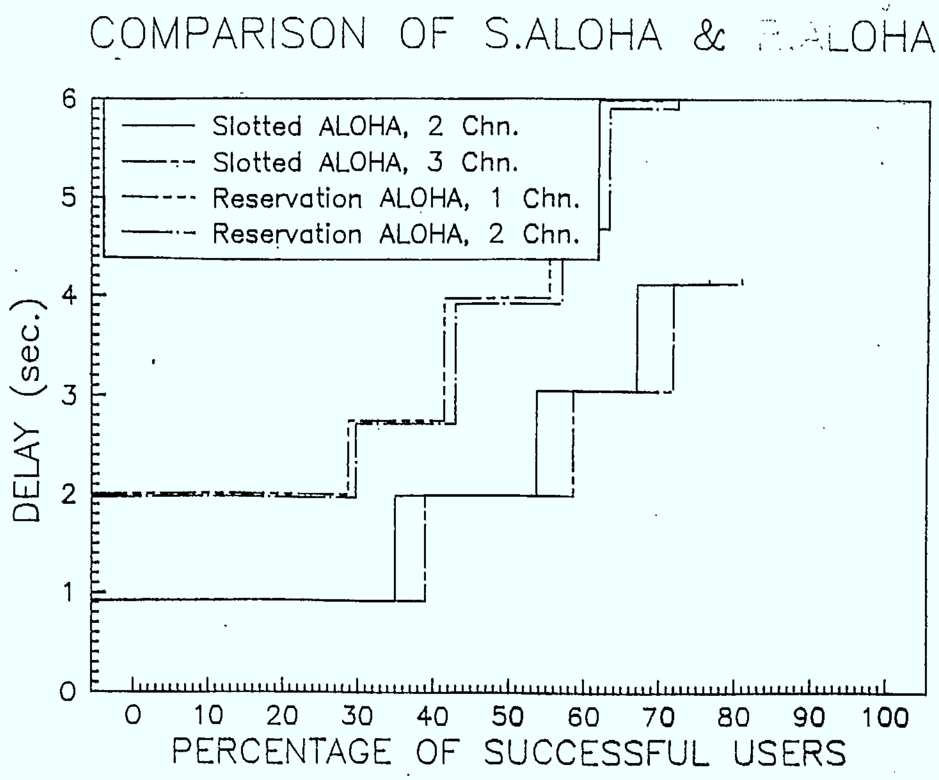


FIGURE 3.12 Delay performance for users located at 15^{o} elevation angle where Delta(EIRPs)=0 dB and call attempt under light shadowing conditions, packets transmitted only once on Assignment channels.

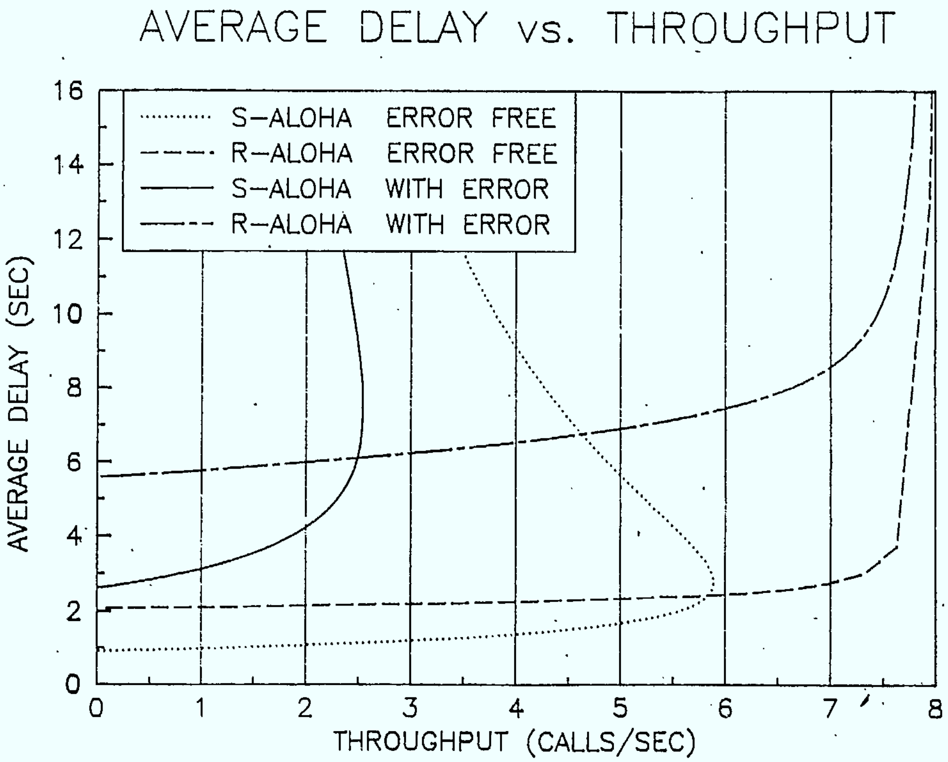


FIGURE 3.13 Average delay performance for error free channels and channels with error for users located at 15^{o} elevation anglewhere Delta(EIRPs)=0 dB and call attempt under light shadowing conditions, packets transmitted only once on Assignment channels.

messages for those mobiles located below 20° elevation angle and, therefore, reduce the probability of packet loss on the channel as discussed in part A.

Transmission of short data messages consisting of few packets could be handled by reservation ALOHA scheme more efficiently compared to slotted ALOHA. In order to provide this service, after a particular large slot is assigned to a user, it would not be assigned to any other user until the successful reception of last data packet.

Table 3.2 compares the performance of reservation and slotted ALOHA schemes. It is seen that under the assumptions used in this study slotted ALOHA outperforms reservation ALOHA, thus, it is recommended to use slotted ALOHA for call requests and the token scheme for on-hook/off-hook/ACK signallings.

TABLE 3.2

Reservation ALOHA (RA)	Slotted ALOHA (SA)	Advantage
– Transmission of 2 messages from each side; therefore, average delay twice of that for SA.	– Transmission of one message from each side during call set-up	SA
– Due to packet loss in F/R links and more message transmissions, it is more susceptible to high P_{PE}	– It is more adaptable to the environments with various propagation effects	SA
– Its performance is restricted to channel propagation characteristics and improvement due to increment of No. of channels is insignificant	– Increasing the number of signalling channels results in better performance	SA
– The C/N for signalling channels must be increased to overcome the P_{PE} effects	– Increasing the power level of signalling channel is not a must	–
– Ranging messages could be transmitted over the empty slots	– Ranging messages are overhead to this scheme	RA
– For call rate over 7 calls/sec a second channel is required	– Can handle up to 4 calls/sec/channel	RA
– Can handle traffic due to log-on attempts during BH, if empty slots are available	– Traffic due to log-on attempts during BH decreases performance	RA
– Uses 1 more UHF downlink channel compared to slotted ALOHA for every RRC	–	SA

4.0 System Protocols and Procedures

4.1.0 Call Handling Protocol

The call set-up/take-down protocols for MRS and MTS services are basically of the same structure; however, some changes are required in MTS due to interfacing with PSTN. For example, the DAMA system would not be aware of the status of the PSTN subscriber; as a result, longer time-outs should be encountered into the procedure to allow for provision of the required information.

The call set-up/take-down procedure for MRS and MTS calls will be described below.

List of abbreviations for Figures 4.1, 4.2, 4.3 and 4.4.

ACK	Call Acknowledgment
CI	Call indication
CR	Call request
CT	Call termination
OFH	Off-hook
ONH	On-hook
RB	Ringback
REJ	Call reject
RG	Ringing
VC	Voice channel assignment

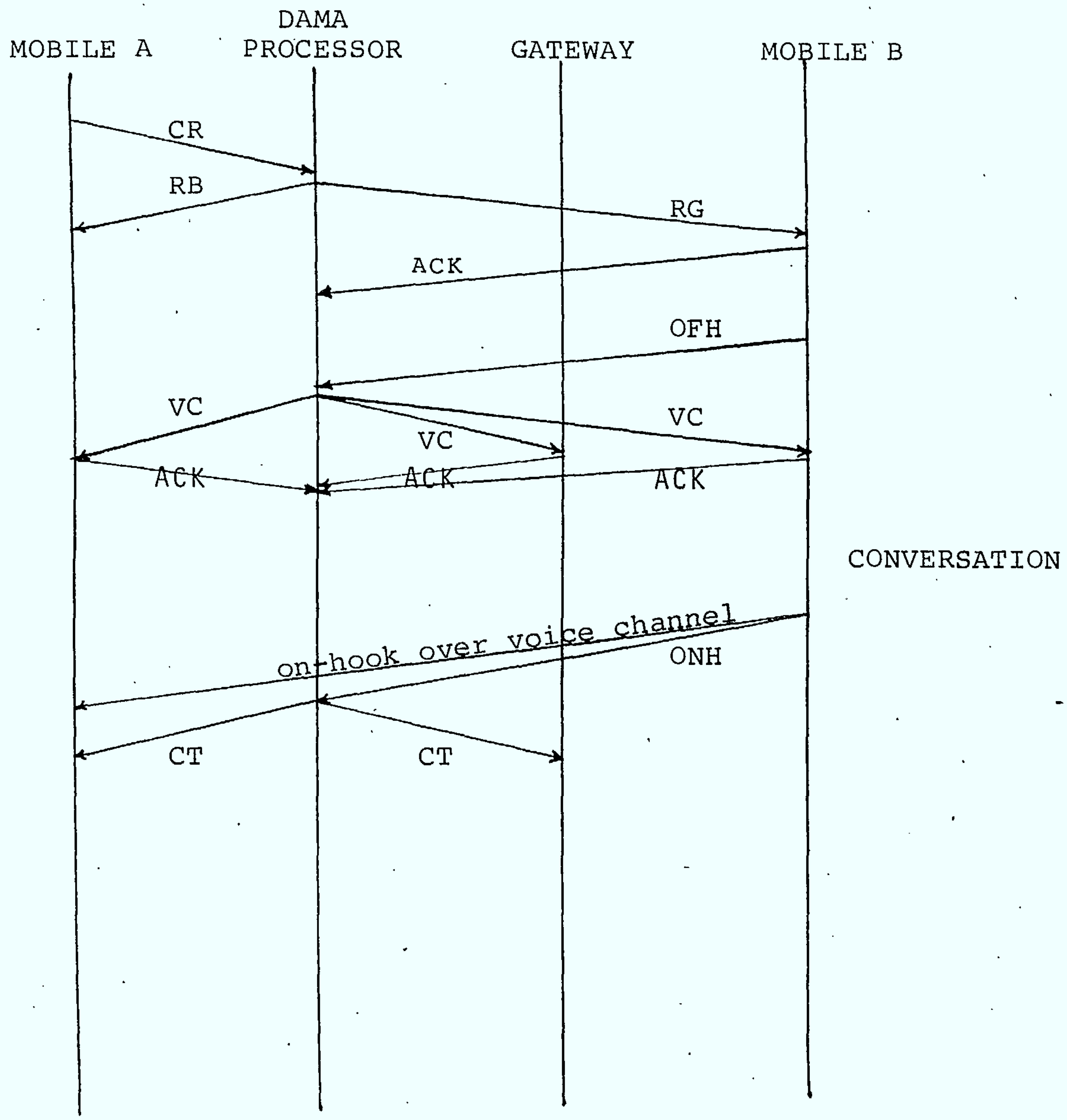
4.1.1 MRS Call Handling Protocol

The basic communication type would be between a mobile and a base station, or between two mobiles. Figure 4.1 describes the call procedure between two mobiles. In case of a base station, all the required messages will be transmitted via SHF signalling channels.

The set-up procedure is straightforward as follows:

- party A makes a successful call request,
- DAMA responds by a ringing message if party B is available (i.e. logged on and is not involved in another call),
- party B acknowledges reception of ringing message by sending a token in its designated slot (if mobile) or an ACK over the SHF signalling channel (if base station),
- party B goes off hook and informs DAMA on the Token channel,
- DAMA assigns a voice channel,
- Both parties acknowledge reception of voice channel assignment message by inserting a token into their slot (if mobile) or an ACK over the SHF signalling channel (if base station),
- Conversation starts.

a) Successful mobile to mobile communication



b) Unsuccessful call

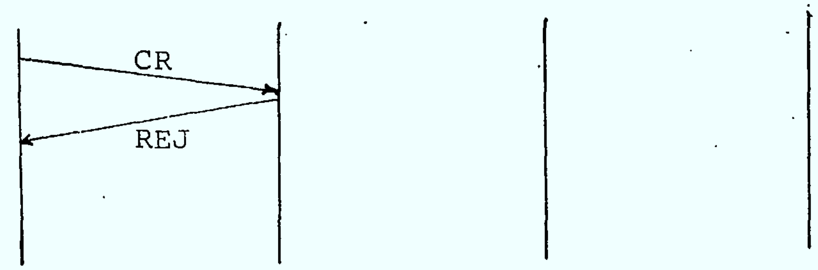


FIGURE 4.1 M-M MRS call set-up/take-down procedure

The take-down procedure is as follows:

- At termination of the call, an on-hook signal is transmitted over the voice channel and on-hook token/ACK over the signalling channel to DAMA,
- DAMA transmits a call termination message over the voice channel after reception of first on-hook message. Then it reclaims the voice channel and both token slots associated with the call.

The inter-beam call set-up procedure follows the same procedure as in intra-beam except it must allow for inter-communication among involved beam processors.

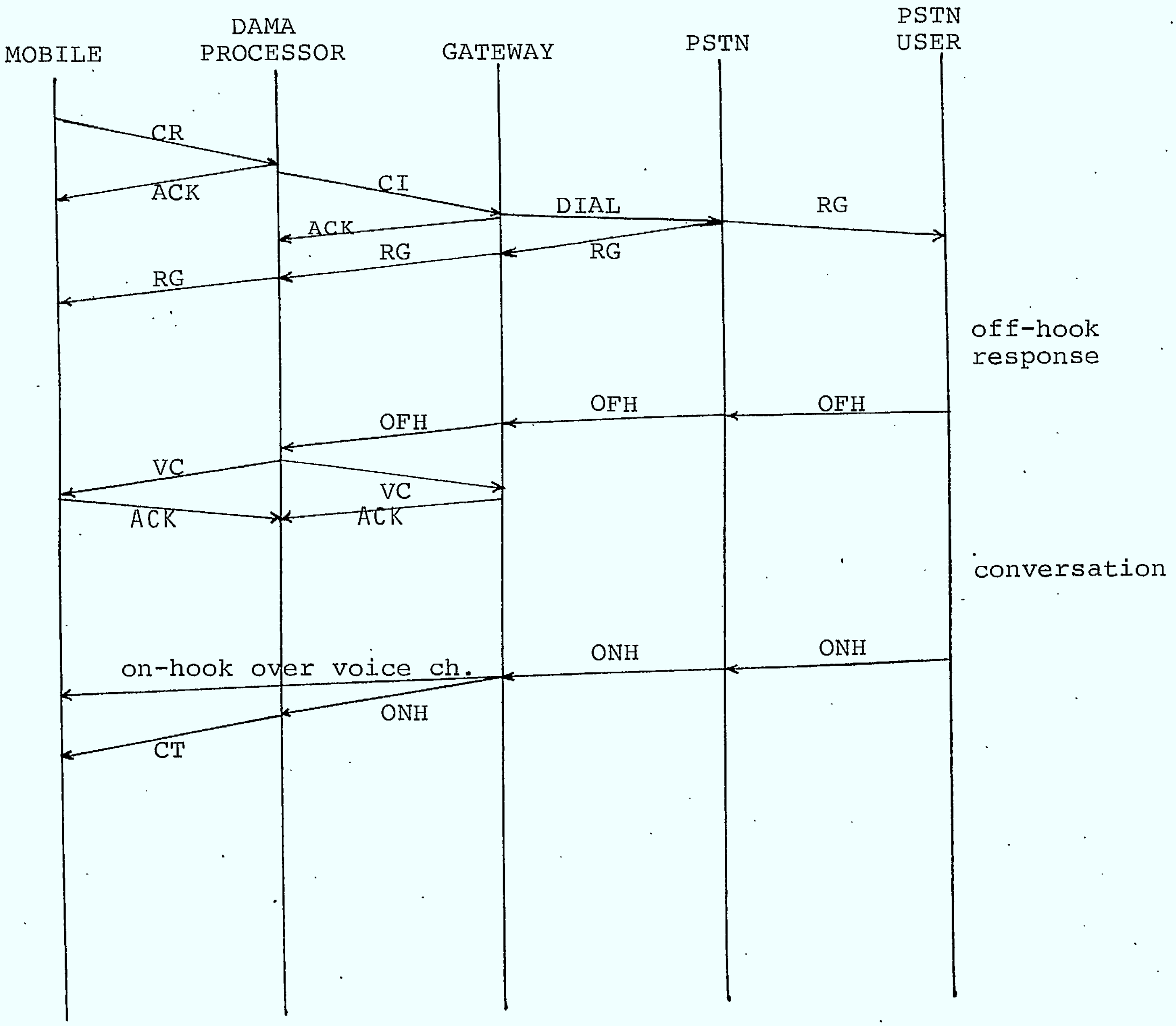
4.1.2 MTS Call Handling Protocol

As mentioned before, the major difference between MTS and MRS call handling protocols is the time required for the DAMA to obtain the information regarding the PSTN subscriber or PSTN link availability when the call is mobile originated. The PSTN originated calls will first interface with gateway stations and the next phase of call set-up could be treated as MRS base station originated call.

The MTS call set-up procedure when MTS user has initiated a call will be described below (Figure 4.2):

- Mobile makes a call request,
- The DAMA acknowledges reception of call request without issuing a ringing message. Meanwhile, it informs the appropriate gateway,
- Gateway station interfaces with PSTN and informs the DAMA of status of the called party,
- If the called party is available, the DAMA issues a ringback message,

a) Successful mobile originated call to PSTN



b) PSTN user busy (same procedure for out-of-order numbers; different msg.)

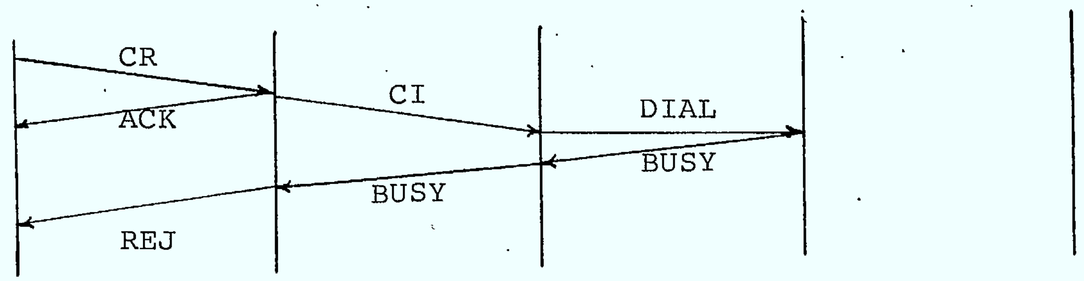
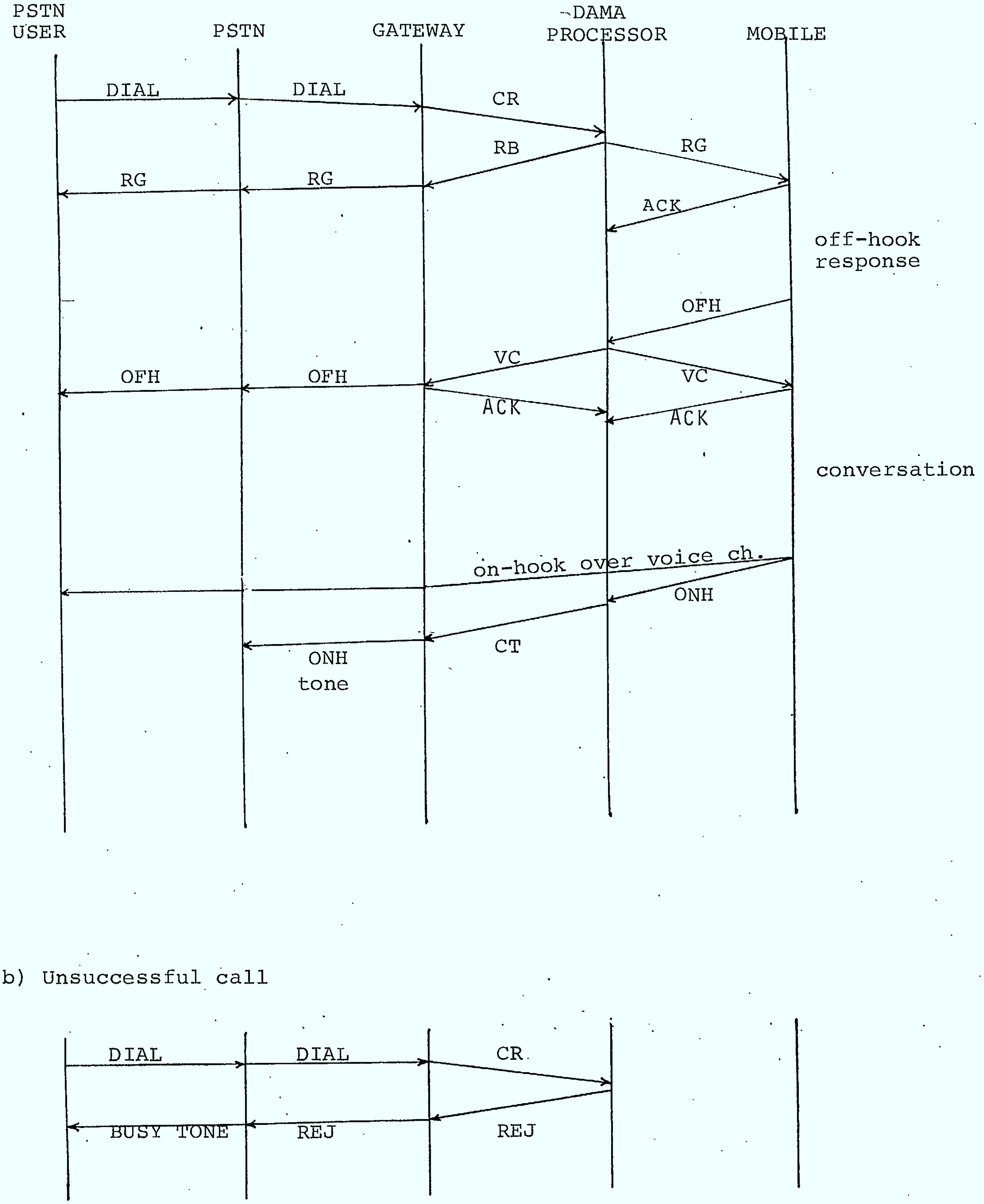


FIGURE 4.2 M-PSTN MTS call set-up/take-down procedure

a) Successful PSTN originated call to MSAT



b) Unsuccessful call

FIGURE 4.3 PSTN-M MTS call set-up/take-down procedure

- Gateway informs the DAMA when PSTN user goes off-hook,
- DAMA assigns a voice channel,
- Both gateway and mobile acknowledge the reception of voice assignment message,
- Conversation starts.

The call take-down is similar to that of MRS protocol.

Figure 4.3 describes an MTS call set-up/take-down when PSTN subscriber is the call originator.

4.2 Call Types

The call handling protocols described in previous section are for calls between two parties only. However, in this section the requirements for multi-party call set-up are discussed. These calls are:

- Broadcast call
- Conference call

The provisions for broadcast calls are considered within MRS and described in [1]. Figure 4.4 shows the call set-up/take-down protocol.

The conference call would be formed by linking a number of point-to-point calls together so that a group of users may share the same communication links. However, depending on the types of users, there are some restrictions introduced to conference call services. The following scenarios describe these restrictions:

1) In MRS, there are three types of links:

- i) UHF-SHF between mobile and base station
- ii) UHF-SHF-UHF between two mobiles
- iii) UHF-UHF between two mobiles in the same beam (optional)

In case (i), The mobile will transmit on UHF uplink transponded to SHF downlink. A second mobile would not be able to receive this signal. In the same manner, the base Station will transmit on SHF uplink transponded to UHF downlink, where a second base station cannot receive this message. As a result, there is no conference call capability with the existing channelization scheme for the above mentioned case.

In case (ii), the additional user could be a base station within the same SHF beam or a mobile within the UHF beam(s) involved in the call.

In case (iii), the additional user could be a mobile within the same UHF beam, since there are one UHF uplink and one UHF downlink and one SHF downlink channel only.

2) In MTS, there are two types of links:

- i) UHF-SHF between mobile and PSTN subscriber
- ii) UHF-SHF-UHF between two mobiles

In case (i), the additional party could be a PSTN subscriber connected to a gateway within the same SHF beam only.

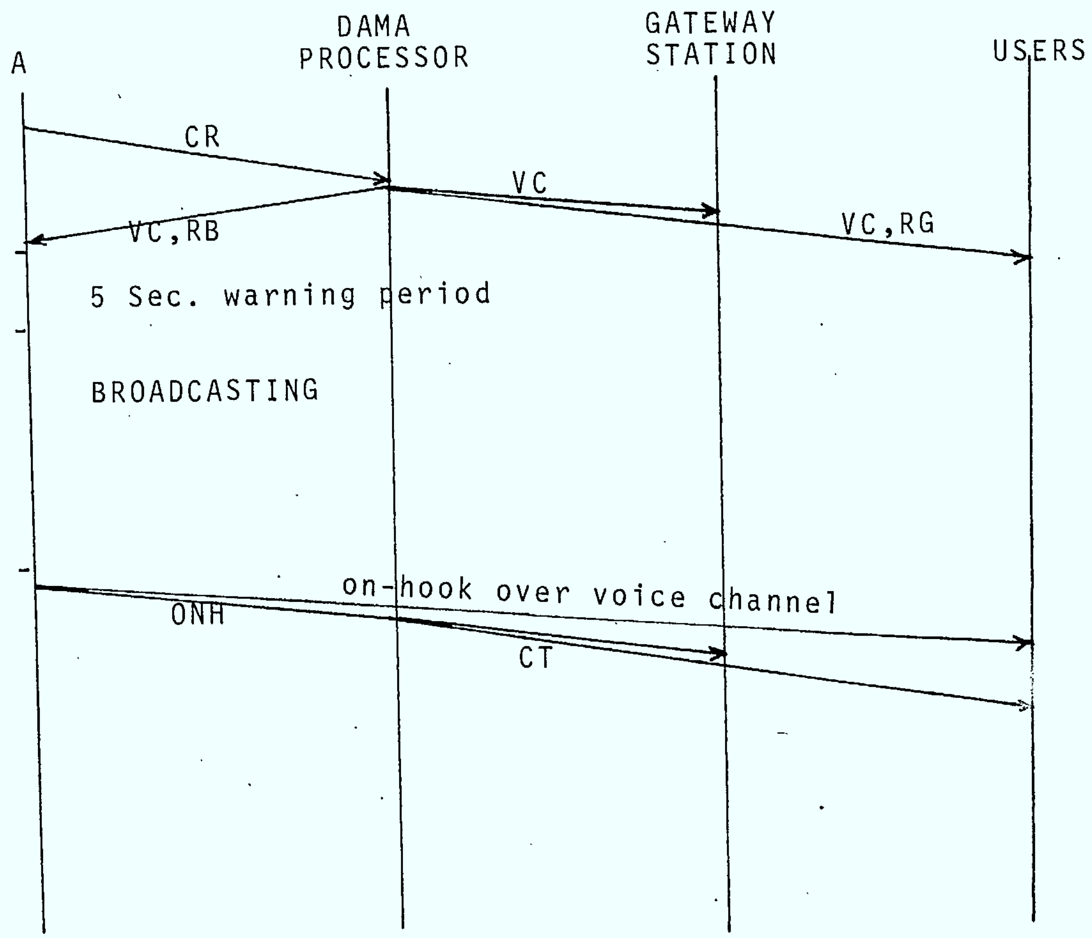


FIGURE 4.4 Broadcast call

In case (ii), the additional party could be a PSTN subscriber connected to a gateway within the same SHF beam or a mobile within the UHF beam(s) involved in the call.

These restrictions would not be that severe in the first generation system due to the assumed beam configuration. However, as the number of beams increases, the imposed restrictions due to channel requirements will disable the proper operation of conference call services. Statistics regarding the user requirements of conference call service must be determined in order to decide if further enhancement of this service is justifiable by introducing some complexity into system design; otherwise, this service may have to be eliminated.

4.3 Call Termination Procedure

If a user is shadowed for a long time, there is a need to have a call termination mechanism within the DAMA to reclaim the assigned voice channel and avoid inefficient use of these channels.

A mobile user may experience shadowing while he is travelling. This would result in a warning signal issued from the terminal to the user if the received signal is attenuated extensively for a predetermined length of time. The user will be instructed to try to re-register. If he activates the re-registration feature, then the terminal will try to choose a signalling channel with the strongest received signal power, in case of operating in fringe areas or using the signalling channel it had previously used (if signal blockage is eliminated). If the warning signal were due to roaming into another beam coverage area, re-registration would be successful. However, during the excessive shadowing, re-registration would no longer be successful and the user cannot be accessed by the rest of the users and the DAMA centre for the shadowed period.

Now, let us assume a user is in the process of setting up a call. Before a voice channel is assigned to him, he loses reception of any further messages from the DAMA centre due to signal level being below the designed threshold. The terminal must warn the user of the new happenings in the signalling channels and, depending on the time-out period for call set-up, it may abort the call and re-try the call when the shadowing is diminished. This event would not happen in case of roaming, because of the short call set-up period and the large beam sites.

A more severe situation is when the user is in the conversation mode and he/she is shadowed. The user may decide to hold on to the call or release the channel. Due to lack of connection between the shadowed terminal and the DAMA, the DAMA cannot receive the terminal's on-hook signal. However, the called party would go on-hook and inform the DAMA. The voice channel would be taken away by the DAMA without having to wait for the second on-hook signal. This would prevent inefficient use of the voice channels. The same scenario would be true if the called party is shadowed for a long period instead of the call initiator. Gradual signal attenuation of the voice could also be due to roaming. However, for the short holding time of 20-180 seconds, the "hand-off" procedure seems to be unnecessary for the two-beam configuration. This procedure could be implemented for a system with a large number of beams as well as aeronautical communications.

The most severe case occurs when both parties experience shadowing losses for a long duration almost simultaneously. The DAMA centre cannot be informed by neither party. As a result, the DAMA would time-out, for example, after 3 minutes for MRS users and 5 minutes for MTS users. It monitors the channel and takes it away if there is no voice activity on the channel.

For billing purposes, these calls must be flagged to be treated differently upon user's complaint.

4.4 Log-on/Log-off procedures

The log-on/log-off process is one of the major procedures to be carried out by users/terminals to enable the DAMA to keep a list of users registered in the system at any given time. None of the above procedures can be by-passed. During the log-on procedure, the beam and the signalling channels the user is registered to, will also be recorded. It is desirable to have the least number of log-on/log-off attempts per user during a day. The traffic generated due to these processes is overhead to the system; however, it is assumed that these attempts occur during the non-BH period.

For dynamic assignment of signalling channels, every beam will have a known (fixed) set of Request/Assignment channels. The terminal monitors the signal level of the assignment channels of all the beams. Then it transmits its log-on request via the request channel corresponding to the assignment channel with the highest signal reception level (when mobile is travelling in an overlapped region).

The DAMA responds back and may assign a new set of signalling channels for the mobile to tune to. The log-off procedure will be treated as a call request message and the terminal will automatically initiate this procedure as the power switch is turned off. After reception of the DAMA log-off response, the terminal shuts itself off.

Automatic log-off of unattended terminals (by the terminal) is an annoyance to the users and is considered as a drawback rather than a feature of the system. The terminal could be equipped with a storage mechanism to record the calls when it is unattended and provide some of the features of the telephone answering devices.

4.5 Ranging Procedure

It is necessary to have a mechanism to maintain timing information for the mobile terminals. A terminal adjusts its timing offset at log-on and every successful call request attempt. However, a mobile travelling at 100 km/h for two hours without attempting to make a call, could lose its uplink synchronization since the guard time allowed is only 8 bits. Therefore, at log-on, a timer will be set and it would be reset at every successful call request. If the timer times out after two hours, the terminal will generate a special log-on message (referred to as ranging message). The ranging message should be different from log-on message to avoid the extra processing required for registering a user who has already been registered. The DAMA will provide the time offset information. This activity most likely occurs even during the BH. The overhead traffic generated due to ranging messages is computed in Appendix A.

4.6 Priority Calls

Three major priority level user groups could be defined among MSAT users. These are emergency, voice, and data groups with different G.O.S. The resources will be best utilized by having a common signalling environment among all users. The remaining channels will be grouped into three distinct subgroups of emergency, voice and data. Depending on the history of events, the system will be able to balance the number of channels dedicated to every subgroup at any instant of time. This technique will avoid inefficient use of resources by dedicating a fixed number of channels to each subgroup. The algorithm used for this purpose should avoid starvation of the lower priority groups while it keeps the required G.O.S for other groups.

The introduction of pre-emptive process seems to be the most efficient technique for resource utilization. However, it requires that the users be able to receive commands from DAMA processor even during conversation mode. This requires that:

- terminal should tune to signalling channels continuously
- DAMA be able to transmit pre-emption commands on the voice/data channels

Both of the above techniques introduce complexity into terminal design.

5.0 Data Services

The required data services (DS) could be categorized into two distinct types: short data burst and long data stream transmissions via MSAT terminals. The response time for these services is dependent on the nature of service required by the user. For example, in emergency and interactive services a small delay in the order of 1 to 5 seconds is expected, whereas the response for non-interactive services could be delayed longer. Unfortunately, the statistics regarding the data traffic are not available for analysis at this time.

The long data stream services can be treated the same as the voice services and a voice/data channel would be assigned to provide the transmission medium. The service request message transmission would be via the same signalling channels as the call request messages.

The short data burst transmission is characterized as transmission of approximately 50 characters. For this type of service, it is not practical to assign a dedicated channel for the service duration due to the short transmission period. By allowing these services to use the signalling channels used for other services (i.e. MRS, MTS, etc.) as data transmission media, the performance of the overall system could be seriously jeopardized. It appears at this moment that the best solution would be to dynamically assign a number of channels for short data transmissions. These channels could operate in any of the following modes:

i) Random Access
ii) Demand Assignment TDMA (DA-TDMA)
iii) Polling

Depending on the actual service requirements and traffic characteristics, the above schemes perform differently. The optimum slot size for the above schemes is dependent on the traffic statistics, delay requirements and channel characteristics. Due to lack of proper information on user requirements, the discussion of the performance of these schemes will not appear in this report. However, a brief description of each scheme is given below.

Random Access

The random access schemes to be considered are the following:

i) Pure ALOHA
ii) Slotted ALOHA
iii) Reservation ALOHA

In short data transmissions, approximately six packets would be transmitted for a complete message of 50 characters (where a packet is 150 bits long and a character is 7 bits long). As a result, pure ALOHA and slotted ALOHA would not be recommended due to long delay experienced for successful transmission of all the packets.

In reservation ALOHA, the channel is divided into two different size slots. The smaller slots are used by a user to request for reservation of a larger slot. After accessing the large slot, the user is the sole user of that slot in the next frames until reception of the acknowledgment of the user's last packet. During this period, the control centre acknowledges reception of every data packet individually and the last packet is flagged to inform the controller.

DA-TDMA

In this scheme the user would request for data services using the same signalling channels as those used for voice services. The data packets format is shown in Appendix B. The user would specify its own I.D., the destination I.D. and the number of packets to be transmitted for a message. The DAMA would acknowledge the reception of the request and specify the data channel and slot number in the frame as well as a reference number to be attached to all the data packets to be sent for a message. The reference number prevents the repetition of I.D. number in the data packet. It is also a measure of protection for received packets against any possible errors in transmission. The channel used for transmission of data packets is of DA-TDMA type. This is a very efficient technique for an environment with large number of users generating bursty type traffic.

Polling

Polling scheme in satellite environment would be a recommended scheme where the traffic is generated at random and the propagation delay to terminals is fixed. The terminals then could be polled in a predefined order and the polling responses would be received in an expected order. However, in a mobile environment the sychronization of poll responses is a very difficult task if the poll request is transmitted to the next terminal before the reception of response from the last polled terminal. Due to the long propagation delay, polling in "Stop and Wait" manner is not practical either. Polling cannot be considered as a candidate access scheme for MSAT data services due to its inefficiencies.

5.1 Recommendation

Among the schemes discussed for DS, reservation ALOHA and DA-TDMA are the most suitable techniques. In reservation ALOHA the DS is completely separated from other services; however, DA-TDMA would use the same signalling channels as used for other services. This may result in performance degradation of other services, if the traffic generated by data service users is an addition to the existing traffic statistics. The performance trade-offs between these techniques is a subject for further study.

6.0 DAMA Design for L-band

This section is intended to provide the preliminary outcome of the DAMA studies conducted for L-band services. According to the latest analysis undertaken for the MSAT baseline system, the following assumptions were made:

- Traffic distribution as given in Figure 2.2.
- The average BH offered traffic of 0.0106 Erlangs/user
- Maximum capacity of 25,000 users subscribing to MSAT L-band services
- Uniform distribution of users among four L-band beams
- Message structure as given in Appendix B
- Fade statistics as given in Appendix J
- No L-band to L-band cross-strap

6.1 System Architecture

The DAMA system architecture for L-band services would be of a centralized configuration and preferably co-located with the DAMA controller for UHF services as discussed in section 3.1. There will be the requirement of having one processor per L-band beam. The reliability and flexibility requirements of the L-band DAMA would be similar to those discussed in section 3.1.

6.2 Signalling Requirements

The access schemes discussed in section 3.3 were considered for L-band services. Based on the analysis shown in Appendix J, the probability of packet loss on forward and reverse links is 11% and 11.6% respectively. The delay performance curves for both slotted ALOHA and reservation ALOHA are given in Figure 6.1 assuming that the messages are not repeated on the Assignment channel. Figure 6.2 presents the delay performance assuming the messages are repeated 3 times on the Assignment channels.

For the case of messages transmitted only once on Assignment channel, 3% of call requests would be rejected due to packet loss or collision in the reservation ALOHA mode. In the slotted ALOHA mode 0.85% of call requests would be rejected. However, from Figure 6.2, with repetition of messages on Assignment channels, the call request rejection rate would be reduced to 1% and 0.25% for reservation and slotted ALOHA schemes, respectively.

It is, therefore, suggested to use slotted ALOHA together with Token scheme for L-band services. Furthermore, there is a need for a mechanism to identify the elevation angle of users to allow for repetition of messages from DAMA centre for those users at the elevation angles less than 20°, as discussed for the UHF case.

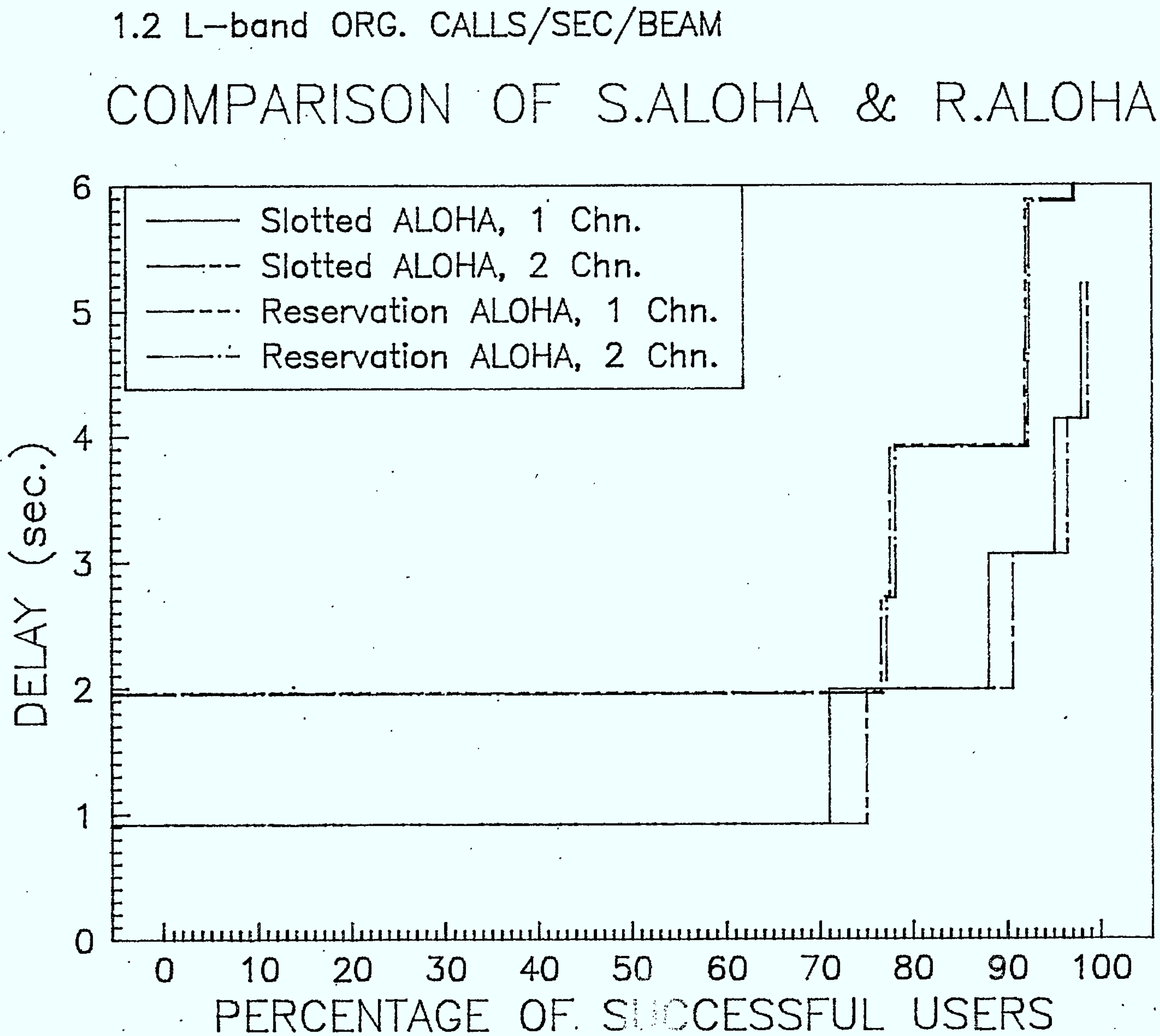


FIGURE 6.1 Delay performa   or L-band users located at
20° elevation   when Delta(EIRPs) = 0 dB
and packets   smitted only once on
Assignment

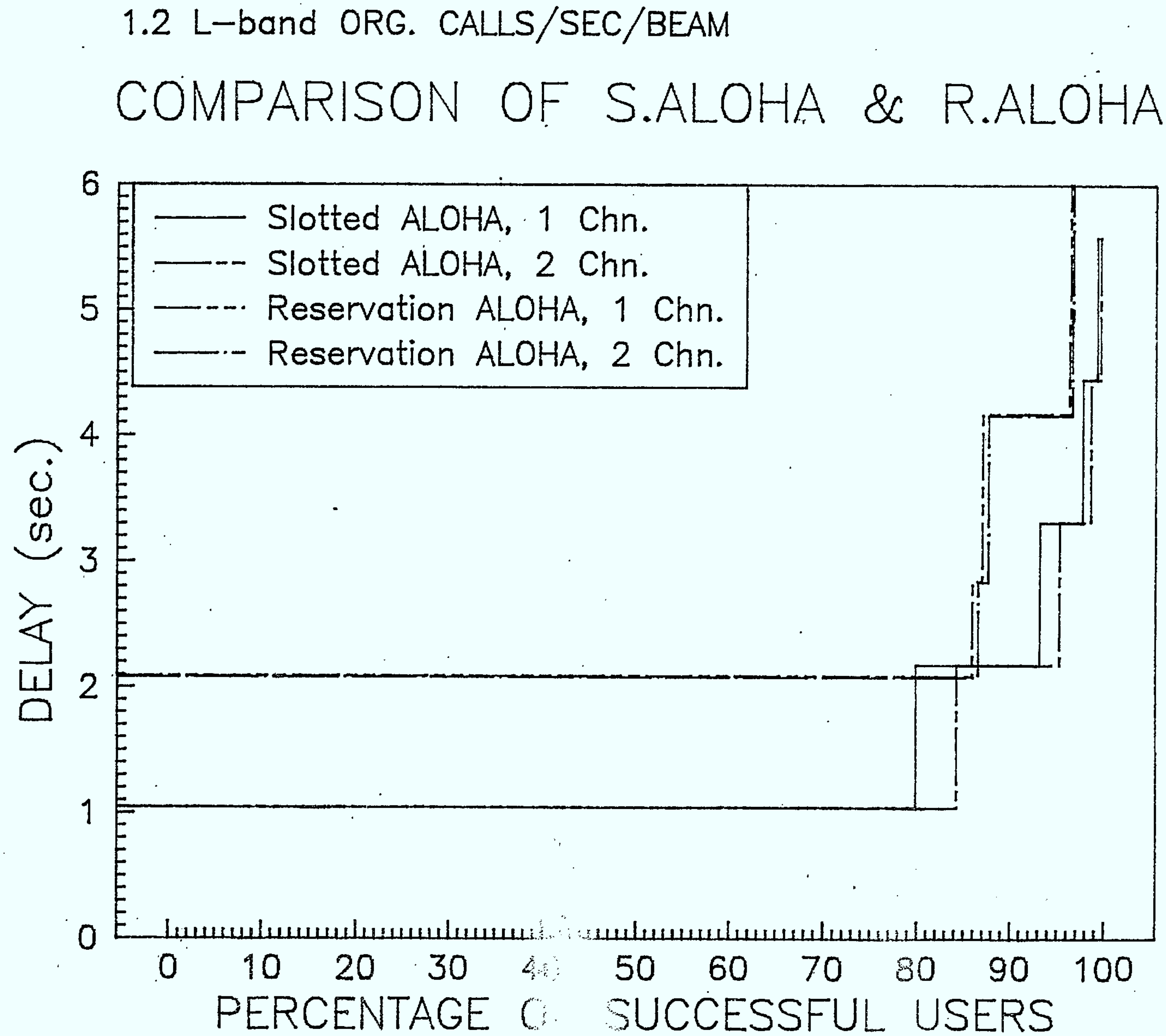


FIGURE 6.2 Delay performan... L-band users located at 20° elevation ... en Delta(EIRPs) = 0 dB and packets ar... d 3 times on Assignments channels.

7.0 Conclusions

The DAMA system requirements for mobile communications via a geostationary satellite have been studied in this report and several technical network design issues have been addressed. The major technical issues discussed in this report are:

- DAMA system architecture
- Network configuration
- Signalling requirements

The DAMA processor is one of the main elements of MSAT. The successful execution of the DAMA algorithm requires close interactions between various pieces of control software residing in different network elements. The required algorithms for proper operation of the DAMA are detailed signalling specifications related to connection establishment/release, information transfer, error control/recovery and call handling procedures among various elements. The proposed integrated DAMA scheme is relatively new and future work plans should devote a substantial portion of the design effort to the software engineering.

The MSAT system will be centrally managed by a Network Control System (NCS). The major constituent elements of the NCS are the DAMA and the Network Management System (NMS). The DAMA is responsible for short term network supervision while the NMS is in charge of the overall control of the MSAT system. The records regarding the usage of system equipment and resources would be gathered by the DAMA and sent to the NMS for billing purposes and to effectively plan long term system modifications and upgrades.

A centralized DAMA controller colocated with the MRS Switching Centre is presently viewed to be the preferred approach in conjunction with a distributed structure for the MTS gateway stations. The MRS SC is responsible for channel switching of double-hopped calls and for monitoring the channels.

The system architecture should allow for modular design of the communication network as a means for timely infusion of new technologies. This will permit a smooth transition to the follow-on generations without requiring an unacceptably large capital outlay for the first generation DAMA.

For maximum system flexibility within and in transition between generations, the satellite channel resources would best be utilized through a dynamic channel partitioning scheme. The DAMA will optimally distribute the satellite capacity in a manner consistent with the offered traffic from various user categories over a 24-hour period. This would permit realization of a more stabilized access protocol in the presence of unexpected traffic variations and a more orderly and rapid traffic transfer to a back-up satellite in the event of a catastrophic failure.

A similar DAMA architecture for Canada and U.S. is highly desirable to allow sharing a greater portion of the non-recurring engineering and software development costs. However, a joint DAMA back-up capability is a concept which requires further detailed trade-off studies to quantify the real advantages as well as the associated cost implications.

The numbering plan is one of the major design issues for the MSAT system. The MRS and MTS are quite distinct in terms of the type of connections they provide to their respective users. The MRS numbering plan can be an innovative one to connect users within a community. However, the proposed MTS numbering plan should satisfy the following criteria:

- compatibility with the existing PSTN
- minimization of toll charges

The most cost effective solution for MSAT users appears to be a single dedicated area code for MTS services which would be shared with all the MSAT operators in North America.

The performance of the signalling channels among the various components of the DAMA has been investigated for two candidate access techniques: namely, Reservation ALOHA and Slotted ALOHA, with Token scheme. The key issues considered in the selection of the most appropriate access scheme are:

- the number of signalling channels to support the expected traffic load
- the delay experienced for a successful call set-up
- stability of the channels
- terminal complexity

The relative performance of the above schemes has been studied under the following operational conditions:

- UHF mobile users in geographical areas limited by15° elevation angle to the satellite
- UHF mobile users in areas limited by 20° elevation angle
- L-band mobile users in areas limited by 20° elevation angle

The results of these studies indicate that the combination of Slotted ALOHA scheme for call requests and Token scheme for ACK/on-hook/off-hook signalling is the optimum approach as opposed to a combination of Reservation ALOHA and Token schemes.

Among the signalling schemes considered for data services, reservation ALOHA and DA-TDMA were found to be the most suitable techniques for transmission of bursty data traffic. However, due to a lack of information, the performance trade-offs between these schemes were not discussed in this report.

7.1. Areas to be Studied

There are a number of issues to be studied further as the MSAT project progresses. The complete discussion of these issues was not in the scope of this report. Furthermore, some issues were not discussed in this report due to lack of information or due to limited time. The areas to be explored are:

- The MTS numbering plan is an unresolved issue. It is desirable to have a dedicated area code for MSAT; however, due to lack of NPA's, it could be a difficult task to satisfy the numbering coordinators for North America. It is worth mentioning that the remaining unassigned NPA's will be exhausted by the year 1995 [5]. However, most of the switches must be modified until then to accommodate new NPA's (new area codes). As a result, this issue must be investigated in more details in order to determine an optimized solution which is agreeable to both Telesat and Telcos.

- The statistics regarding the required data services via mobile terminals are not available at the moment. These statistics are most needed to decide upon an acceptable system design as well as an appropriate signalling scheme for data services.

- It is desirable to have a joint agreement with the U.S. licencee(s), to provide service back-up in case of a catastrophic failure to either the Canadian or U.S. system. This would influence the system design in the following areas:
  - Identical structure for both systems
  - Sufficient capacity of signalling
  - Processor requirements

- The DAMA hardware and inter-connection among processors must be studied in more detail to identify the processor power and speed requirements.

- It is essential to conduct a detailed study on the required NMS characteristics and its role in the MSAT system.

- The billing requirements and regulations for the MSAT should be identified, since they would influence the DAMA system design.

- The study of dual-band DAMA for combination of UHF and L-band services.

- The study of signalling requirements for SHF signalling channels.

8.0 References

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APPENDIX A

Computation of Call Rate

A.1.0 Busy Hour Traffic Intensity

To extract the busy hour traffic from the data provided by market analysis studies, the following equation from [2] would be used:

$$E_{BH} = C1.C2.C3.Tx/60$$

Where:

E_{BH} = Busy-hour offered traffic in Erlangs

C1 = A fraction defining that portion of the daily traffic concentration in the busiest hour of the day = 0.074

C2 = A coefficient which takes into account the busiest period of the year = 1.206

C3 = The ratio of the peak weekday airtime to the total airtime during an average month = 0.0415

Tx = MSAT share of the total airtime offered during an average month(min/month)

For the given Tx = 150 min/month/user the BH offered traffic intensity per user will be:

$$E_{BH} = 0.009259 \text{ Erlangs/user}$$

The Effective E_{BH}, discussed in section A.3.0, should account for any possible voice circuit wastage such as the successful transmission of voice channel assignment to both call parties during call set-up or delay involved in the call take-down procedure.

The Effective E_{BH} will affect the required number of voice channels to support this traffic; however, E_{BH} will be used to compute the average number of call attempts per user.

A.2.0 Call Attempt Rate

The total number of call attempts at the busy hour (N_{CBH}) by users within a beam is obtained by adding up the number of calls contributed from each of the two distinct services of MRS and MTS according to the traffic distribution given in Figure A1.

$$N_{CBH} = \sum_{i=1}^{2} E \times L_i / d_i \qquad \text{(calls/sec/user)}$$

where:

d_i = call holding time in seconds for service i

L_i = system loading for service i

E = total traffic per beam

The call holding times are taken to be 180 seconds and 20 seconds for MTS and MRS services respectively.

$$N_{CBH} = E(L_{MRS}/20 + L_{MTS}/180)$$

It is of great importance to distinguish between UHF and SHF originated calls. The SHF base stations and PSTN originated calls access the SHF signalling channels. Table A1 describes the messages transmitted on different signalling channels for various call scenarios.

The following table describes the percentage of traffic generated using UHF or SHF access channels.

	UHF Originated %	SHF Originated %
MRS	39.38	35.62
MTS	19.06	5.94

As a result, the average number of UHF originated call attempts per second per beam is:

N_{CBH} = 0.009259 x 17500 (0.3938/20 + 0.1906/180)

N_{CBH} = 3.36 UHF originated calls/sec/beam

N_{CBH} = 2.94 SHF originated calls/sec/beam

Total = 6.30 Calls/sec/beam

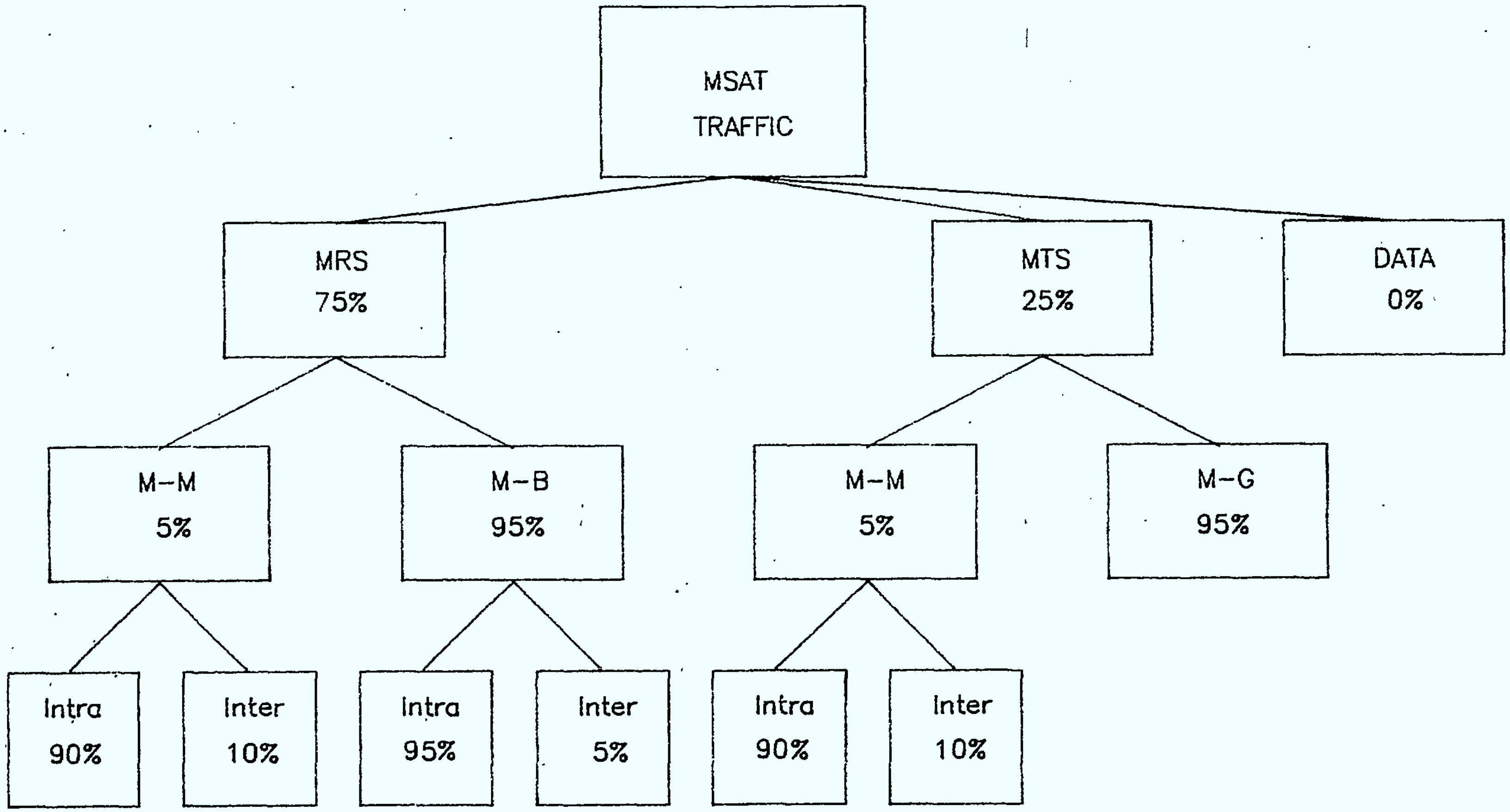
The average number of SHF generated calls/sec/beam would be used to compute the number of token slots in the Token channel. From the total number of calls/sec/beam as well as the percentage of total traffic generated by each particular service (provided in table A1), the average number of messages required to be transmitted by the DAMA processor via forward link channels is computed to be 2.02 packets/call attempt.

List of abbreviations for Table A1.

ACK	Call Acknowledgement
CI	Call indication
CR	Call request
CT	Call termination
OFH	Off-hook
ONH	On-hook
RB	Ringback
REJ	Call reject
RG	Ringing
VC	Voice channel assignment

SERVICE TYPE	SUCCESSFUL OR UNSUCCESSFUL	UHF SIGNALING CHANNELS		SHF SIGNALLING CHANNELS		VOICE CHANNEL	PERCENTAGE OF CALLS	PERCENTAGE OF TRAFFIC
		ACCESS	ASSIGNMENT	ACCESS	ASSIGNMENT			
MTS								
Mobile To PSTN	S	CR, ONH, ACK	ACK, RB, VC	OFH, RG, ONH, ACK	CI, VC	CT	2.54	17.8
	U	CR	REJ	REJ	CI	–		
PSTN to Mobile	S	OFH, ONH, ACK	RG, VC	CR, ONH, ACK	RG, VC	CT	0.84	5.95
	U	–	–	CR	REJ	–		
M-M	S	CR, OFH, ONH, ACK	RB, VC(2)	–	VC	CT	0.17	1.25
	U	CR	REJ	–	–	–		
MRS								
M-M(UHF-BS)	S	CR, OFH, ONH(2), ACK	RB, VC	–	VC	CT	4.81	3.75
	U	CR	REJ	–	–	–		
M to SHF-BS	S	CR, ONH, ACK	RB, VC	OFH, ONH, ACK	VC, RG	CT	45.6	35.63
	U	CR	REJ	–	–	–		
SHF-BS to M	S	OFH, ONH, ACK	RB, VC	CR, ONH, ACK	RG, VC	CT	45.6	35.63
	U	–	–	CR	REJ	–		

TABLE A1: REQUIRED MESSAGES FOR DIFFERENT CALL SCENARIOS



UHF gen.	100%	100%	50%	50%	100%	100%	75%
SHF gen.	0	0	50%	50%	0	0	25%
No. of voice ch. per call	1	2	1	1	2	2	1

FIGURE A1 MSAT TRAFFIC DISTRIBUTION

A protocol overhead which contributes to the traffic on access channels is the transmission of ranging messages. Ranging is the process of requesting timing information after 2-hours of service during which no call attempt has occurred. The ranging request is one call (message) by itself which is considered as overhead of the system and will occupy a portion of the signalling channels. This overhead will also occur during the busy-hour period. As a result, it must be added to the overall traffic generated by users for the call requests.

The average BH call attempt rate = 0.691 UHF originated calls/hour/mobile user

$$\text{Prob(k call attempts in t for a call) rate of M calls/hr} = e^{-Mt}\frac{(Mt)^k}{k!}$$

$$\text{Prob(No call attempts in 2 hours)} = e^{-Mt} = e^{-2x0.691} = 0.251$$

The upperbound for the number of ranging messages transmitted is 0.251 calls per two hours assuming all of the users in a beam (17500) are active. The average call attempt rate per hour (N) is:

$$N=E(k) = \sum_{k=0}^{\infty} k.P(\text{k call attempts in one hour})$$

However, since for k=0 the terminal would transmit a message, the above equation must be modified to compute the average total call attempt rate (N_T):

N_T = P(0 attempt in t) + $\sum_{k=1}^{\infty}$k.P(k call attempts in t)

N_T = 0.251 + 2N

N_T = 0.251 + 2 x .691

N_T = 1.633 UHF originated calls/2hr/mobile user

N_T = 3.97 UHF originated calls/sec/beam

A.3.0 Voice Channels

The number of voice circuits required per beam for a given grade of service is determined from the well-known Erlang B formula.

$$P_B = \frac{E^N}{N!} \Bigg/ \sum_{i=0}^{N} \frac{E^i}{i!}$$

Where E = Busy-hour traffic per beam in Erlangs

N = Number of voice circuits per beam

P_B = Blocking probability

The Effective BH traffic intensity is calculated according to the average air-time usage by a terminal. All the services would use one uplink/downlink pair of voice channels except the interbeam double hop and Mobile to Mobile MTS services which require two channel pairs. These particular services would increase the traffic by $(e_R L_R + e_T L_T)\%$. As a result, E should be modified to account for these increases.

L_R = effective system loading by MRS subscribers
L_T = effective system loading by MTS subscribers
e_R = fraction of MRS traffic involving two voice channels
e_T = fraction of MTS traffic involving two voice channels

The following assumptions are made.

MRS (HALF DUPLEX)

- all intrabeam UHF-SHF-UHF and interbeam UHF-SHF calls would use one UHF channel pair
- all interbeam UHF-SHF-UHF calls would use two UHF channels pairs

MTS (FULL DUPLEX)

- the mobile-mobile communication uses two UHF channel pairs for both intrabeam and interbeam calls.

From Figure A1 the following ratios could be extracted:

MRS M-M: all interbeam calls use UHF-SHF-UHF
5% x 10% of MRS traffic

MTS M-M: this service uses two UHF channel pairs
5% of MTS traffic

Finally the values of e_R and e_T could be calculated as follows:

$e_R = 0.1 \times 0.05 = 0.005$
$e_T = 0.05$

Effective system load for different services would be calculated as follows:

$L'_R = L_R (1 + e_R) = 0.75 (1 + 0.005) = 0.754$
$L'_T = L_T (1 + e_T) = 0.25 (1 + 0.05) = 0.262$

Therefore, the effective E_{BH} traffic due to assignment of two voice channels per call as well as accounting for any possible voice circuit wastage is:

Effective $E_{BH} = E_{BH} (1 + Su) (L'_R + L'_T)$
Su = fraction of time the voice circuit is wasted.

Since deffered voice channel assignment is used, Su is taken to be approximately 0.15; otherwise, for immediate voice channel assignment, Su is more likely to be equal to 1. Thus,

Effective $E_{BH} = E_{BH} \times (1 + .15) \times (0.754+0.262)$
$= 0.0108$ Erlangs/user

APPENDIX B

User Access Protocol Message Specification

B.1.0 Introduction

In this Appendix the detailed structure of the message packets required for signalling between the DAMA processor and the mobile user terminal is specified.

The empty fields are left for any additional features to come. At the time being they are set to 0's or 1's.

The call originator ID field is 24 bits for both MRS and MTS mobile terminals. The called party ID field is 24 bits in MRS and 34 bits for MTS.

In case a dedicated area code for the MSAT services is available the 24-bit address field accommodates the unique 7-digit MTS telephone number. However, in case of no dedicated area code we have acquired a look-up table for MTS telephone numbers where every 10-digit MTS telephone number will be represented by a unique 7-digit number to be used internally by DAMA system.

The service type field is 3-bit long to allow for distinction among various services such as MRS, MTS, DATA, etc. Another bit will be used to distinguish between the U.S. and Canadian customers.

B.2.0 Request Packets

Figure B.1 depicts the message format of the various messages transmitted over the request channel. The fields are:

UW	Unique Word
UID A	requesting user number
UID B	Called party telephone number
TYP	Service type (MRS,MTS,DATA....)
A/C	American or Canadian user
Status	Terminal status
Tokc	Channel ID for originator's token channel
Slot	Token slot number assigned to originator
Beam	Alternative beam ID
CKS	Check Sum
GRDT	Guard Time

B.3.0 Assignment packets

Figure B.2 depicts the message format sent by DAMA processor for the various messages using the assignment packet. The fields are:

UID	User/subnetwork identification number
Slot	Token slot number (0-255)
M	Modulation bit
Token	Token Channel token slot block number
TIM	Terminal timing correction factor
TOKC	Token Channel assignment
REJ	Call rejection reason
RESC	Reservation channel assignment
BID	Assigned beam
POW	Power level
CA	Voice channel assignment
TYP	Service type
CKS	Check sum
A/C	American or Canadian user

MRS	15	1	3	24	24	4	20	12	15
point-to-point call request	UW	A/C	Type	UID_A	UID_B	0000	CKS		GRDT
Broadcast call request	UW	A/C	Type	UID_A	UID_B	0001	CKS		GRDT
Abort on-hook	UW	A/C	Type	UID_A	UID_B	0010	CKS		GRDT
Status report	UW	A/C	Type	UID_A	Status	0011	CKS		GRDT
Log-off request	UW	A/C	Type	UID_A		0100	CKS		GRDT
Add-on request	UW	A/C	Type	TOKC Slot	UID_B	0101	CKS		GRDT

10 8

	15	1	3	24	3	4	20	60
Log-on request	UW	A/C	Type	UID_A	Beam alt	0110	CKS	GRDT
Ranging request	UW	A/C	Type	UID_A		0110	CKS	GRDT

MTS	15	1	3	24	34	4	20	2	15
Mobile-to-Mobile call request	UW	A/C	Type	UID_A	UID_B	0000	CKS		GRDT
Mobile-to-land call request	UW	A/C	Type	UID_A	UID_B	0001	CKS		GRDT
Land-to-Mobile call request	UW	A/C	Type	UID_A	UID_B	0010	CKS		GRDT
Abort on-hook	UW	A/C	Type	UID_A	UID_B	0011	CKS		GRDT
Status report	UW	A/C	Type	UID_A	Status	0100	CKS		GRDT
Log-off request	UW	A/C	Type	UID_A		0101	CKS		GRDT
Add-on call request	UW	A/C	Type	TOKC Slot	UID_B	0110	CKS		GRDT

10 8

	15	1	3	24	3	4	20	60
Log on request	UW	A/C	Type	UID_A	$Beam_{alt}$		CKS	GRDT
Ranging request	UW	A/C	Type	UID_A	UID_B	0001	CKS	GRDT

Figure B.1: request packet format

	15	1	3	24	4	10	8	1	5	6	20
Ringing											
Ring back	UW	A/C	Type	UID	0000		Slot		TOKEN	TIM	CKS
Call rejection	UW	A/C	Type	UID	0001	REJ			TOKEN	TIM	CKS
Ring & Channel Assignment	UW	A/C	Type	UID	0010	CA	Slot	M	TOKEN	TIM	CKS
Abort call	UW	A/C	Type	UID	0011	CA	Slot	M	TOKEN	TIM	CKS
Shed command	UW	A/C	Type	UID	0100				TOKEN		CKS
Status command	UW	A/C	Type	UID	0101				TOKEN		CKS
log-off response	UW	A/C	Type	UID	0110					CKS	
log-on response	UW	A/C	Type	UID	0111	TOKC	BID/RESC/POW			TIM	CKS
Ranging response	UW	A/C	Type	UID	1000					TIM	CKS
Call Ack	UW	A/C	Type	UID	1001				TOKEN	TIM	CKS
Call indication	UW	A/C	Type	UID	1010		Slot		TOKEN		CKS

Figure B.2: Assignment Format

B.4.0 Data Packets

Figure B.3 depicts the message formats required for transmission of data using slotted ALOHA scheme.

NP	Number of data packets
PN	Packet number (0 - 16)
REF	Reference number assigned to a task
DATA	Information to be transmitted
Slot	Slot number in data channel
CA	Data channel number

	15	1	3	24	34	4	20	15
Data transmit request	UW	A/C	Type	UID_A	UID_B	NP	CKS	GRDT

	15	4	4	60	20	15
Data packet	UW	REF	PN	DATA	CKS	GRDT

	15	1	3	24	4	10	3	6	20
DAMA response	UW	A/C	Type	UID_A	REF	CA	Slot	TIM	CKS

Figure B.3: Data packets format

APPENDIX C

Guard Time

C.1.0 GUARD TIME REQUIREMENTS

Table C1 shows the guard time required among the location of DAMA centre and the most extreme South/North points in the coverage area for various combinations of elevation angles. The elevation angle of 30° may be chosen as the possible location of DAMA centre, since most of the major Canadian cities are located on this elevation angle belt. The most extreme South point for CONUS is at about 60° elevation as shown in Figure C1 for the satellite longitude of 106.5° W.

Table C2 describes the possible options for guard time for Canada coverage as well as North American coverage. From this table, the best possible option is case 3 with the required 41 bits of guard time when DAMA centre is located at 30° elevation angle and the coverage area is from 5° to 60°. However, due to uncertainty of the DAMA centre location, we assume a guard time of 48 bits when the DAMA centre is located at 35° elevation angle (most Southern Canadian covered point) and coverage area is between 5° and 60° elevation angles.

In case of joint back-up with the U.S., during the back-up period by the U.S. system, the Canadian mobiles located at low elevation angles may suffer depending on the location of the U.S. DAMA centre (using Canadian satellite). Furthermore, depending on the longitudenal location of U.S. satellites during the satellite backup mode, the Canadian users may suffer due to the lack of sufficient guard time allowed within the packet structure used for signalling purposes among Canadian system components.

	MOBILE LOCATION (DEGREE)			
DAMA CENTRE (degree)	EXTREME NORTH	EXTREME SOUTH	EXTREME SOUTH U.S.A	GUARD TIME (bits)
30	10			32
30	5			41
30		35		8
	5	35		48
	5		60	75
30			60	34
		35	60	27
	10	35		39
	5	10		9

TABLE C1: VARIOUS ELEVATION ANGLES

CASE	1	2	3	4	5	6	7	8
North	5	5	5	5	10	10	10	10
DAMA Centre	30	35	30	35	35	30	30	35
South	35	35	60	60	35	35	60	60
G. Time (bit)	41	48	41	48	39	32	34	39

TABLE C2: GUARD TIME REQUIREMENTS FOR VARIOUS COVERAGE AREAS

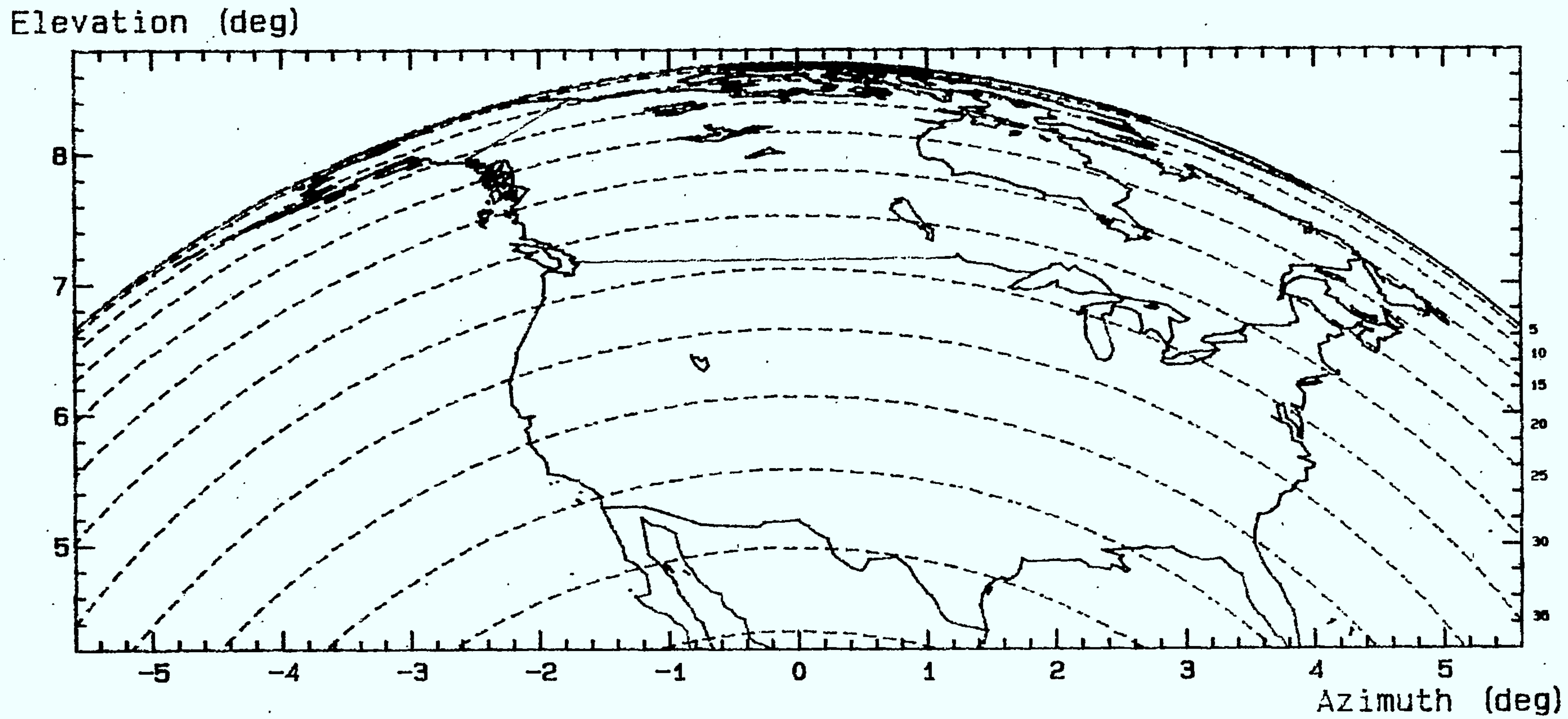


FIGURE C1 : ELEVATION ANGLE CONTOURS; SATELLITE LONGITUDE 106.5 W

APPENDIX D

Number of Token Channels and

Delay Calculations

D.1.0 The number of Token Channels

The Token channels are used for transmission of on-hook/off-hook messages and acknowledgments to DAMA messages by involved UHF users. The key criterion in assigning the proper number of token channels is the number of token slots required.

The token slots will be assigned and used as follows:

- After the DAMA responds to a call request, it assigns one slot to the called UHF party. The called party will immediately acknowledge the reception of this message by inserting a token in its designated slot. Then it will send a second token in its slot if it goes off-hook. Both parties will transmit a token in their slot after reception of voice channel assignment message as well as when they go on-hook.

The offered traffic at BH per beam is:

0.0106 x 17500 = 185.5 Erlangs/beam.

Five percent (5%) of it involves two mobile users and two token slots are required, while each of the other calls in progress needs only one token slot. The number of voice channels required to support a G.O.S. of 15% is 163 according to Erlang B table. However, for 95% of given traffic 155 token slots would be used where the other 5% would require 2 x 11 = 22 token slots. As a result, 176 token slots would be needed to handle the on-hook messages for calls in progress. Considering an average of 15 seconds called party response time and call rate of 2.94 SHF originated calls/sec/beam plus 0.17 calls/sec/beam of M-M type, there is a requirement of 47 token slots for calls awaiting an off-hook message.

However, if a significant percentage of calls are not answered, the number of token slots must be increased to compensate for unanswered calls in order to utilize the voice channels as much as possible.

This scenario has been simulated in [1] and by approximation the number of unanswered calls can be estimated to half of the calls awaiting an off-hook signal.

The total number of tokens = 176 + 47 x 1.5 = 247

Having a 2400 bps token channel divided into 15-bit slots allows for 160 slots. Two token channels (providing 320 token slots) will be sufficient to handle the given average call rate.

D.2.0 Probability distribution of successfully transmitted packets:

In order to be able to distinguish packets transmitted in a given slot as being either newly generated or one collided with other packets previously, the following analysis is done [6].

Let:

q = prob. [newly generated packet is successfully transmitted]

q_t = prob. [previously collided packet is successfully transmitted]

K = the number of slots in which retransmission of a collided packet would occur at random.

S = the number of packets transmitted successfully in one slot time.

G = the number of packets offered to the channel in one slot time.

The following relationships are derived:

$$S = Gq_t/(q_t + 1 - q)$$

$$q = [e^{-G/K} + (G/K)e^{-G}]^K \; e^{-S}$$

$$q_t = [1/(1 - e^{-G})] \; [e^{-G/K} - e^{-G}] \; [e^{-G/K} + (G/K)e^{-G}]^{K-1} \; e^{-S}$$

$$q_t \simeq (K - 1)e^{-G}/K$$

The above equations form a set of non-linear simultaneous equations for S, q and q_t. For our purposes K is taken to be six slots. The values of G, q and q_t are calculated for S and K.

A transmitted packet would be received successfully at the reception site if it has not collided with another packet or has not been damaged due to shadowing/fading effects. As a result, the values for q and q_t obtained would be affected by the probability of packet loss (PL).

$$q = q \times (1 - PL)$$
$$q_t = q_t \times (1 - PL)$$

Let's define:

M = number of retransmissions of a packet before it is successfully transmitted.

The probability distribution of M can be obtained as follows [8]:

$$\text{Prob}(M = 0) = q$$
$$\text{Prob}(M = 1) = (1 - q)q_t$$
$$\text{Prob}(M = 2) = (1 - q)(1 - q_t)\, q_t$$
$$\text{Prob}(M = 3) = (1 - q)\,(1 - q_t)^2\, q_t$$

$$\text{Prob(Rejection)} = 1-q-\sum_{i=0}^{2} (1-q)\,(1-q_t)^i\, q_t$$

D.3.0 Delay Analysis

The following delay analysis for slotted ALOHA and Reservation ALOHA access techniques are carried out assuming:

D = average call set-up delay

R = one-way propagation delay = 270 ms

K = the maximum number of slots a user waits after time-out for acknowledgement reception before retransmitting = (6 slots)

T = packet transmission time = 62.5 ms

r = average retransmission delay due to randomized waiting=(K-1)/2

The call set-up period accounts for the time from transmission of first indication of call request until the successful reception of the ringing/ringback message.

D.3.1 Slotted ALHOA

The relationship between average call set-up delay (D) and throughput (S) is as follows:

$$D=(G/S-1)(2R+4.5T+r+Dp)+2R+4.5T+Dp$$

where:

$G/S-1$=prob(retransmission due to collision or loss)

$S = Ge^{-G}(1-P_R)(1-P_F^3)$

P_F = prob(packet loss due to fading on forward link)

P_R = prob(packet loss due to fading on reverse link)

Dp = processing delay

The average ringing message transmission delay is taken to be 3 slots, since this message will be transmitted three times during six slot period.

Figure D1 describes the average throughput of the channel versus average delay for the MSAT baseline link budget. According to Appendix F, the P_F is 0.54 which will be decreased to 0.16 after three transmissions. Moreover, it is assumed that the user is provided with a fade status light indicator which is adjusted to the threshold considered light shadowing environment. The user will make a call request under light shadowing conditions where $P_R = 0.013$.

In section D.2, the probability distribution of successful transmissions was computed. Now, the delay for various number of retransmissions would be calculated as follows:

$$Delay(M) = 2R + 4.5T + DP + M(2R+4.5T+DP+r)$$

where M= 0,1,2,3

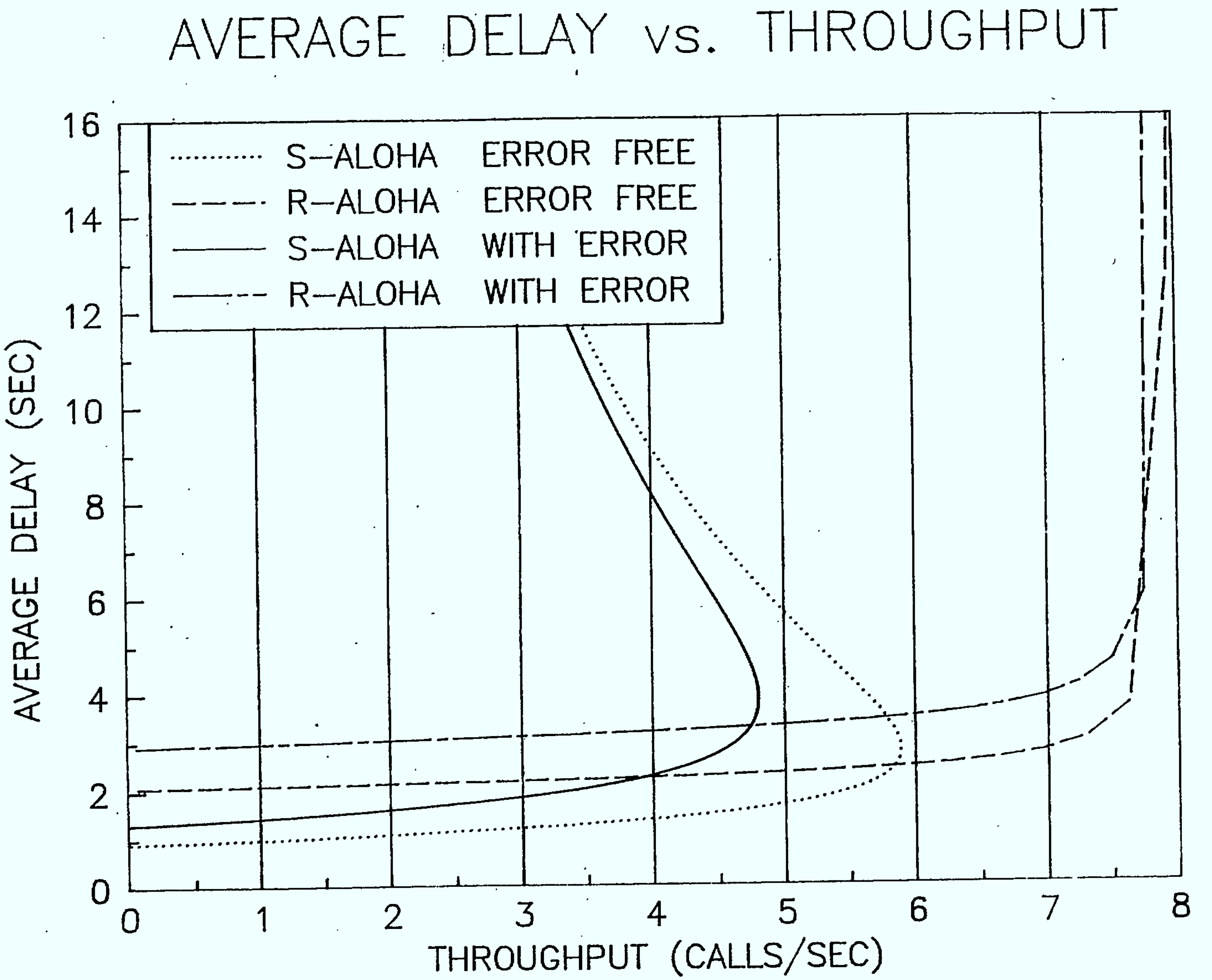


FIGURE D1 Average delay performance for error-free channels and channels with errors for users at 15^{o} elevation angle where Delta(EIRPs) = 0 dB and call attempt under light shadowing conditions, packets repeated 3 tomes on Assignment channels.

D.3.2 Reservation ALOHA

Having the number of call attempts for every beam, the number of signalling channels could be determined to support the traffic load for the average delay imposed by the user and system requirement.

The mini-slots are accessed in a slotted ALOHA mode. There are 80 mini-slots/sec on the 2400 bps channel. The throughput of the system is the same as the number of call attempts per slot duration denoted as S.

S = UHF originated call attempts per sec./80 packet/slot

The offered traffic (G) of a slotted ALOHA channel could be obtained from the following equation:

$$S = Ge^{-G}\ (1-P_R)\ (1-P_F^3)$$

P_R = prob(packet loss due to fading in reverse link)
P_F = prob(packet loss due to fading in forward link)

If the reservation message is not successful (no slot assignment received), it will repeat the procedure. The probability of this is equal to probability of packet loss as well as token loss due to fading. Collision in mini-slots cannot be detected and it will not contribute to the delay experienced in the primary portion of call set-up procedure.

The average delay associated with obtaining a slot reservation (Dr) is computed as follows:

$$Dr = (DA+2R+DP1+1.5T)\ (1/(1-P_T)\ (1-P_F{}^2))$$

where:

Da = average delay to access mini-slot = T/2

DP1= average token processing delay = 1.5T

P_T= prob(Token loss due to fading) = .002

P_F= prob(Assignment packet loss due to fading)

Probability of slot assignment packet loss is decreased by transmitting the packet twice on the RAC channel.

The average delay (D) for the overall call set-up procedure can be defined as:

$$D = (DP+Dr+Dd+Dq+2R+DP2+4T)\ (G/S)$$

where:

Dd = the initial average dialing access delay = T/2

DP2= terminal processing delay = 150 ms

Dq = the average slot reservation queueing delay

The average queueing delay experienced by a reservation message (Dq) is:

$$Dq = [(u/(1-u))\ (1-u/2)]\ /(\text{UHF originated calls per sec})$$

Where U = UHF originated calls per sec/No. of large slots per frame.

The delay for various number of retransmissions would be calculated as follows:

When the slot reservation for call set-up procedure does not fail at all,

$$Delay (M) = (Dp+D1+Dd+Dq+2R+DP2+4T).(M+1)$$

where $D1 = Da+2R+DP1+1.5T$
$M = 0,1,2,3$

Otherwise:

$$Delay(M) = (Dp+2D1+Dd+Dq+2R+DP_2+4T).(M+1)$$

APPENDIX E

Further Consideration to enhance

Signalling Channels performance

E.1.0 ANALYSIS OF ASYNCHRONOUS SLOTTED ALOHA

The following analysis is provided to prove that slotted ALOHA would perform in the worst situation same as pure ALOHA if synchronization is totally lost in the channel.

The number of packets transmitted successfully in one slot duration (S) depends on the actual number of packets transmitted during one slot (G) and probability of the vulnerable period being empty (P_o).

$$S = GP_o \qquad \text{packets/slot}$$

For pure ALOHA, the vulnerable period is equal to two slots. The probability that K packets are generated during a given interval (or vulnerable period) with average arrival rate of G (packets/slots) would be given by the poisson distribution:

$$Pr[K] = (G^K e^{-G})/K!$$

The probability of zero packets for the interval of two packet times long is:

$$P_o = e^{-2G}$$

therefore:

$$S = G e^{-2G} \qquad \text{packets/slots}$$

For slotted ALOHA, the vulnerable period is only one packet time long, resulting in:

$$S = Ge^{-G} \qquad \text{packets/slots}$$

However, if the transmission start time synchronization is lost, the successful transmission of a packet would depend on the asynchronous behavior of packet transmitter. The packets are independent of each other and their arrival is a random process.

A packet may be received before its "prescribed start time", and collide with the packet transmitted in previous slot. Also, a packet may be transmitted such that it would collide with the packet transmited in the next slot period. Figure E.1 describes the possible collisions due to Asynchronous Slotted ALOHA transmission.

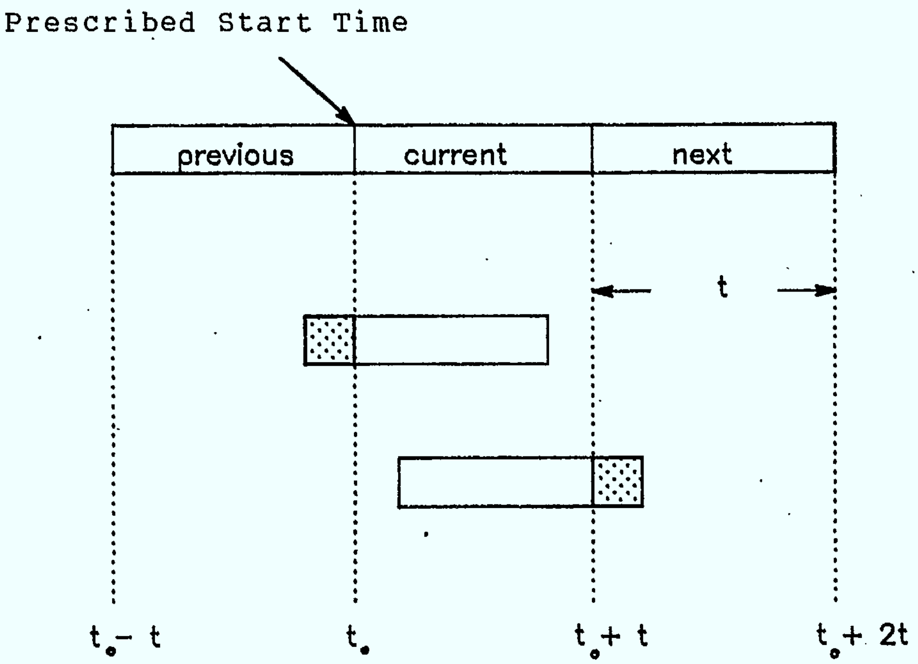


Figure E.1: Asynchronous Slotted ALOHA

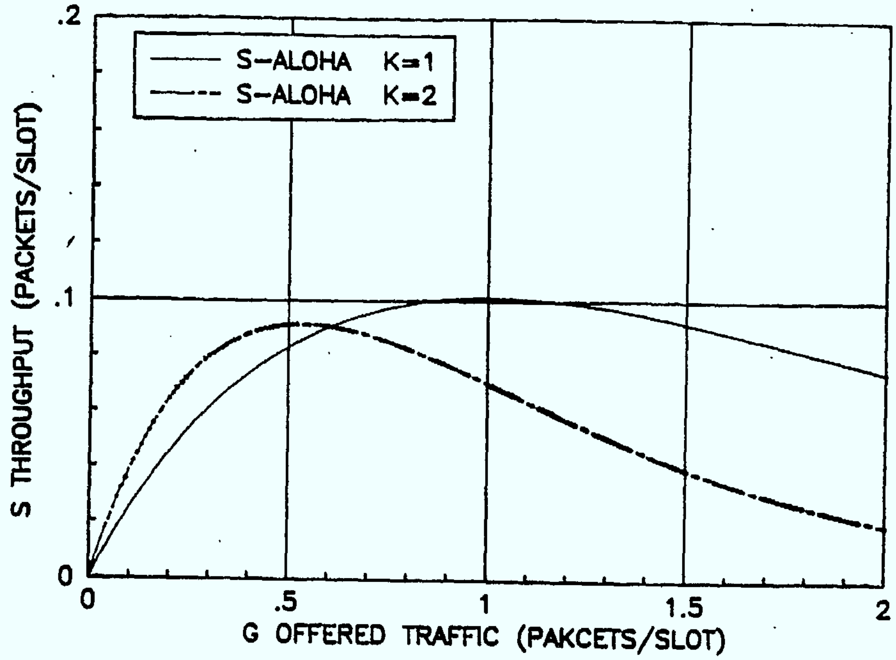


FIGURE E2 Average throughput VS. offered traffic in slotted ALOHA channels, (K is the number of times a message is repeated) with P_{PE}= .54 in forward link and .68 in reverse link

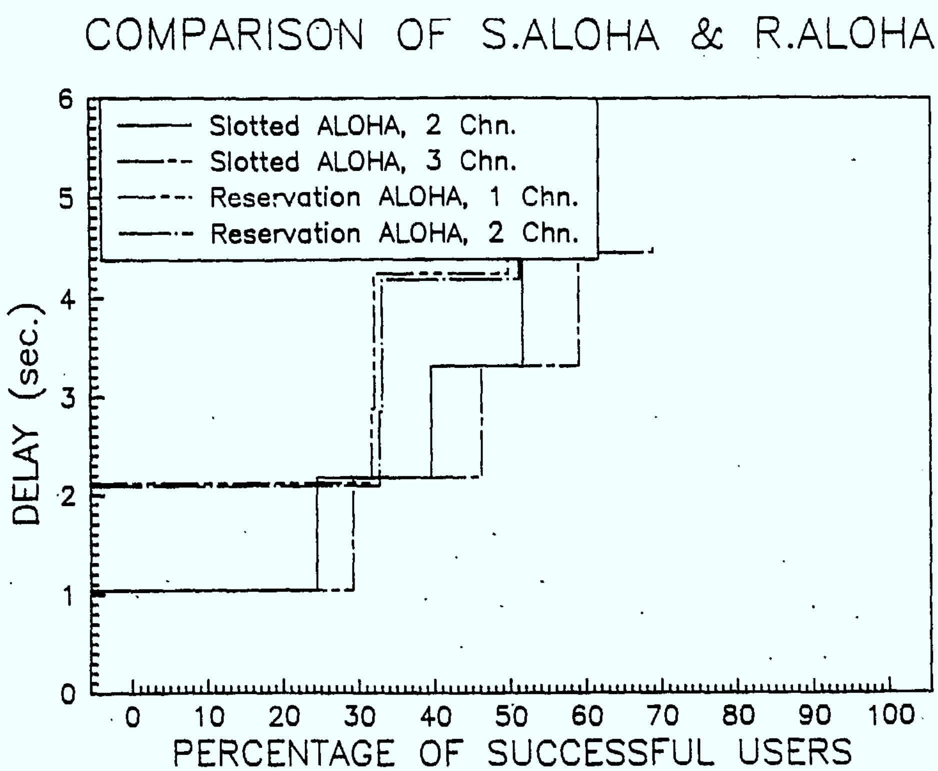


FIGURE E3 Average delay performance for error-free channels and channels with errors for users at 15°elevation angle where Delta(EIRPs) = 0 dB and call attempt under medium shadowing conditions, packets repeated 3 tomes on Assignment channels.

APPENDIX F

Probability of Packet Error

(15° Elevation Angle)

F.1.0 Introduction

The purpose of this Appendix is to present the results evaluated for the probability of packet error for the present link budget calculations of MSAT operational links. The results are plotted for CRC in-house modem (described in Figure F1) as well as the ideal DPSK modem performance. The UHF fade statistics are shown in Figure F2. These results are based on the data gathered in September 1982 for 15° elevation angle [3]. These fade statistics have a higher fade existence of 3% compared to that of [1] for most of the considered fade range. This difference will result in a higher probability of packet errors for both forward and reverse links as discussed below compared to the results in [1].

F.2.0 Forward Link

The present MSAT link budget (Table F1) allows for a total link margin of 11.6 dB on the forward link where the allowed fade margin on the downlink portion of the link is 13.9 dB. This provides a probability of packet error due to error occurrence in the coded segment of the packet (P_{PE}) of 28.7% for fast fading case while it operates at 7.4% P_{PE} for slow fading case, as indicated in Figure F3.. The overall P_{PE} for the forward link is somewhere between these two values. Note that as the downlink C/N increases (EIRP s), the value of P_{PE} decreases, Figure F4 illustrates the effects of C/N downlink variations from the baseline design on probability of the packet error; increasing this parameter by 6.5 dB would result in P_{PE} = 2%.

Further investigation reveals that, the change of uplink thermal C/N by as much as 10 dB has almost no effect on channel performance. These observations leads us to conclude that the forward link performance is dominated by the downlink C/N.

Figures F5 and F6 provide the same information as Figures F3 and F4 for an ideal modem.

F.3.0 Reverse Link

The present link budget (Table F1) allows for a total link margin of 12.35 dB on reverse link where the allowed fade margin in the uplink portion of the link is 13 dB. This margin provides 34.58% P_{PE} for fast fading case and 8.52% P_{PE} for the slow fading case as shown in Figure F7. Increasing the downlink C/N from the baseline design could improve the link performance up to a certain range, as illustrated in Figure F8. However, after 6 dB increment of the downlink thermal C/N the performance of the channel does not improve appreciably any further. This is due to the fact that the uplink fade is transferred directly into the downlink by reducing the satellite EIRP at SHF dB for dB; therefore, the other noise and interference sources in both links will be the dominating factors and no improvement could be achieved.

Figures F9 and F10 present the same information as in Figures F7 and F8 for an ideal modem.

F.4.0 Overall Packet Loss Performance

The UW and coding scheme used in the packet structure are such that each of these factors has an equal probability of loss contribution in a given link. If these two effects are assumed to operate independently of each other, this translates into:

$$\text{overall } P_{PE} = P_{PE} \text{ (coded segment)} + P_E \text{ (UW)}$$

The probability of UW loss due to fading is given in Figures F11 and F12 for forward and reverse links respectively. However, this is a somewhat pessimistic assumption if slow fading is the predominant interference mode. In this case, the fades that corrupt the UW would do the same in the coded segment. Therefore, the P_{PE} thus obtained may be considered as the upper limit on the overall packet loss performance.

F.5.0 Summary

It is clear from this study that the system performance for reverse link is certainly poor compared with that of the forward link. In addition, changing any parameters from the baseline system design cannot improve the performance significantly. The best possible solution is that mobile operators avoid the excessive loss due to the signal shadowing. A method to assist the mobile user is to provide a warning mechanism, e.g. a light indicator, which informs the operator of the status of his/her surroundings. A plot of P_{PE} in light shadowing condition is given in Figure F13.

The performance of the forward and reverse links would be improved by:

- Increasing the satellite EIRP
- Repeating the messages
- Increasing the ground terminal G/T
- Improving the interference budget
- Applying coding scheme with improved correction capabilities

The performance of the forward link would be upgraded significantly when the downlink C/N is increased from the baseline design by as much as 6.5 dB. An improvement of the G/T mobile terminal is not possible at this time. The budget for interference appears to be tight as well. The increase in the satellite power would result in fewer carriers which may not be viable economically. The present coding scheme is BCH (15, 11) which allows for correction of one bit in a block of 15 encoded bits including 11 information bits. A coding technique which provides more correction capabilities for the given typical block size with the same number of information bits would result in a better link performance.

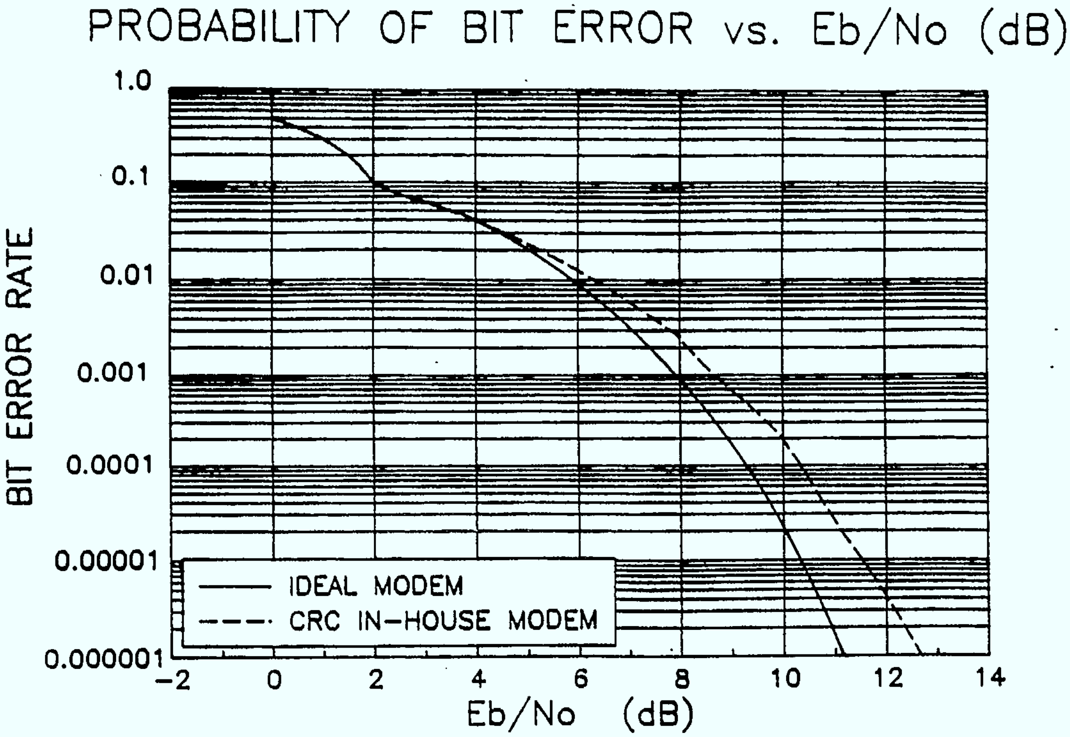


FIGURE F1 Probability of bit error rate VS. Eb/No for ideal modem as well as CRC in-house modem.

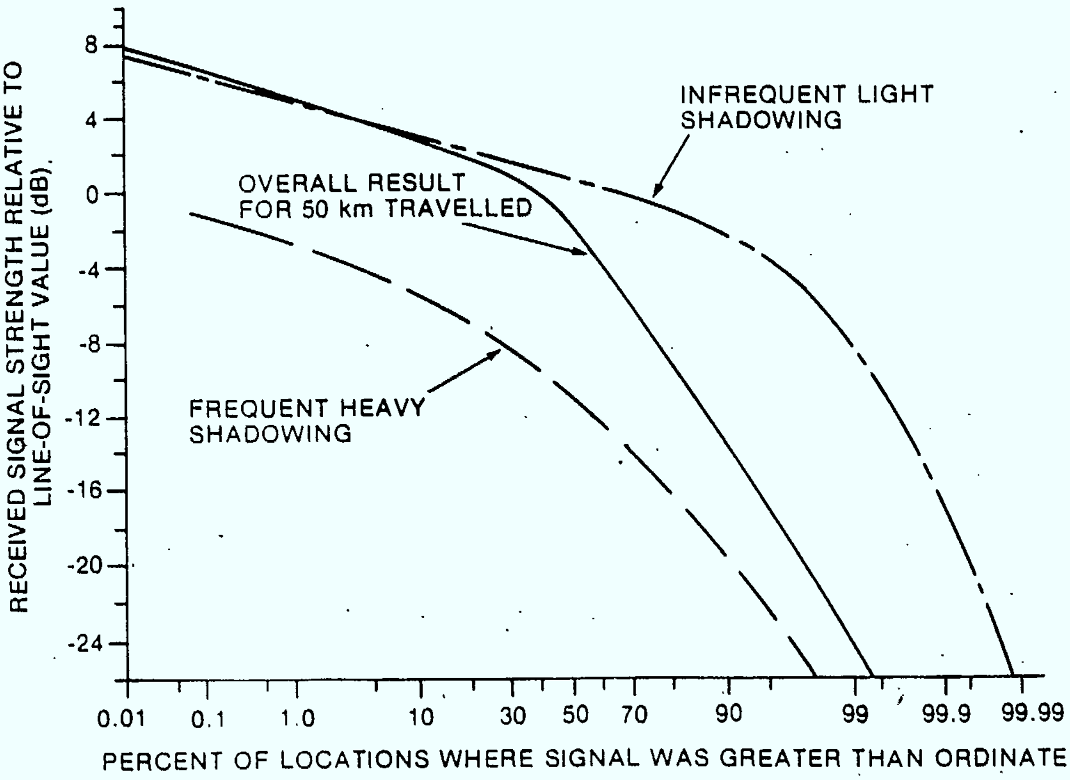


FIGURE F2. Cumulative distribution function for September 1982 data

TABLE F1

2-Beam Canada/US (MRS Service)
Link Calculations UHF-SHF

M = Mobile
FP = Field Portable

PARAMETER	UNIT	FORWARD LINK 3.5m M	FORWARD LINK 3.5m FP	REVERSE LINK 3.5m M or FP
UPLINK				
Satellite G/T	dB/K	-3.0		-2.0
Uplink EIRP/ Voice Act. Carr.	dBW	40.1		11.1
Path Loss	dB	206.8		182.8
Total IPBO/Transp.(Av. Pwr)	dB	N/A		12
Req'd. Flux Density/Voice Carr.	dBW/m^2	-122.8		-151.9
C/No Thermal	dB-Hz	58.9		54.9
Noise Bandwidth	kHz	3		3
C/N Thermal	dB	24.1		20.1
DOWNLINK				
Req'd EIRP/Voice Act. Carr.	dBW	26.5		8.6
Req'd Total OPBO	dB	N/A		7
Path Loss	dB	183.2		205.8
Receive Terminal G/T	dB/K	-19.1	-15.1	25.9
C/No Thermal	dB-Hz	52.8	56.8	57.3
Noise Bandwidth	kHz	3.0		3
C/N Thermal	dB	18.0	22.0	22.5
INTERFERENCE (C/I)				
Intermod & Energy Spread				
Uplink	dB	32		25
Downlink	dB	22		25
Interbeam Co-channel				
Uplink	dB	–		–
Downlink	dB	–		–
Other Sources				
Uplink	dB	32		–
Downlink	dB	–		29
Total Interference	dB	21.2		21.2
Total Unfaded C/N	dB	15.6	17.5	16.4
Total Unfaded C/No	dB-Hz	50.4	52.3	51.2

9(15, 11) FORWARD LINK , UHF
DOC IN–HOUSE MODEM PERFORMANCE 15 ELEVATION ANGLE

PROBABILITY OF PACKET ERROR vs. LINK MARGIN

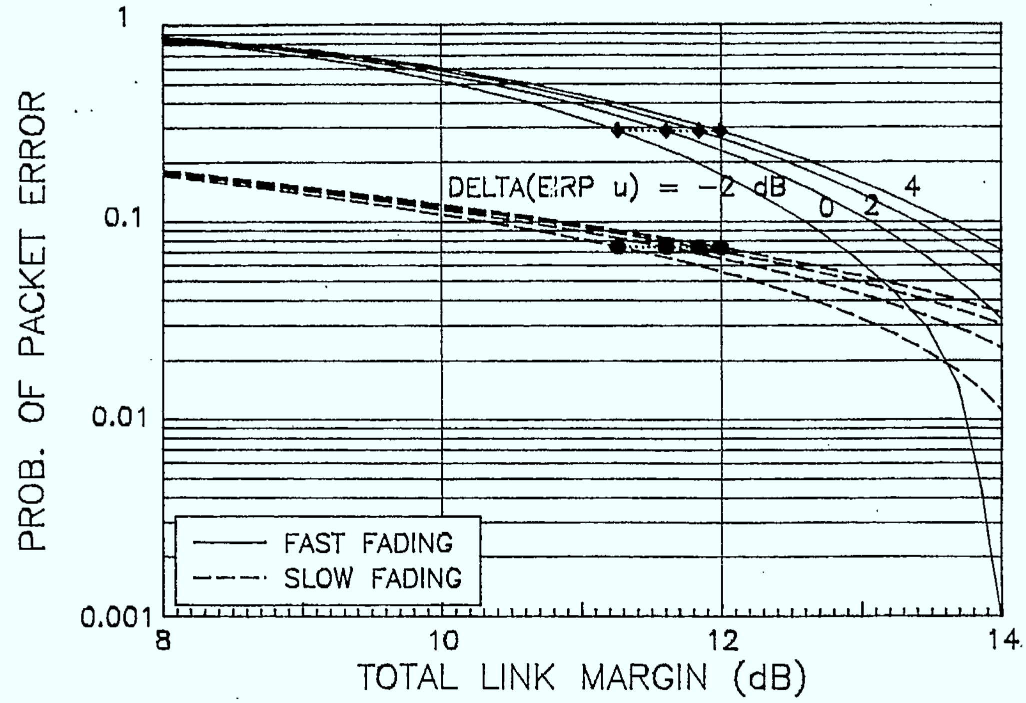


FIGURE F3

9(15, 11) FORWARD LINK
DOC IN–HOUSE MODEM PERFORMANCE

PROBABILITY OF PACKET ERROR vs. DELTA(EIRP s)

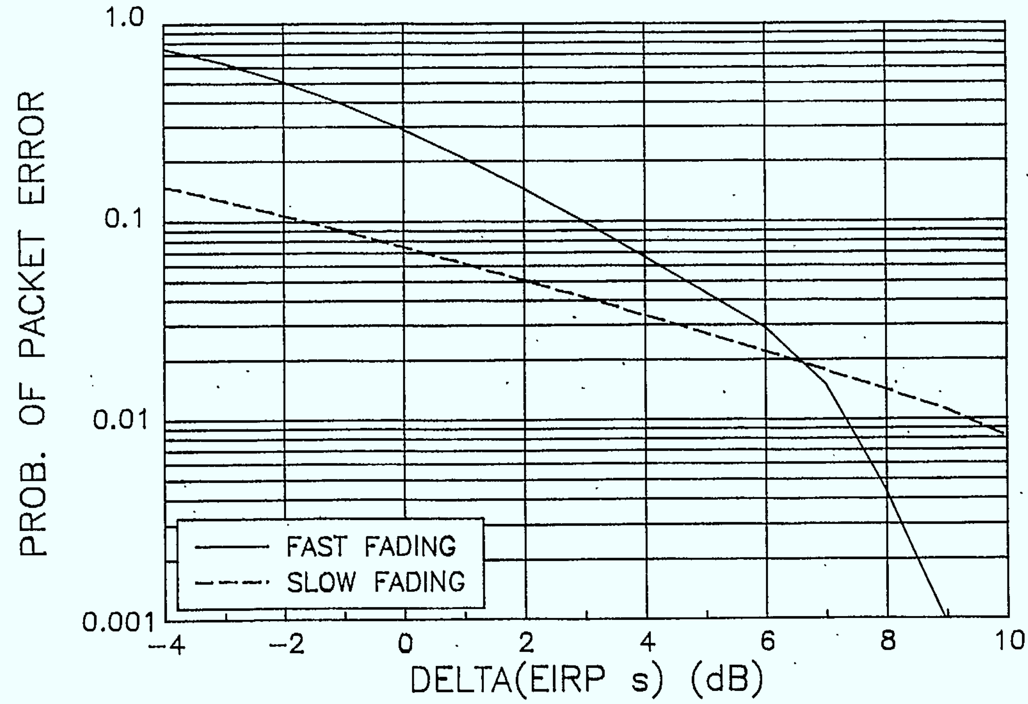


FIGURE F4

9(15, 11) FORWARD LINK , UHF
IDEAL MODEM PERFORMANCE 15 ELEVATION ANGLE

PROBABILITY OF PACKET ERROR vs. LINK MARGIN

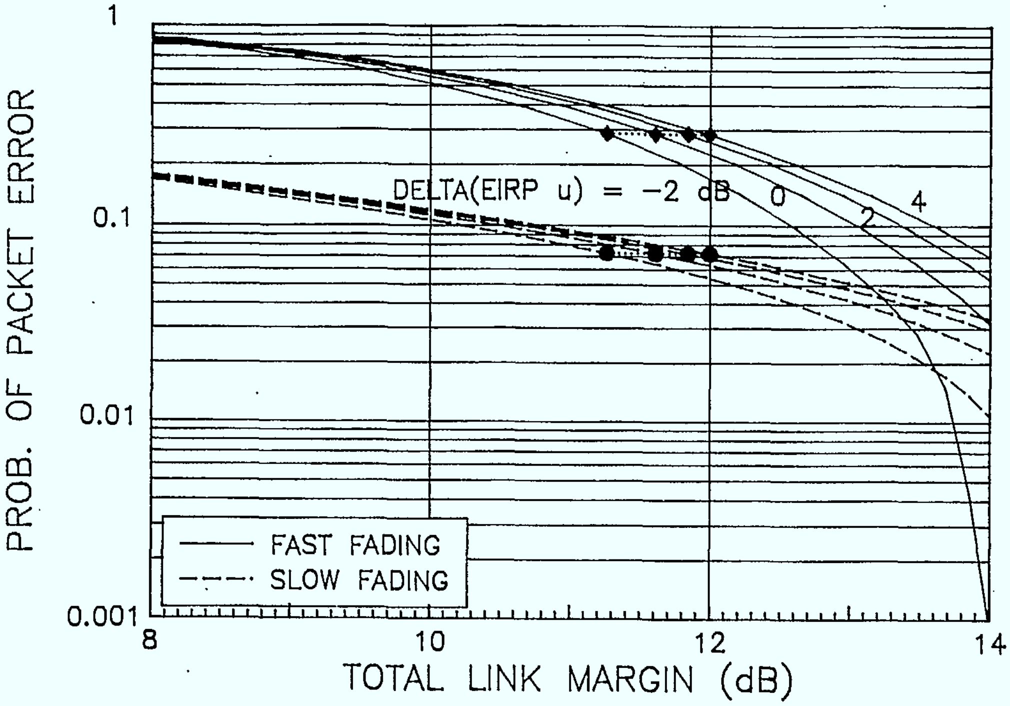


FIGURE F5

9(15, 11) FORWARD LINK
IDEAL MODEM PERFORMANCE

PROBABILITY OF PACKET ERROR vs. DELTA(EIRP s)

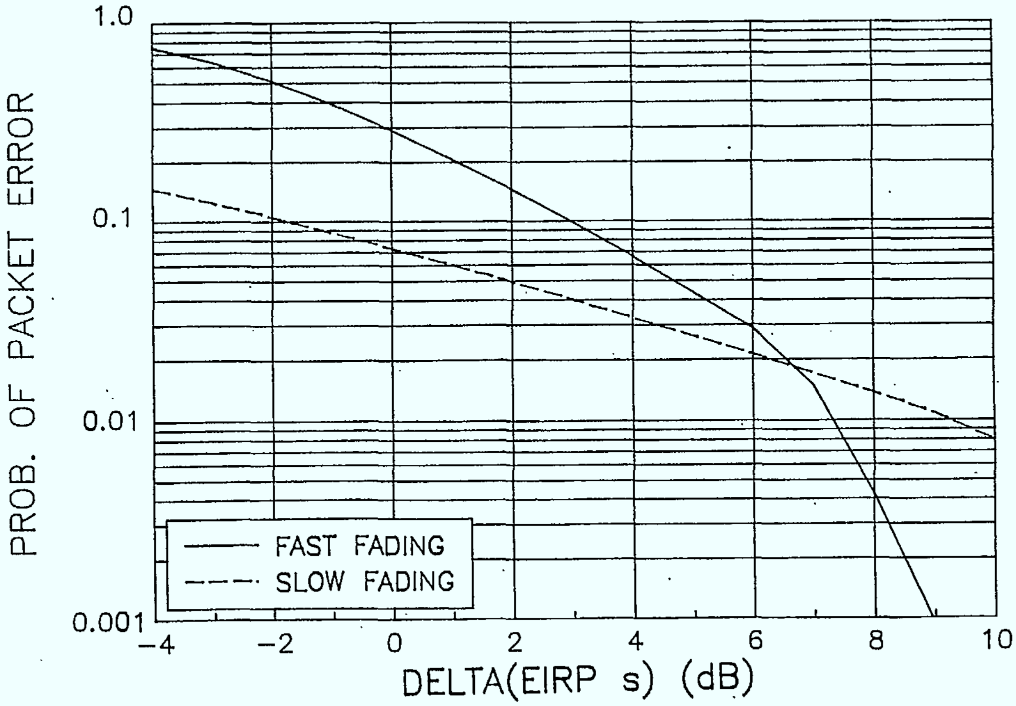


FIGURE F6

8(15, 11) REVERSE LINK , UHF
DOC IN-HOUSE MODEM PERFORMANCE 15 ELEVATION ANGLE

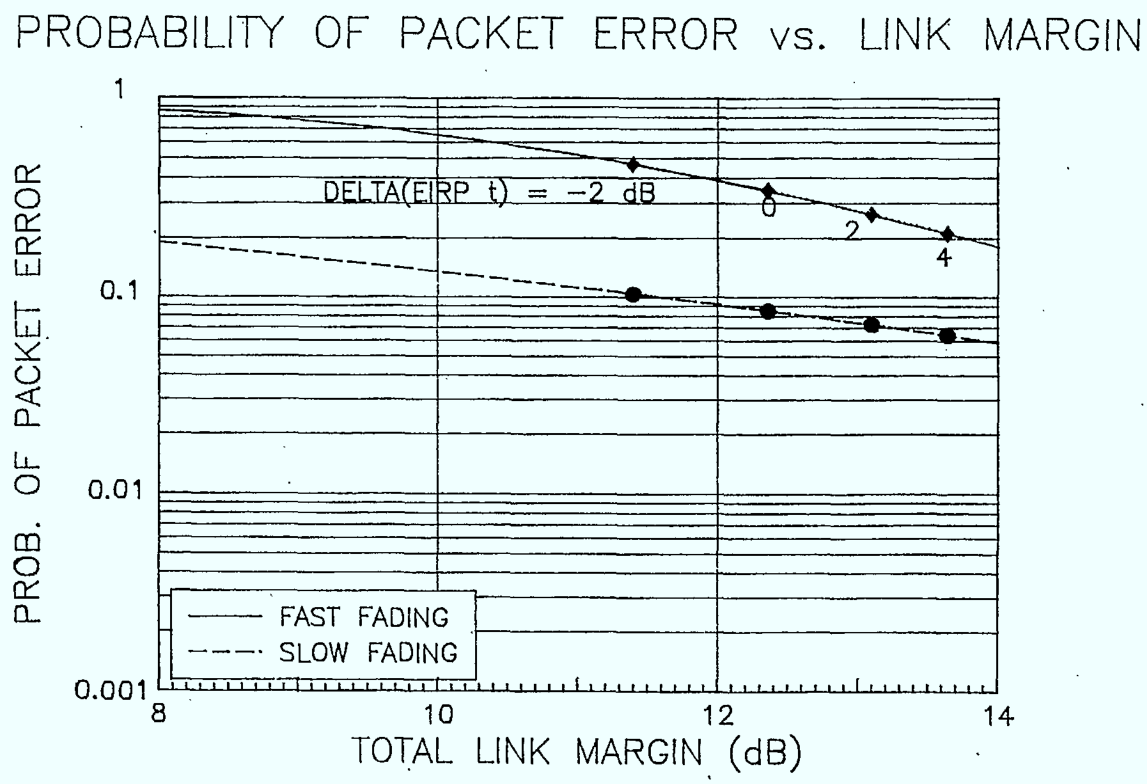


FIGURE F7

8(15, 11) REVERSE LINK
DOC IN-HOUSE MODEM PERFORMANCE

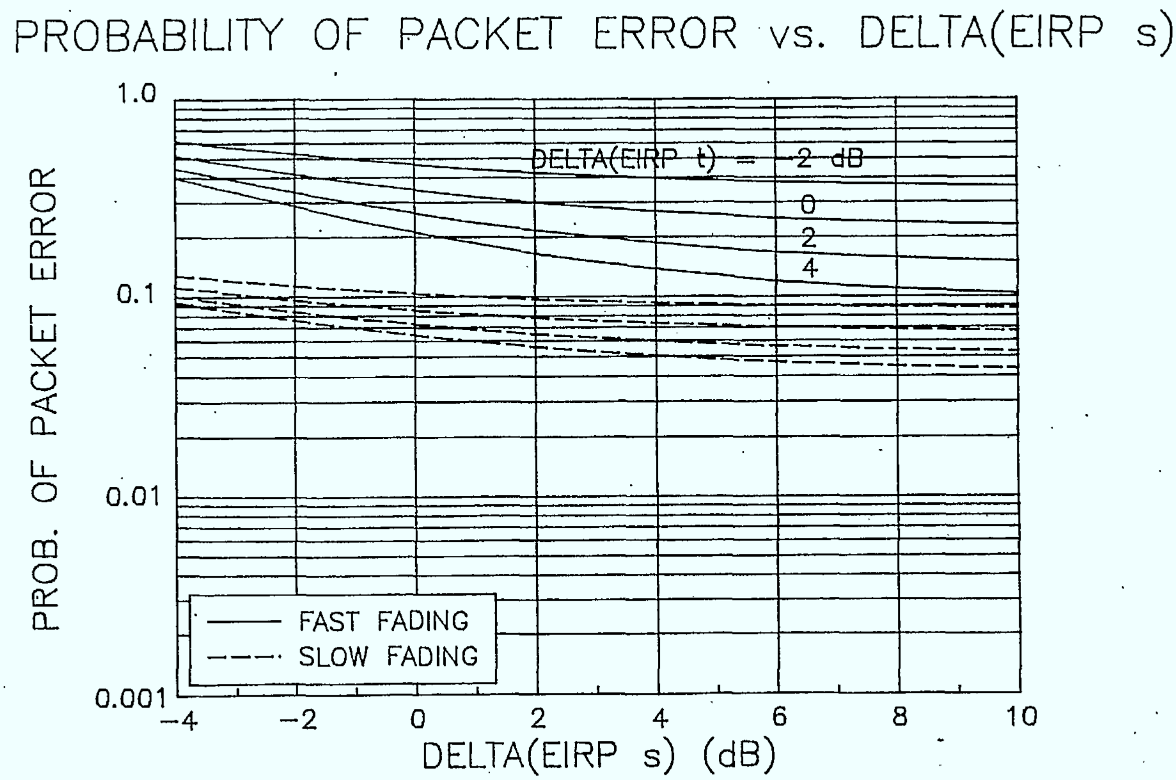


FIGURE F8

8(15, 11) REVERSE LINK , UHF
IDEAL MODEM PERFORMANCE 15 ELEVATION ANGLE

PROBABILITY OF PACKET ERROR vs. LINK MARGIN

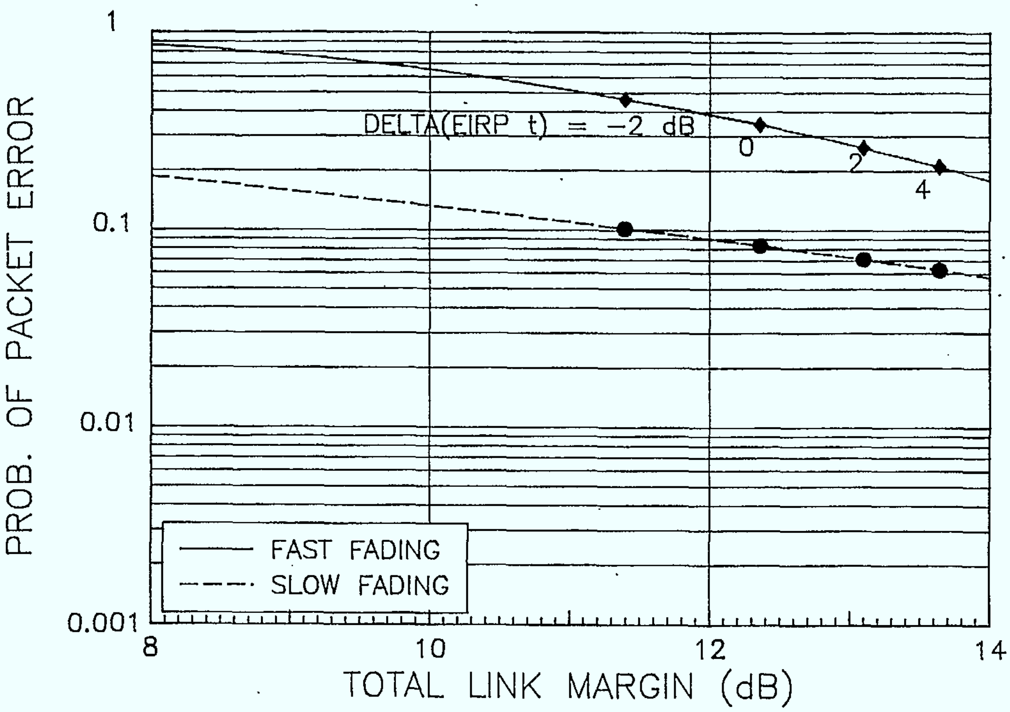


FIGURE F9

8(15, 11) REVERSE LINK
IDEAL MODEM PERFORMANCE

PROBABILITY OF PACKET ERROR vs. DELTA(EIRP s)

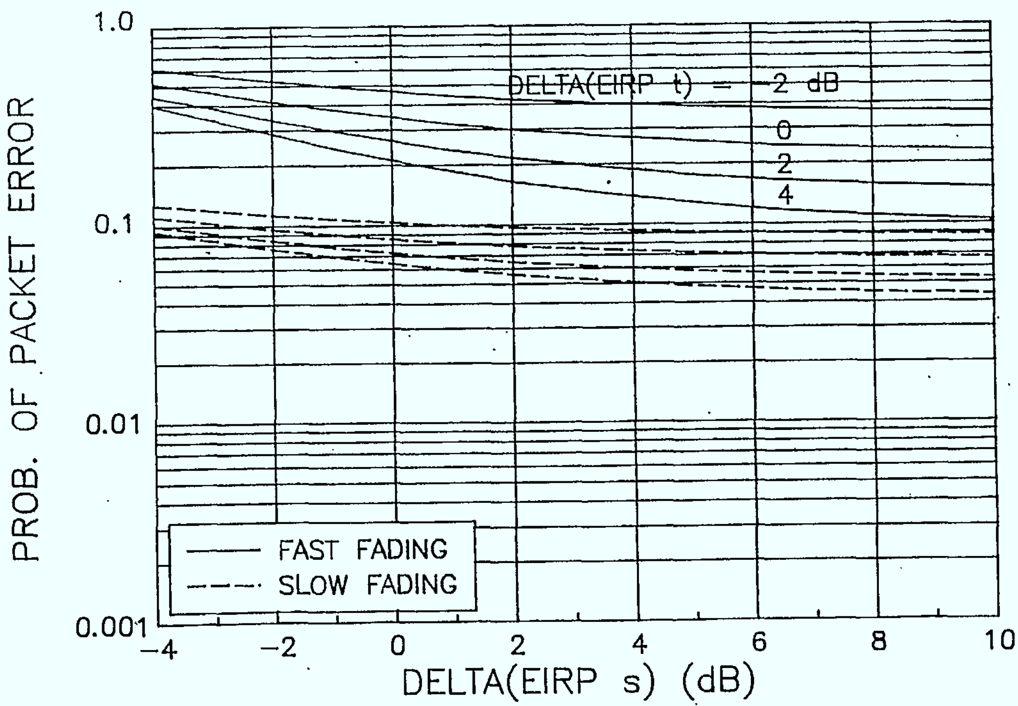


FIGURE F10

UNIQUE WORD   REVERSE LINK , UHF
DOC IN-HOUSE MODEM PERFORMANCE   15 ELEVATION ANGLE

PROBABILITY OF PACKET ERROR vs. LINK MARGIN

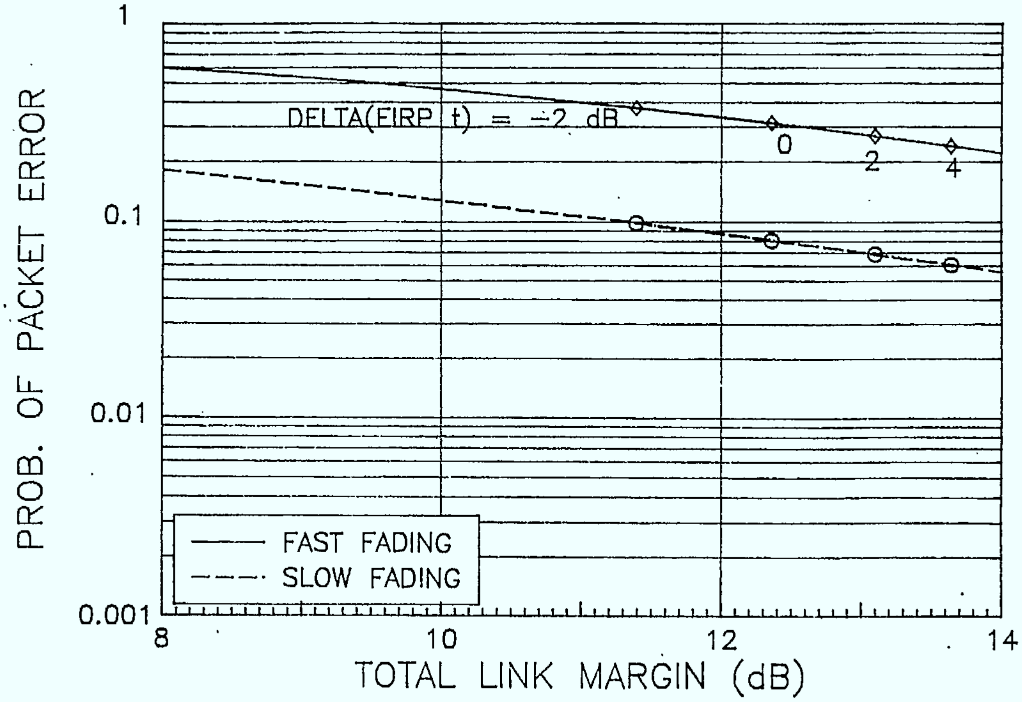


FIGURE F11

UNIQUE WORD   FORWARD LINK , UHF
DOC IN-HOUSE MODEM PERFORMANCE   15 ELEVATION ANGLE

PROBABILITY OF PACKET ERROR vs. LINK MARGIN

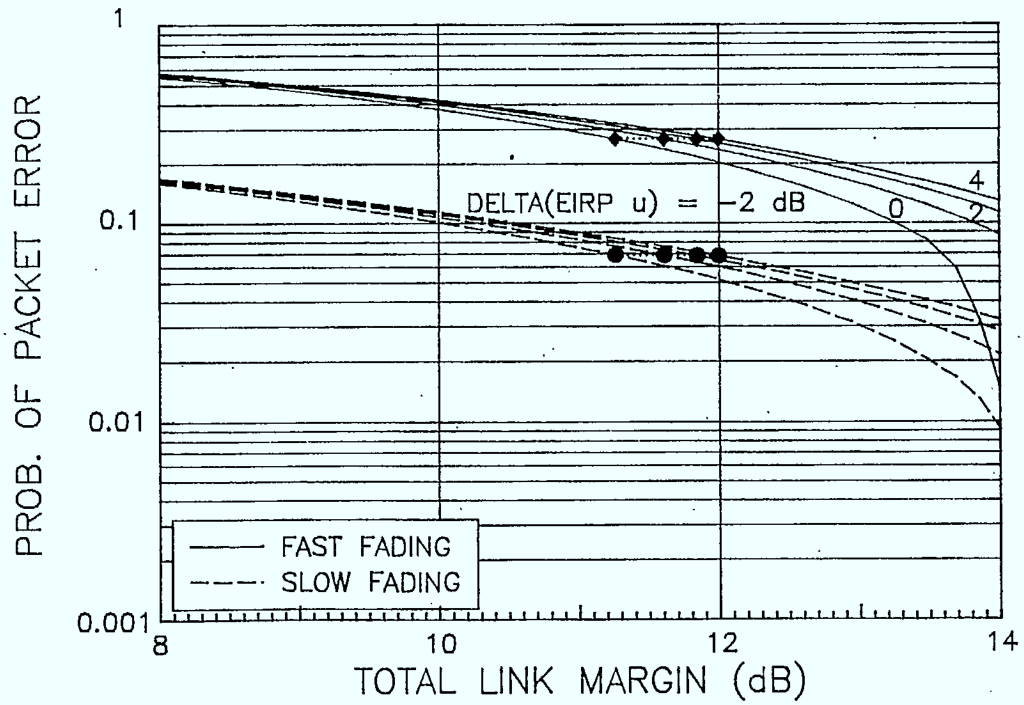


FIGURE F12

8(15, 11) REVERSE LINK, UHF, LIGHT SHADOWING
DOC IN-HOUSE MODEM PERFORMANCE 15 ELEVATION ANGLE

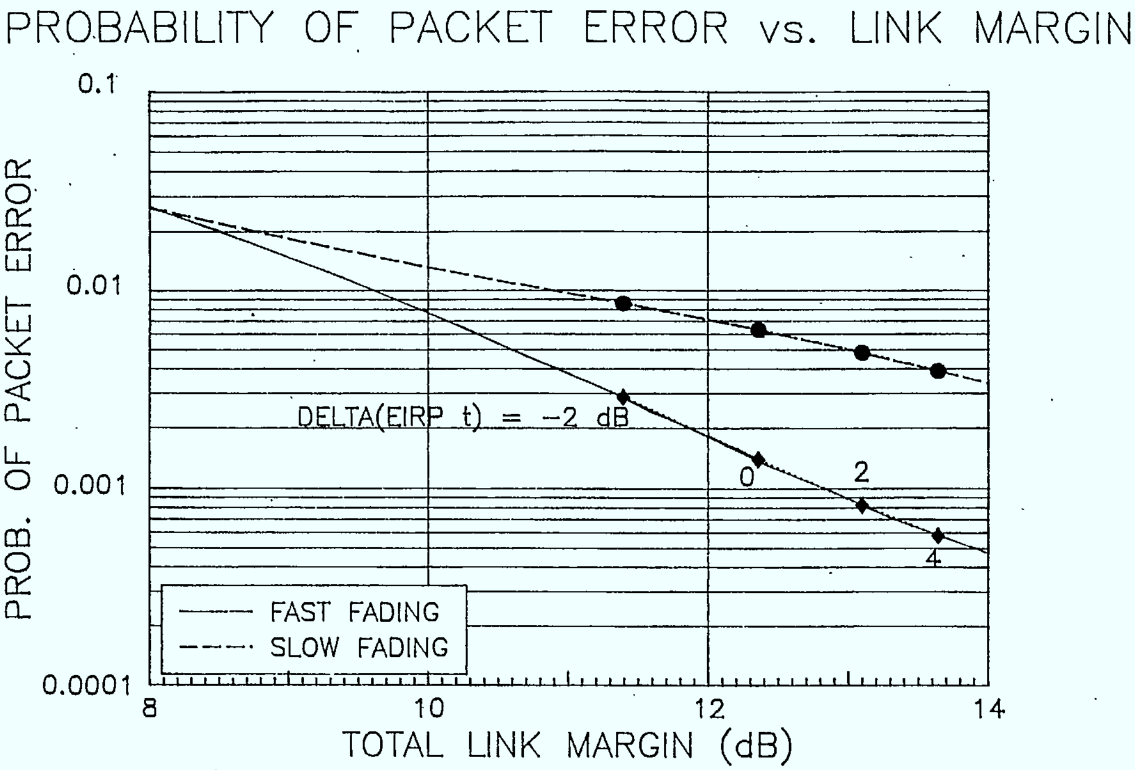


FIGURE F13

APPENDIX G

The proposed DAMA Systems by 12 American Applicants

G.1.0 Introduction

A general study of the DAMA Systems proposed by 12 American Applicants in their FCC filings was pursued and a summary of each proposal is given in this Appendix.

It has been observed that they propose almost the same traffic type and primary resources to be shared among all network entities. The satellite networks are of thin-route type with a large number of nodes to be interconnected.

G.2.0 Description of DAMA Systems

The type of DAMA control proposed by each applicant is described below.

1) GLOBAL LAND MOBILE SATELLITE, INCORPORATED (GLMS)

The aspects of the Mobile Satellite Service (MSS), considered by GLMS are:

-dispersed narrowband streams of traffic
-mobile terminals roaming from one spot beam to another
-light-weight and affordable terminals
-relatively modest spectrum allocation

GLMS has proposed to operate two services namely mobile and fixed rural telephone services. It believes the existing terrestrial facilities can route traffic all across the Continental United States of America (CONUS), once the network is accessed. As a result, it has decided to concentrate its MSS resources to provide access to fixed rural and mobile subscribers.

Its Network Operation Control Centre (NOCC) would assign channels in response to a request for service. These channels would be selected from channel groups serviced by specific transponders according to the characteristics of the service requested. Although each transponder has its own channel plan, it is necessary to have one or more Request and Assignment Channels on each transponder. The signalling channels are shared among many mobile users; therefore, each unit would contend to access the system. It is suggested that a modified version of the Slotted ALOHA protocol, similar to techniques used in land-based radio systems, would be sufficient.

The users would listen to their downlink assignment channels. If the unit is alerted of a service request, it would respond back on its uplink channel. However, provision will be made so that part of the call setup and supervision process uses voice or data traffic channels. The GLMS claims, this would allow the efficient engineering of services which are characterized by short, bursty packet-type data communication.

2) GLOBESAT EXPRESS

In the given proposal, there is no indication of any DAMA system.

3) HUGHES COMMUNICATIONS MOBILE SATELLITE SERVICE, INC.

The design of the DAMA architecture has been carried over from the one developed by Hughes Aircraft in 1975 to interconnect 120 telephone exchange trunk centers in Indonesia via the Palapa satellite. However, some of the major changes required for this application are as follows:

- Introduction of contention channels (common Random-Access)

- Voice call setup via poll-response/command-response channels

- Data message handling in a store-and-forward mode

The bandwidth is subdivided into three different types of sub-bands named voice, data and control channels. These channels are full duplex at UHF and L-band with Ku band backhaul to gateway and base stations and the DAMA centre. In each band, a certain minimal number of channels are dedicated to control. The remaining channels could be selected for voice, data or more control channels. Each voice call would be assigned a channel for the duration of the call. On the other hand, most data services would be provided by packet switching or store-and-forward protocols on the control links. Data service that requires a full channel is handled as a voice call.

Most channels are controlled by DAMA and would be assigned on demand, except those channels which would be permanently assigned to users (i.e. carriers).

There are two main classes of mobile control links: contention and command circuits. Each of these circuits consists of a pair of channels. Mobile units would send contention messages to set up a call or to inform DAMA when the mobile has moved from the region covered by one contention link into that covered by another. On the downlink channel paired with the contention link, DAMA responds back if the message was successful. However, the command circuits would be used by DAMA system to initiate a command or poll the terminals. It would expect the response on uplink channel paired with command channel.

Contention circuits for mobile users use pure ALOHA in the first generation system due to uncertainty of the range of the users. For thin-route service at L-band, slotted ALOHA is used. When momentary contention traffic on a channel becomes too great, users on that channel can be commanded to wait longer for re-attempts or to reduce the number of re-attempts. If necessary, subgroups of users can be reassigned to another contention channel by global command.

4) MCCA AMERICAN SATELLITE SERVICE CORPORATION

The MCCA's system would enable mobile and fixed terminals and ground stations to transmit or receive voice, data and messages to other terminals in the network as well as public and private telephone networks. The DAMA system implemented with this system has at least two control channels per spot beam. The control channels are used by mobile/fixed subscribers for the system access and to respond to central controller's inquiries.

The central controller would be responsible for assigning the voice or data channels to subscribers. It seems that the number of control channels would be fixed at start up (two channels) and other channels would be assigned to voice or data upon requests.

5) McCAW SPACE TECHNOLOGIES, INCORPORATED

The McCaw system is designed to support a variety of services, including mobile and rural telephones (full duplex voice), paging and dispatching (full and half duplex voice and data). The baseline system treats data and voice traffic the same, where channels are allocated using a DAMA control algorithm.

The user terminals and gateway stations access the Network Management Control Centre (NMCC) via several dedicated Request channels for call set-up requests. The access to these channels is based on ALOHA. The number of Request channels is dependent on the characteristics of the traffic. The NMCC would assign a forward and reverse pair of channels for a full duplex service and notifies the user. There is no distinction between voice and data channels.

There is a discussion of incorporating the MSS with cellular mobile systems. As a result, the mobile user could first search for a terrestrial cellular link and if none is available, then it could switch to MSS.

6) MOBILE SATELLITE CORPORATION

The Network Operation Centre (NOC) would establish communication via dedicated common signalling channels. The Request channels are common to all users (mobile and gateway). The users would locate the strongest signal channel in which to initiate a call. However, the technique used for accessing the Request channels is not mentioned in the report. The NOC would assign channels (one/two ways) to the users, depending on the type of service request. The service channels are of one type.

NOC would contact the user via the last signalling channel used by him. However, if it fails, then it would try paging.

The system would start up with four signalling channels per beam (L-band and UHF beams). The report mentions possible addition of common channels if required (not dynamically).

Some channels would be reserved as priority access channels for emergency situations.

7) MOBILE SATELLITE SERVICE, INCORPORATED (MSSI)

MSSI proposes a mobile satellite networks compatible with cellular mobile radio network. This system would allow the present usage of cellular mobile radio where it is available. Furthermore, when service is required beyond the range of cellular network, it would be serviced by satellite network.

The DAMA system is the same as the Mobile Satellite Corporation's proposal except that only one signalling channel is provided with this system.

However, MSSI has subdivided its bandwidth into 15-12 kHz compandored FM, which they claim would provide acceptable performance when operated with cellular mobile radio.

8) NORTH AMERICAN MOBILE SATELLITE, INCORPORATED

The Network Control Centre (NCC) would be responsible for the mobile system as well as the rural telephone system. Its design is based on mobile telephone switching office and INMARSAT's coast network coordination stations.

Any service request by mobile, gateway or dispatch terminals to NCC would be transmitted via ALOHA mode Request channels. The signalling channels for mobiles employ UHF (or L-band) and the fixed stations use C-band links. After successful reception of requests, NCC would assign suitable channels as available and inform the user. The NCC supervises the status of call progress by monitoring signal channels used by dispatch or gateways (C-band) to indicate termination of service. The released channel would be reclaimed and added to the pool of idle channels for later use.

9) OMNINET CORPORATION

The basic elements within the network related to the functioning of DAMA are mobile units, base stations/gateways and DAMA Central Controller. A user communicates with another location by issuing a call request to the Central Controller (CC) via one of the Request channels available on the satellite link. The CC is responsible for assigning voice and data channels in response to call requests when appropriate. It would assign the signalling, voice and data channels dynamically, in response to the number and types of requests presented, using the Integrated Adaptive Multiple Access Protocol (I-AMAP).

The I-AMAP was developed by Jet Propulsion Laboratory under contract to NASA in order to support a mixed data/voice network with a large number of randomly dispersed users. It is based on ALOHA (or Slotted ALOHA) random access Request channels and demand assigned traffic channels. The bandwidth available in the satellite beam is subdivided into N channels of equal size (nominally 5 kHz). At any given time, there are Nr, Nv, and Nd (request, voice and data respectively) channels. In principle, request channels could be shared between mobile stations and base stations and gateways. However, in practice, base stations and gateways will operate at different frequency bands than mobile stations; therefore, they will require separate Request channels.

Since the number of data, voice and Request channels can be varied dynamically, the system is very efficient and adjusts to accommodate demand. Within this context, the satellite simply serves as a pipeline.

10) SATELLITE MOBILE TELEPHONE COMPANY

In the given proposal, there is no discussion of any specific type of DAMA system . However, a brief discussion of call setup is included.

11) SKYLINK CORPORATION

The Network Operations Center (NOC) would have the primary responsibility for overall network management. However, the network intelligence would be distributed among the gateways. The gateways would monitor detailed operational knowledge of individual terminals assigned to them.

There are two basic classes of channels defined for the system: traffic channels, which support user connections; and control channels, used to communicate service requests and to assign traffic channels. The control channels would be subdivided into two different groups. Pilot/assignment channels would be used by NOC to transmit control information. The other group is random-access channels, over which NOC would receive service requests from the user terminals.

The network control architecture is based on Priority Demand Assignment Multiple Access (PDAMA) control subsystem. This subsystem would be a packet-switched control network and would use a version of slotted ALOHA for terminal control access. The PDAMA system would transmit its control information via pilot/assignment channels. The service requests would be received over random-access channels.

A set of channels would be assigned temporarily to performance monitoring subsystem. Another set of channels would be permanently assigned to transmit information to hubs and personal satellite phones. These channels are home pilot channels. They are used upon initial power-up. The home pilot assignments for personal satellite phones would be ROM-encoded at the factory. Additional channels would be assigned as pilot channels, if home pilot channels are overloaded.

The random-access channels would be used by users and hub terminals to transmit requests to NOC. The list of random-access channels would be transmitted by NOC over the home pilot channels a few times every minute. The terminals access these channels and request services. The PDAMA system would then assign a secondary random-access channel to the terminal to use for its requests. These secondary random-access channels would be monitored by NOC. In case of overload, additional channels would be added. On the other hand, when load decreases below a given level, channels would be returned to pool of idle traffic channels. The traffic channels would be assigned as available, depending on the priority of service request.

There are three distinct levels of priority services. A number of channels would be dynamically assigned to different priority levels.

12) WISMER & BECKER/TRANSIT COMMUNICATIONS, INCORPORATED

The proposed DAMA system is a modified form of the Integrated Adaptive Multiple Access protocol (I-AMAP). This DAMA system dynamically assigns channels to different services. The OMNINET Corporation also uses this technique. However, the I-AMAP protocol has been modified in a manner that the gateways can poll mobiles for specific information which can be transmitted in reserved time slots. They claim, polling results in extremely efficient transmission of position estimates and other forms of automatically processed information. The request channels are based on Slotted ALOHA protocol.

G.3.0 CONCLUSION

The performance variation due to the choice of slotted or pure ALOHA has a great influence on the system design. A simple pure ALOHA random-access scheme will give a maximum channel efficiency of 18.4 percent. The channel efficiency will be doubled if the slotted technique is used. Depending on the channel bandwidth and message length one technique would be superior to the other. There is about 15-20 ms mobile- to-satellite propagation delay difference for mobiles on different end of a beam coverage. Slotted ALOHA would be better if this propagation delay is not significant compared to the intended message transmission time. However, this technique requires a more complex timing mechanism for synchronizing all the users to slot-times.

The static assignment of signalling channels at the system start-up would result in an inflexible system. As a result, the dynamically assigned signalling channels would be the solution to this problem. However, note that the dynamical assignment of channels would require complex algorithms, database and report gathering, transmission overhead, processing time and information distribution. In other words, these factors contribute to delay and bandwidth wastage.

The traffic channel subdivision into voice and data sub-bands depends on the requirements of each service individually. Voice call requests require a delay-free service; while, data calls could be stored, packetized and then forwarded to be distributed with a delay. In this manner, data channels could be utilized very efficiently and voice channels (as available) would satisfy the required services.

The above issues are the major criteria for the DAMA System. From table G1, the most interesting DAMA Systems to be considered are the ones proposed by:

- GLMS
- HUGHES
- OMNINET
- SKYLINK
- W&B/TCI

The differences observed in their methods are mostly the access protocol choice, dynamic or static assignment of signalling channels and subdivision of traffic channels to data and voice channels.

TABLE GI: COMPARISON OF DAMA SYSTEMS

		SIGNALLING CHANNEL				
No.	U.S. Company	Protocol	Type	# of Channels	Traffic Channel Types	Comments
1	GLMS INC.	Slotted ALOHA	Static	1/more	Data & Voice	
2	GLOBESAT E.	N/A	N/A	N/A	N/A	
3	HUGHES INC.	UHF-ALOHA L-Band-S.A.	Dynamic	–	Data & Voice	
4	MCCA CORP.	N/A	Static	2	Data & Voice	
5	McCAW INC.	ALOHA	Dynamic	–	One Type	
6	MOBILESAT CORP.	N/A	Static	4-UHF 4-L-Band	One Type	priority channels
7	MOBILESAT S. INC.	N/A	Static	1	One Type	
8	NORTH AMS INC.	ALOHA	N/A	–	N/A	
9	OMNINET CORP.	ALOHA	Dynamic	–	Voice-Data	1-AMAP
10	SAT. MOB. TEL. CO.	N/A	N/A	N/A	N/A	
11	SKYLINK CORP.	Slotted ALOHA	Dynamic	–	One Type	PDAMA distributed system
12	W&B/TC INC.	Slotted ALOHA	Dynamic	–	Voice-Data	1-AMAP

NOTE: N/A stands for not available.

APPENDIX H

800 Service

H.1.0 INTRODUCTION

Outward Wide Area Telecommunications Service (Outward WATS) and 800 Service (Inward WATS) are telephone services designed to meet the needs of customers who make or receive substantial volumes of long distance calls. These services are available by geographical regions called service areas. The Outward WATS or 800 service lines connect subscribers to the network. Generally, each such line is arranged to provide either inward or outward service, but not both.

The rates for these services are based on the service area and hours of service subscribed to by the customer. A fairly complicated numbering plan, routing and screening arrangements are utilized for proper billing and call completion purposes. The rates are based on two basic schemes as follows:

- Full Business Day (FBD): Can have up to 240 hours of calling per month and up to 14400 calls per month at a minimum rate.
- Measured-Time (MT): Can have up to 10 hours of calling per month and up to 600 calls per month at a minimum rate.

The service areas are arranged roughly in regions surrounding a home area and are categorized as Interstate/Intrastate Service areas.

- Interstate Service starts with service area 1 containing the states contiguous to the home state, but not including it, and sometimes one or two nearby states.

- Service area 2 include service area 1 and certain other states.

- The other service areas 3,4,5, and 6 have a larger covering area.

- Service area 6 covers the largest possible area including the home state.

The service area 6 is the only service which could be used by MSAT MTS subscriber, without restricting the user to receive calls from specified areas only.

The above information is applicable to WATS and 800 Service; however, the description of WATS has been omitted from this report.

The following section would describe the 800 Services.

H.2.0 THE 800 SERVICE

The 800 Service is a telecommunications Service which allows a subscriber to receive telephone calls originated within specified service areas without a charge to the originating party.

The numbering plan is as follows:

800 + NXX + XXXX

where X is any digit 0 through 9
N is any digit 2 through 9

800 Special Area Code

NXX Interstate, This central office type code represents the terminating NPA for an 800 service call.

NX2 Intrastate, this is used for Intrastate service designation.

XXXX These digits represent the customer station digits, the first three digits specify the local serving central office for the access line. The last digit is used to designate the particular customer.

The routing scheme is quite complicated, due to complicated numbering plan and required digit translations.

H.3.0 CONCLUSIONS

The 800 service is a very restrict service which would not be applicable to MSAT MTS services. The major disadvantages are:

- provides inward services
- designed for customers with high volume of traffic within a given area

- the numbers would be scarce within every NPA
- there might be a high initial fee for every subscriber
- the MSAT subscriber pays for all toll charges

APPENDIX I

Probability of Packet Error

(20° Elevation Angle)

I.1. Introduction

This Appendix is intended to present the results evaluated for the probability of packet error for the present link budget of MSAT baseline links. The produced results are for CRC in-house modem (described in Figure F1) and fade statistics experienced by mobiles restricted to 20° elevation angle to the satellite (figure I1).

I.2. Forward Link

The present MSAT link budget allows for a total link margin of 11.6 dB on forward link where the allowed fade margin on the downlink portion of the link is 13.9 dB. From Figure I2, the probability of packet error due to error occurence in the coded segment of packet (P_{PE}) is 0.2% for fast fading case while it is 0.65% for slow fading. The probability of packet loss due to error in unique word is 2.1% for fast fading and 0.65% for slow fading, as given in Figure I6. The total probability of packet error, as discussed in Appendix F, is the summation of the P_E due to unique word and P_{PE} in the coded segment of packet.

$$P_{PE} = 2.1 + 0.2 = 2.3\%$$

I.3. Reverse Link

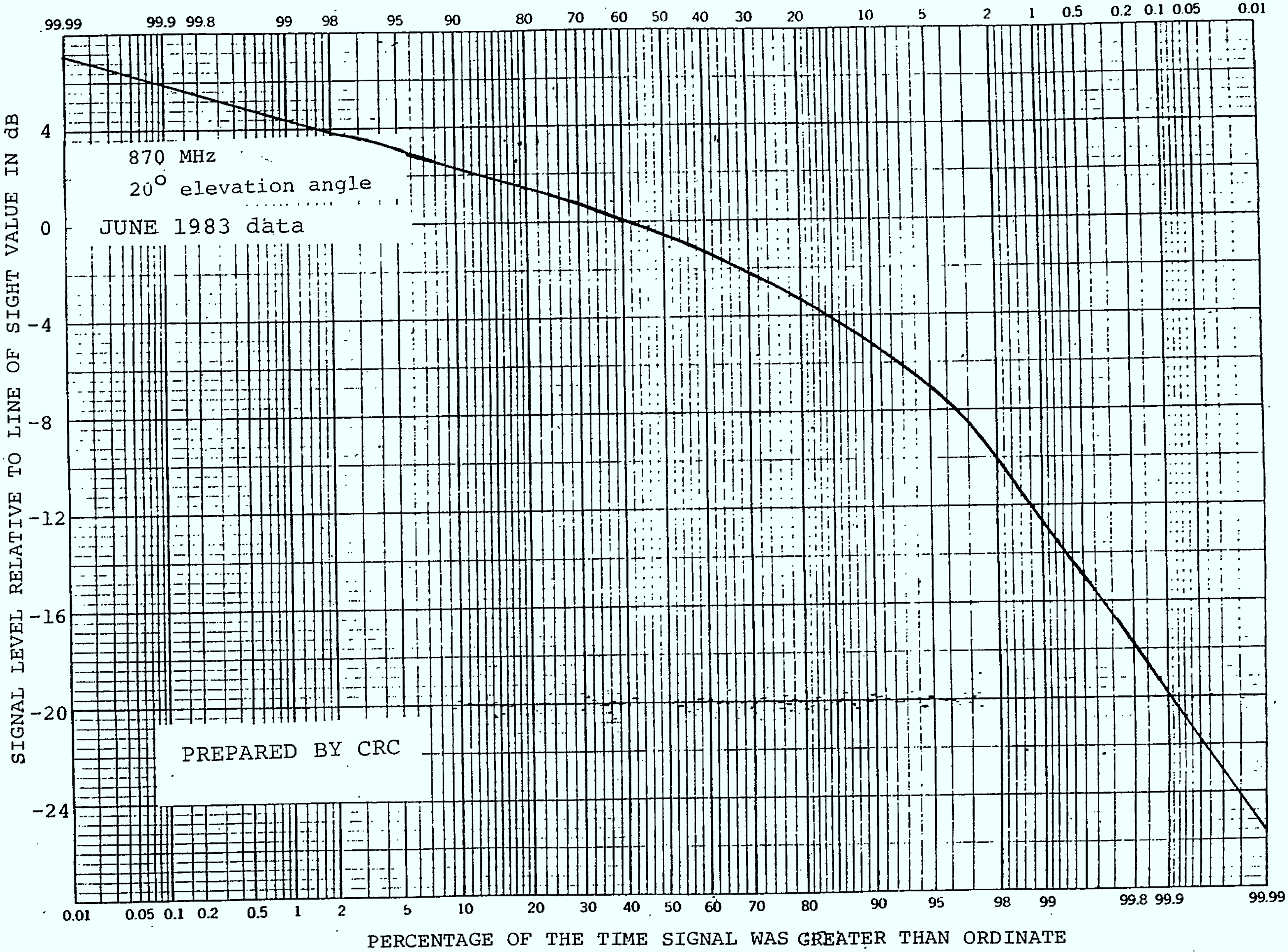
The present MSAT link budget allows for a total link margin of 12.35 dB on reverse link where the allowed fade margin on the uplink portion of the link is 13 dB. From Figure I4, the P_{PE} is 0.3% for fast fading case and 0.85% for slow fading. The probability of error occurence in unique word is 2.9% for fast fading and 0.8% for slow fading in reverse link, as given in Figure I7. The total probability of packet error (upper bound) is 3.2% in reverse link.

The probability of token misdetection in reverse link is 0.2% as shown in Figure I8.

I.4. Conclusion

As discussed above the probability of packet error is very low for the mobiles restricted to 20° elevation angle and there is no requirements to upgrade the existing link parameters; however, the mobiles below 20° would experience higher P_{PE} as it is discussed in Appendix F for mobiles restricted to 15° elevation angle to satellite.

FIGURE I1 Cumulative probability distribution function at 20° elevation anglefor UHF services



9(15, 11) FORWARD LINK, UHF
DOC IN-HOUSE MODEM PERFORMANCE 20 ELEVATION ANGLE

PROBABILITY OF PACKET ERROR vs. LINK MARGIN

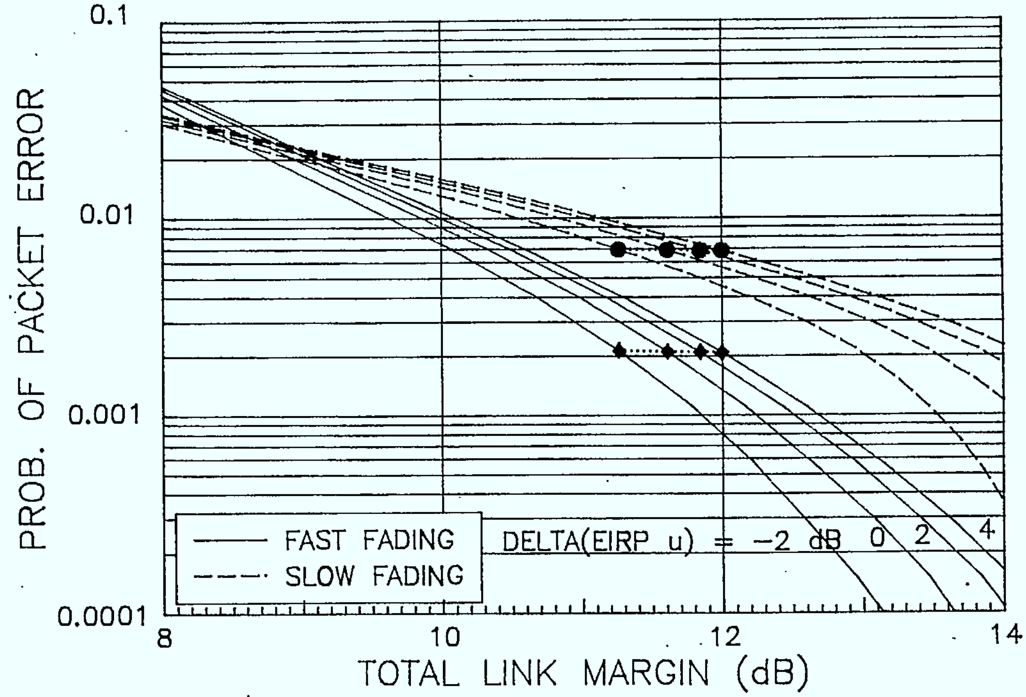


FIGURE I2

9(15, 11) FORWARD LINK
DOC IN-HOUSE MODEM PERFORMANCE

PROBABILITY OF PACKET ERROR vs. DELTA(EIRP s)

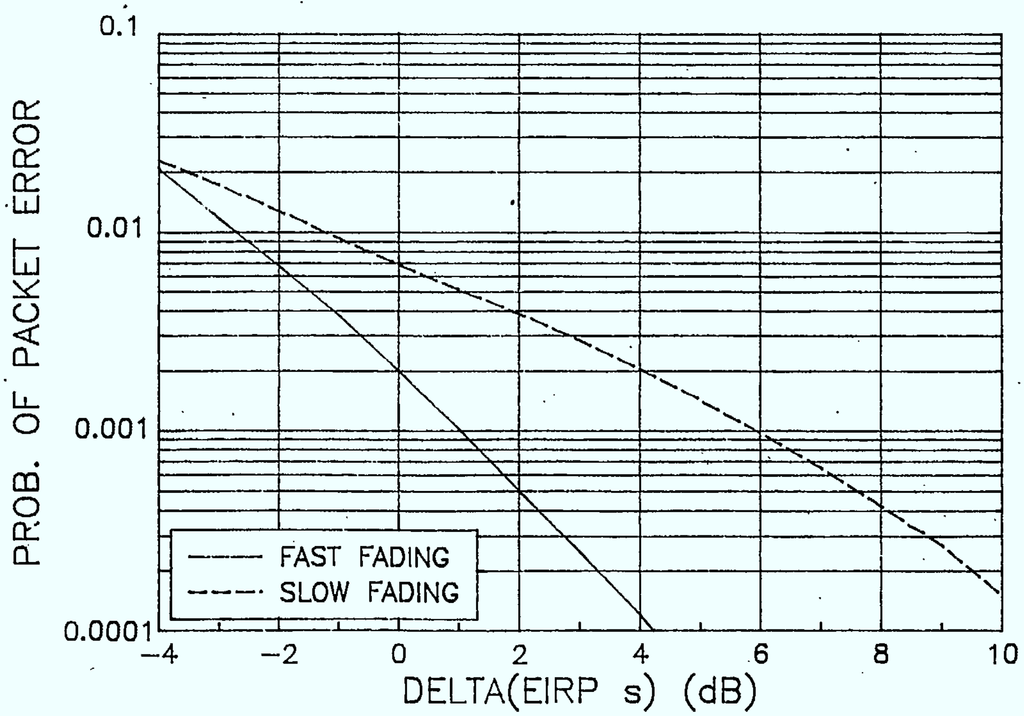


FIGURE I3

8(15, 11)   REVERSE LINK, UHF
DOC IN-HOUSE MODEM PERFORMANCE   20 ELEVATION ANGLE

PROBABILITY OF PACKET ERROR vs. LINK MARGIN

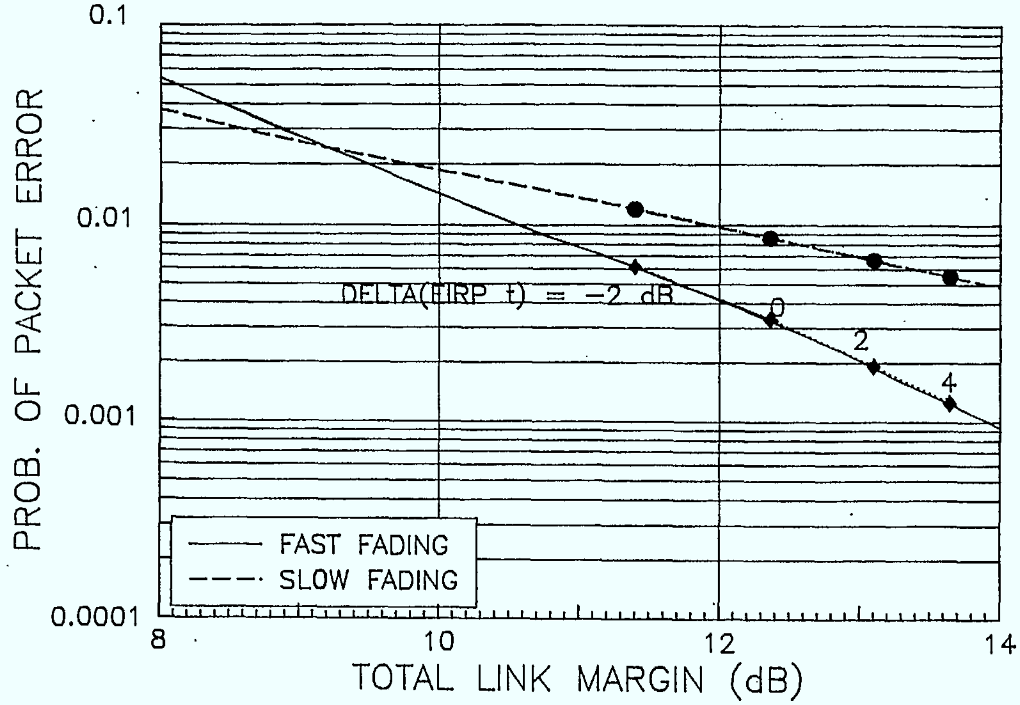


FIGURE I4

8(15, 11)   REVERSE LINK
DOC IN-HOUSE MODEM PERFORMANCE

PROBABILITY OF PACKET ERROR vs. DELTA(EIRP s)

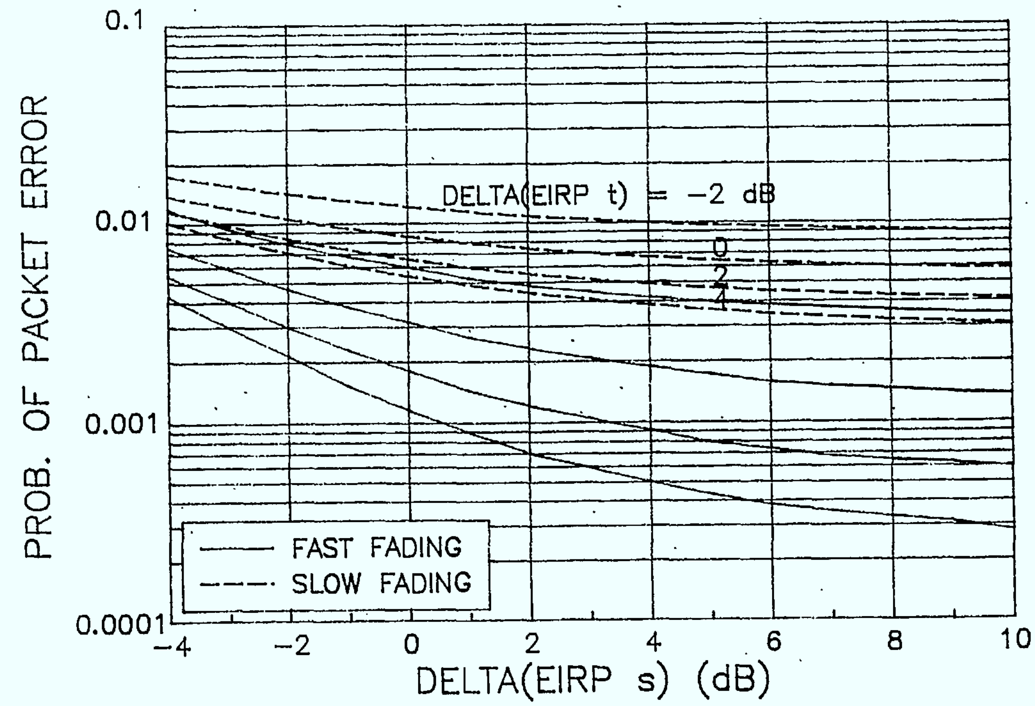


FIGURE I5

UNIQUE WORD   REVERSE LINK, UHF
DOC IN-HOUSE MODEM PERFORMANCE   20 ELEVATION ANGLE

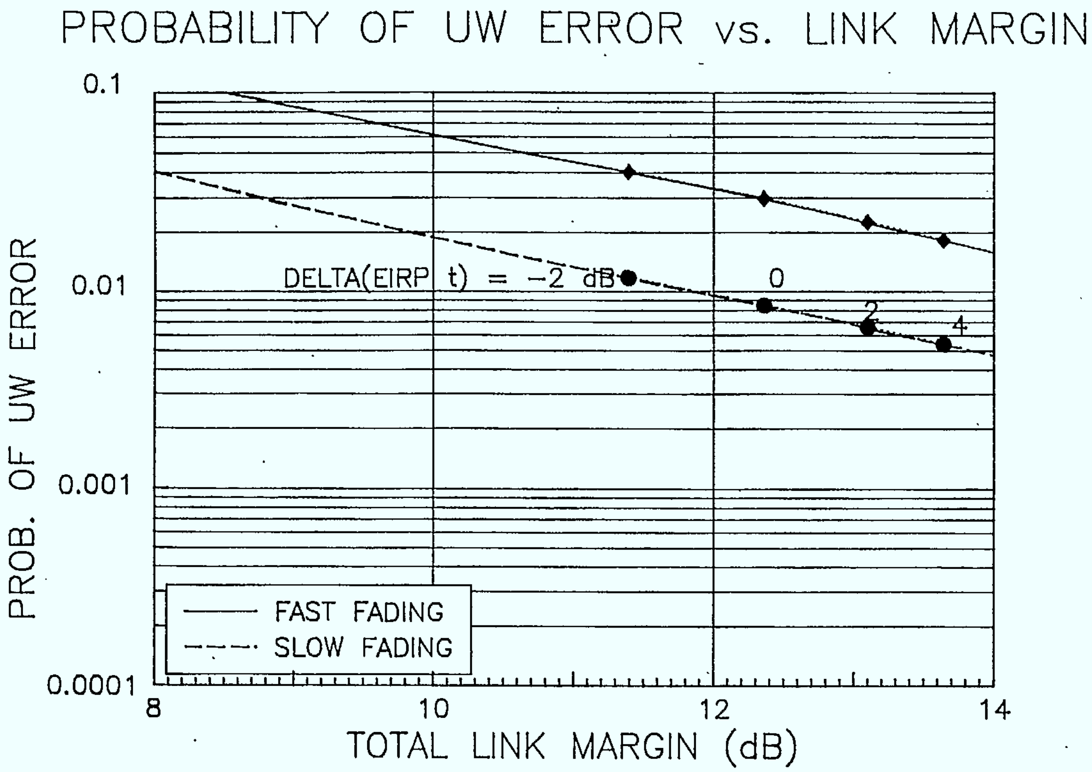


FIGURE I6

UNIQUE WORD   FORWARD LINK, UHF
DOC IN-HOUSE MODEM PERFORMANCE   20 ELEVATION ANGLE

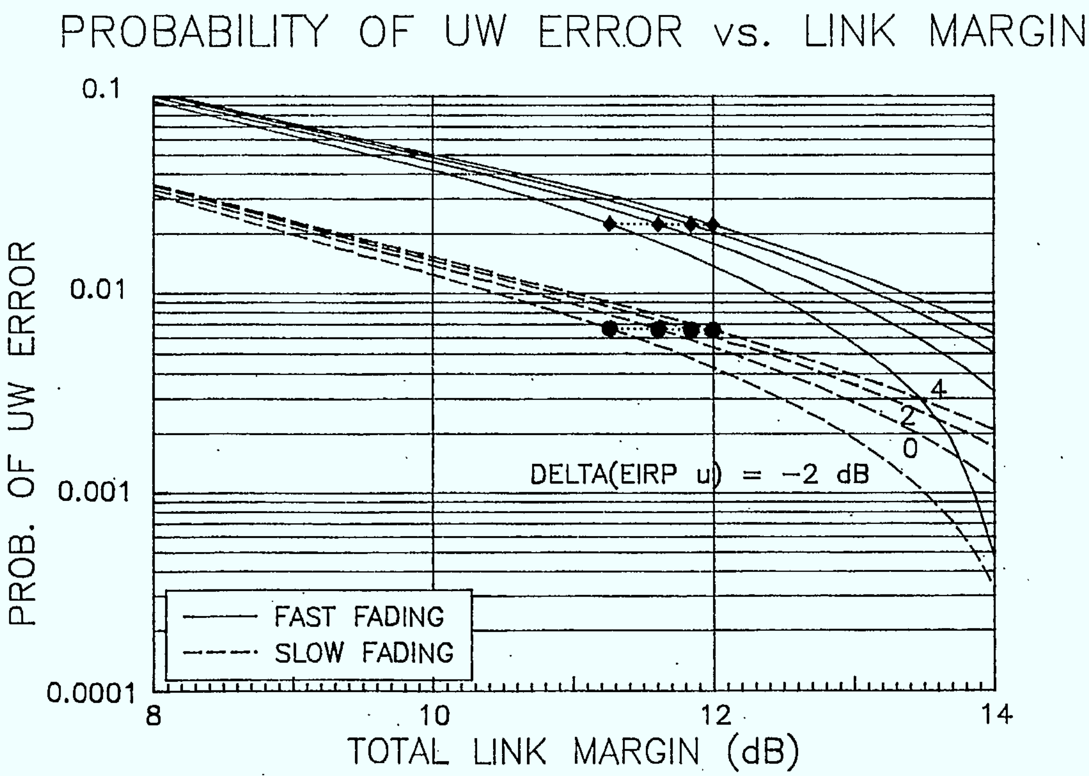


FIGURE I7

4–BIT TOKEN REVERSE LINK, UHF
DOC IN–HOUSE MODEM PERFORMANCE 20 ELEVATION ANGLE

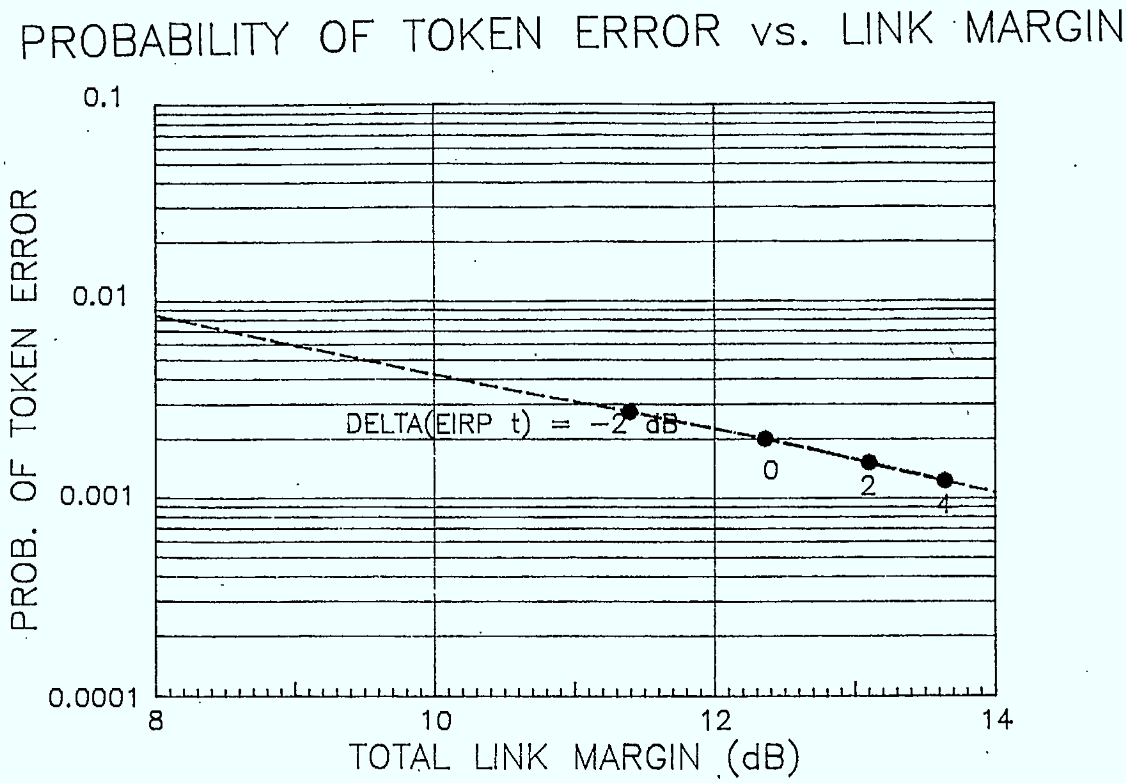


FIGURE I8

APPENDIX J

Probability of Packet Error

(L-Band)

J.1 Introduction

This Appendix is intended to present the results evaluated for the probability of packet error for the present link budget of MSAT baseline links used for L-band services (Table J1). The produced results are for CRC in-house modem (described in Figure F1) and fade statistics experienced by mobiles using L-band services. The cumulative probability distribution function curve for L-band is generated by CRC and is taken from [8] (Figure J1).

J.2 Forward Link

The present MSAT link budget for L-Band allows for a total link margin of 11.8 dB on forward link where the allowed fade margin on the downlink portion of the link is 14.2 dB. From Figure J2, the probability of packet error due to error in coded segment of packet (P_{PE}) is 2.85% for fast fading and 2.15% for slow fading case. The total probability of packet error due to error in unique word and coded segment of packet would be limited but not more than 11% in forward link for mobile users with more than 20° elevation angle accessing L-band channels.

J.3 Reverse Link

The present MSAT link budget allows for a total link margin of 13.13 dB on reverse link where the allowed fade margin on the uplink portion of the link is 13.9 dB. From Figure J4, the P_{PE} is 2.9% for fast fading case and 2.2% for slow fading. The probability of error occurrence in unique word is given in Figure J7. The total probability of packet error would be 11.6% in reverse link for mobiles using L-Band links. The probability of token misdetection in reverse link is 0.6% as shown in Figure J8.

FIGURE J1 CUMULATIVE PROBABILITY DISTRIBUTION FUNCTION for L-Band

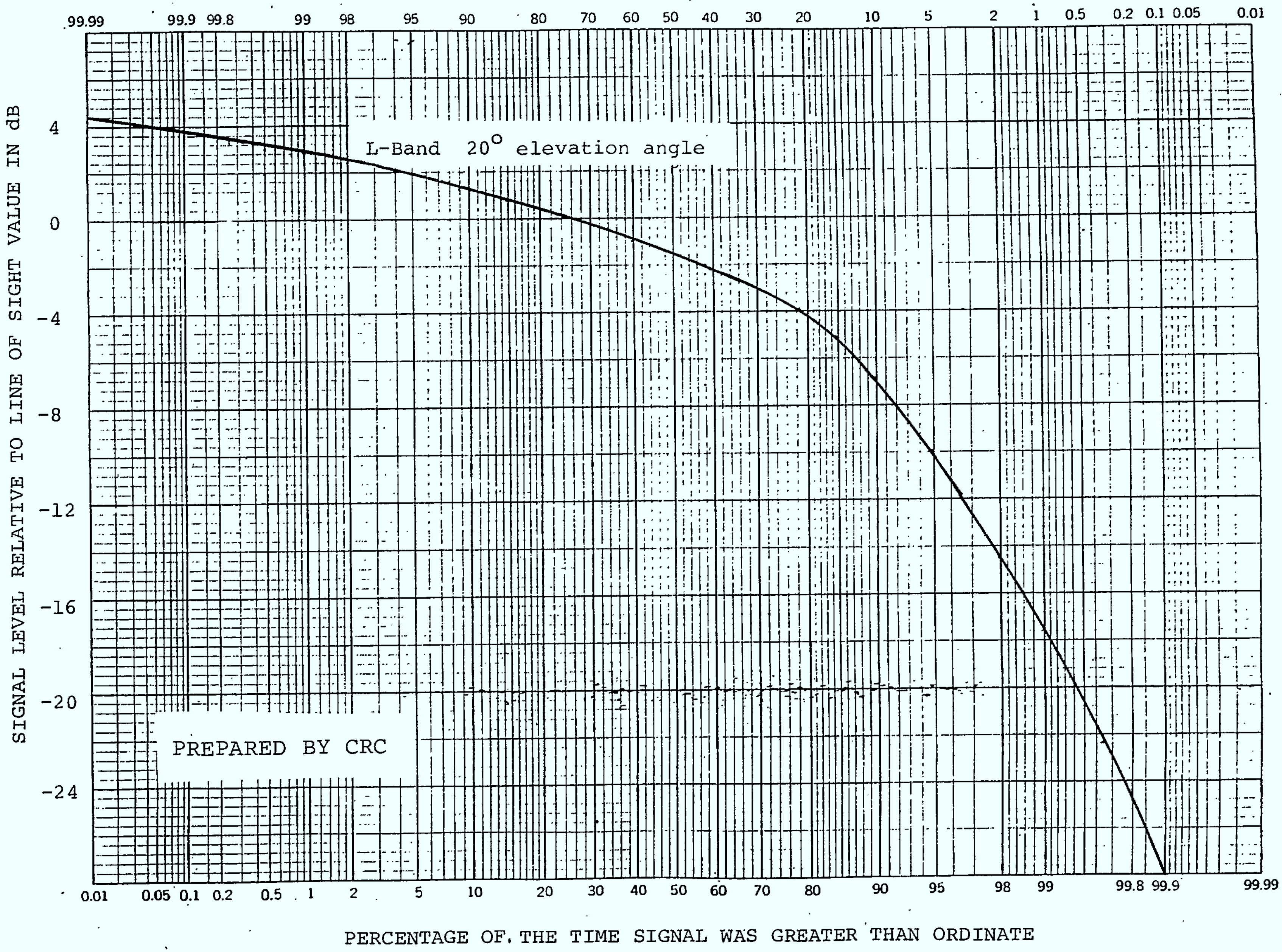


TABLE J1

4 Beams Canada/U.S.
Link Budgets L-Band → SHF with Reduced Availability

PARAMETER	UNIT	FORWARD LINK	REVERSE LINK
UPLINK		3.5m SHF Ant. to Mobile	Mobile to 3.5m SHF Ant.
Satellite G/T	dB/K	-3.0	0.3
Uplink EIRP/ Voice Act. Carr.	dBW	40.1	16.7
Path Loss	dB	206.8	188.7
Total IPBO/Transp.(Av. Pwr)	dB	N/A	12
Req'd. Flux Density/Voice Carr.	dBW/m^2	-122.8	-143.9
C/No Thermal	dB-Hz	58.9	56.9
Noise Bandwidth	kHz	3	3
C/N Thermal	dB	24.1	22.1
DOWNLINK			
Req'd EIRP/Voice Act. Carr.	dBW	28.5	8.6
Req'd Total OPBO	dB	N/A	7
Full Load EIRP/Transponder (edge of coverage)	dBW	TBD	TBD
Path Loss	dB	188.2	205.8
Receive Terminal G/T	dB/K	-15.8	25.9
C/No Thermal	dB-Hz	53.1	57.3
Noise Bandwidth	kHz	3	3
C/N Thermal	dB	18.3	22.6
INTERFERENCE (C/I)			
Intermod & Energy Spread			
Uplink	dB	32	25
Downlink	dB	22	25
Interbeam Co-channel			
Uplink	dB	–	–
Downlink	dB	–	–
Other Sources			
Uplink	dB	32	–
Downlink	dB	–	29
Total Interference	dB	21.2	21.2
Total Unfaded C/N	dB	15.8	17.2
Total Unfaded C/No	dB-Hz	50.6	52.0

9(15, 11) FORWARD LINK, L-BAND
DOC IN-HOUSE MODEM PERFORMANCE 20 ELEVATION ANGLE

PROBABILITY OF PACKET ERROR vs. LINK MARGIN

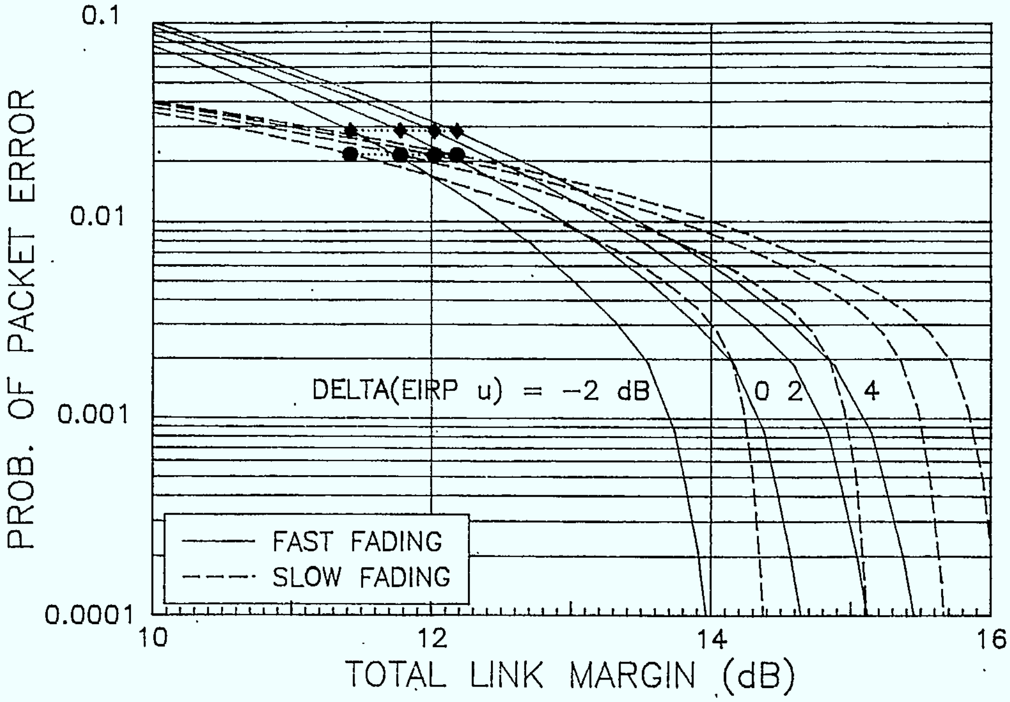


FIGURE J2

9(15, 11) FORWARD LINK, L-BAND
DOC IN-HOUSE MODEM PERFORMANCE 20 ELEVATION ANGLE

PROBABILITY OF PACKET ERROR vs. DELTA(EIRP s)

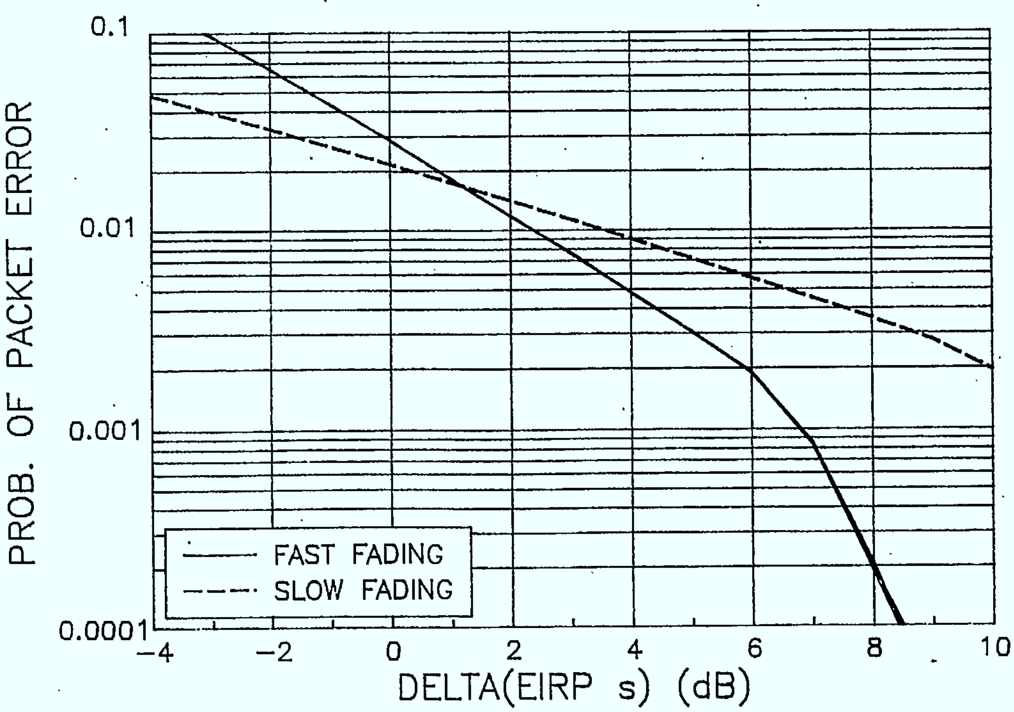


FIGURE J3

8(15, 11) REVERSE LINK, L-BAND
DOC IN-HOUSE MODEM PERFORMANCE 20 ELEVATION ANGLE

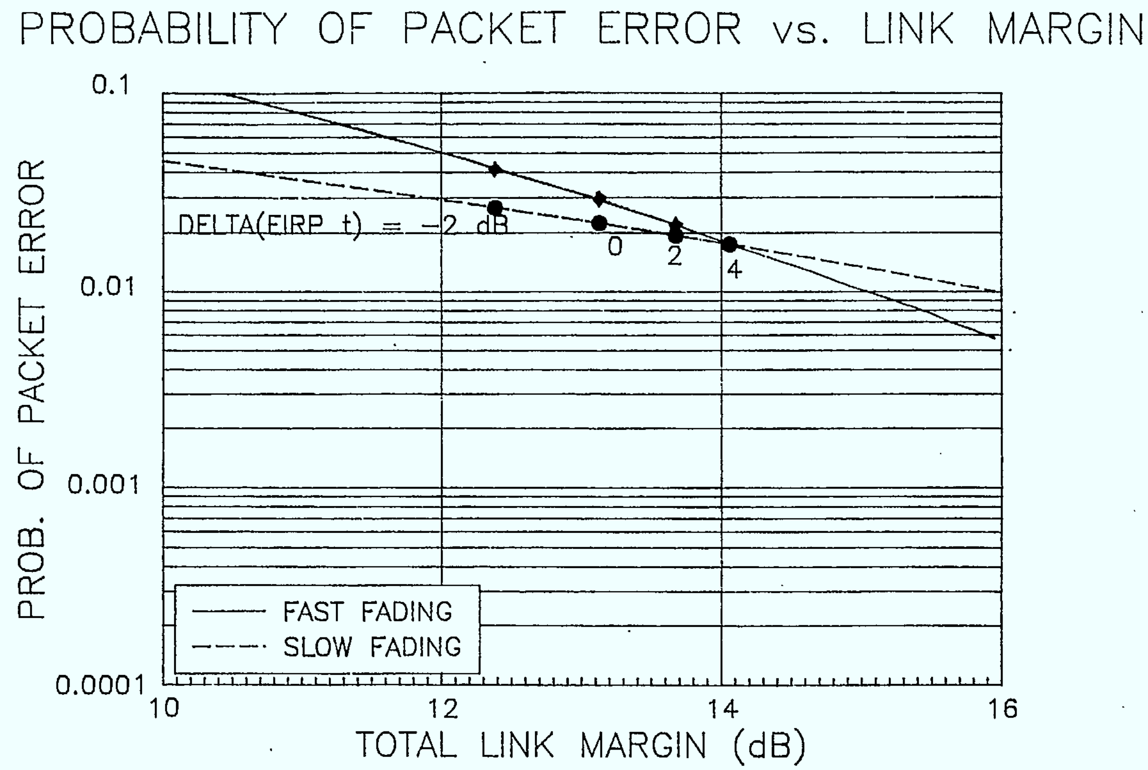


FIGURE J4

8(15, 11) REVERSE LINK, L-BAND
DOC IN-HOUSE MODEM PERFORMANCE 20 ELEVATION ANGLE

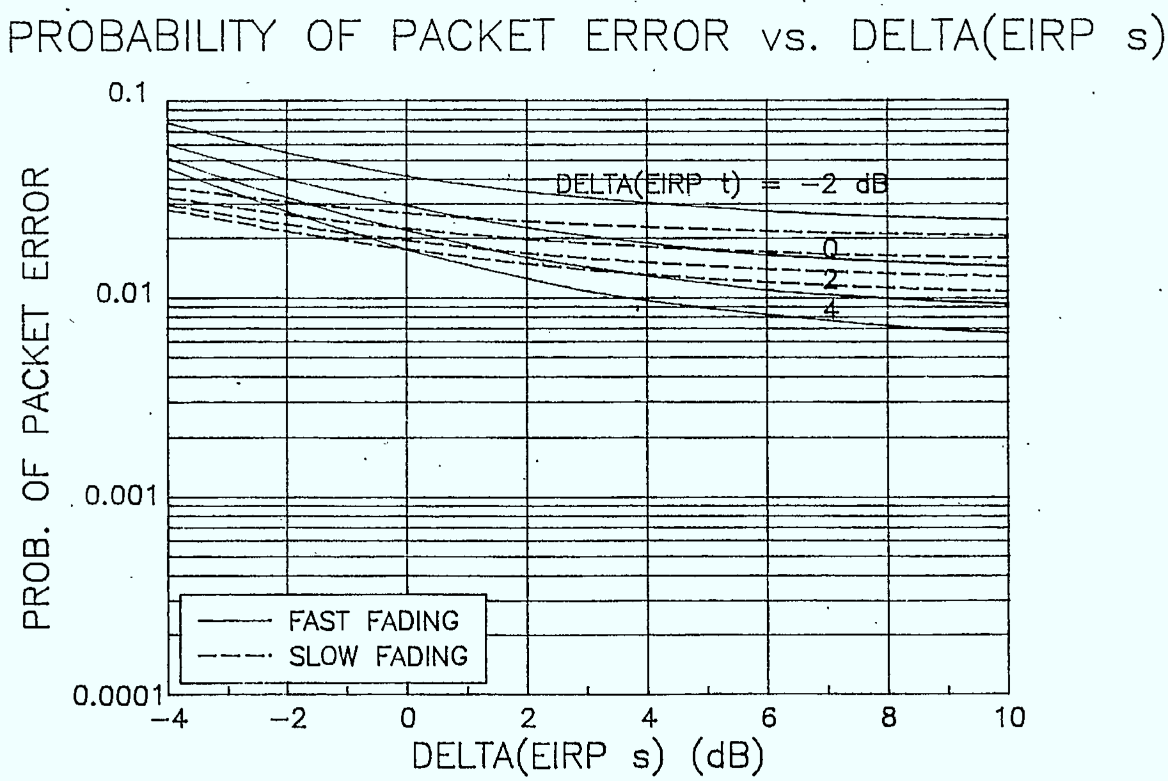


FIGURE J5

UNIQUE WORD FORWARD LINK , L–BAND
DOC IN–HOUSE MODEM PERFORMANCE 20 ELEVATION ANGLE

PROBABILITY OF UW ERROR vs. LINK MARGIN

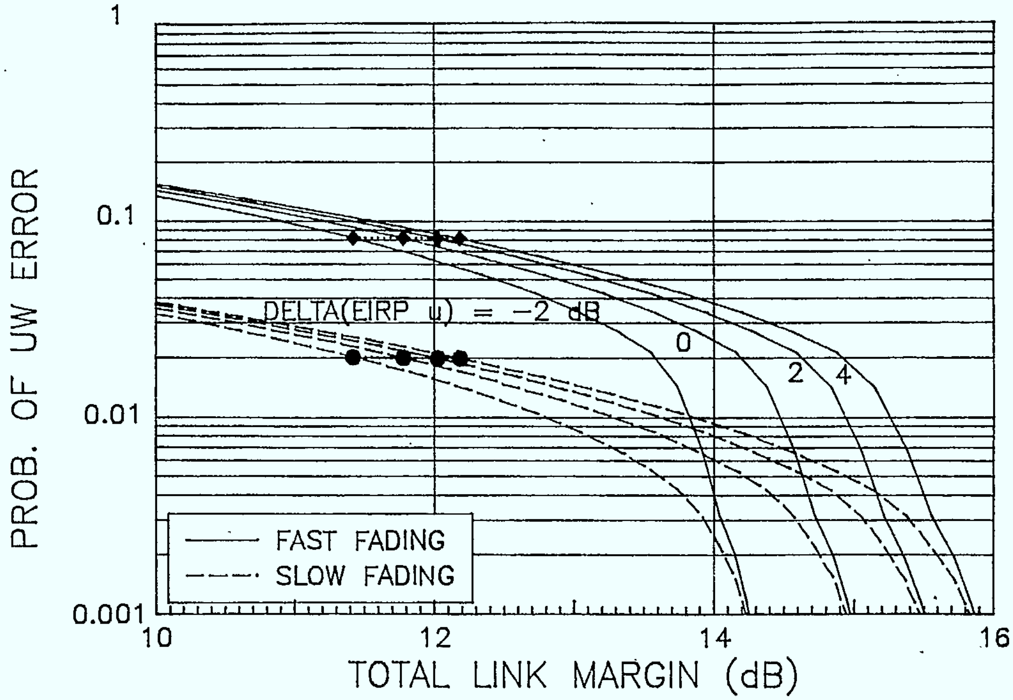


FIGURE J6

UNIQUE WORD REVERSE LINK , L–BAND
DOC IN–HOUSE MODEM PERFORMANCE 20 ELEVATION ANGLE

PROBABILITY OF UW ERROR vs. LINK MARGIN

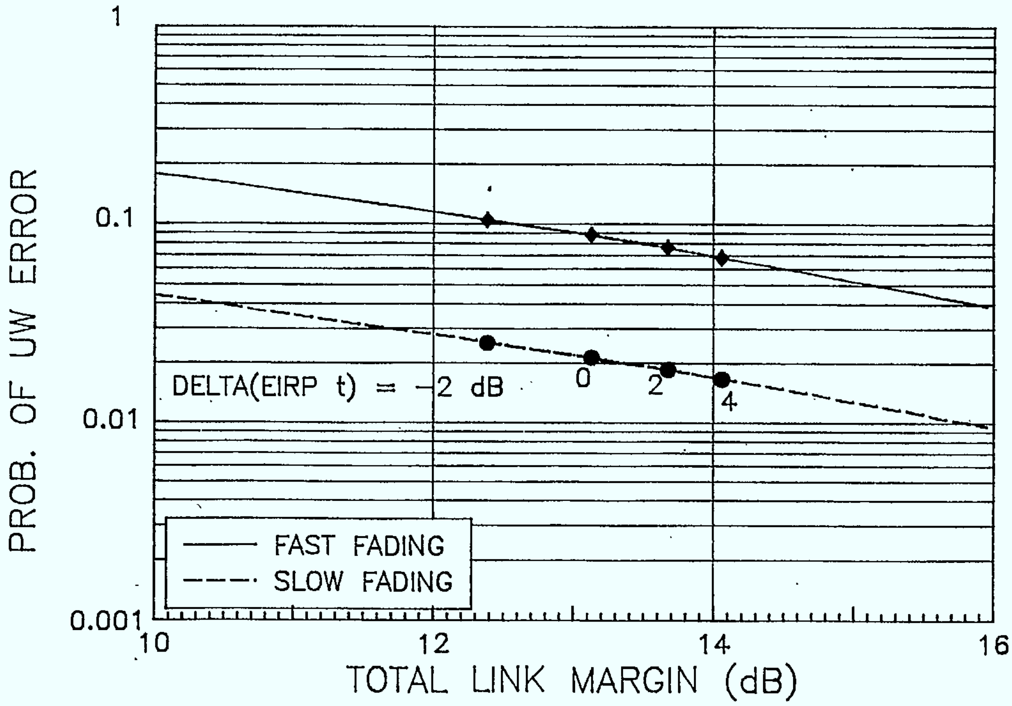


FIGURE J7

4–BIT TOKEN REVERSE LINK, L–BAND
DOC IN–HOUSE MODEM PERFORMANCE 20 ELEVATION ANGLE

PROBABILITY OF TOKEN ERROR vs. LINK MARGIN

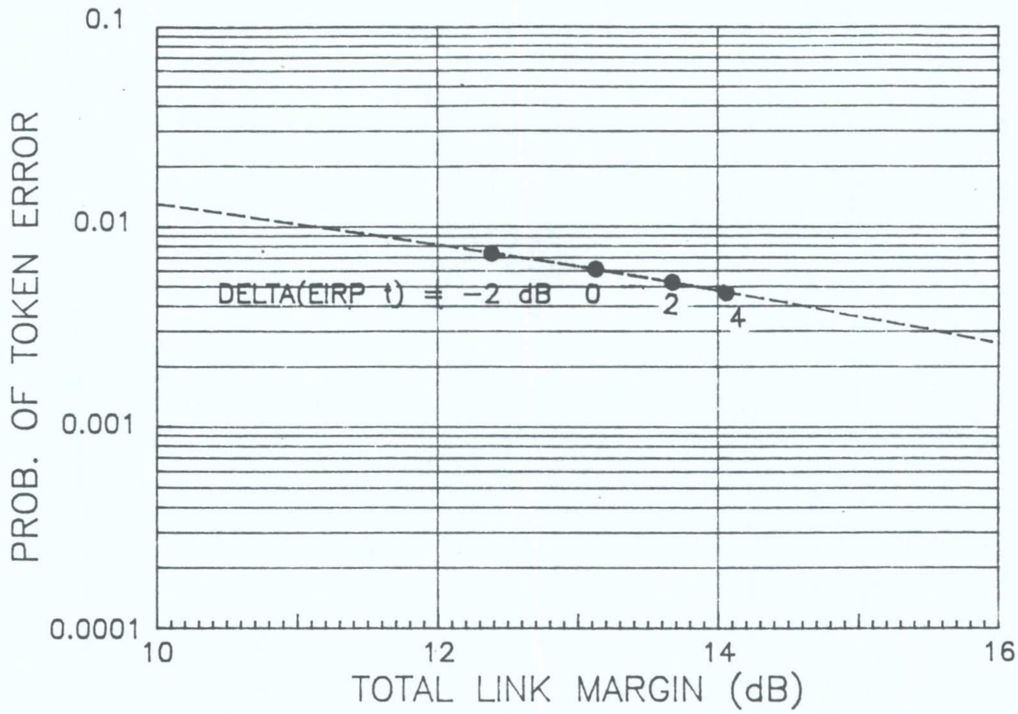


FIGURE J8