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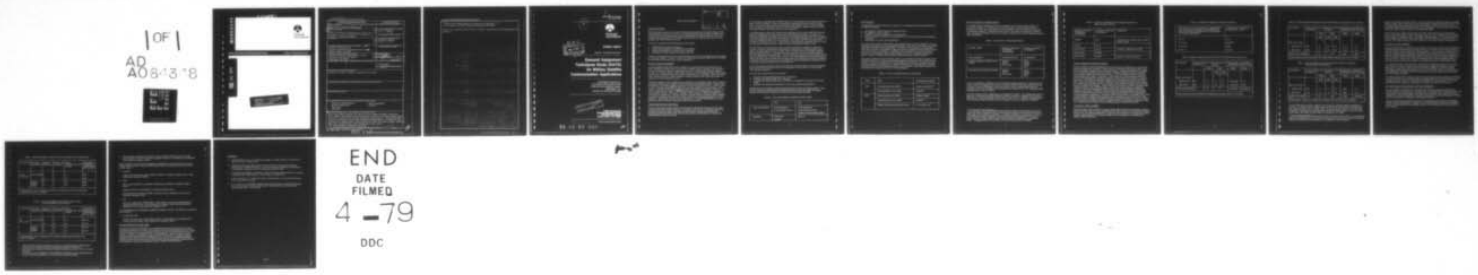

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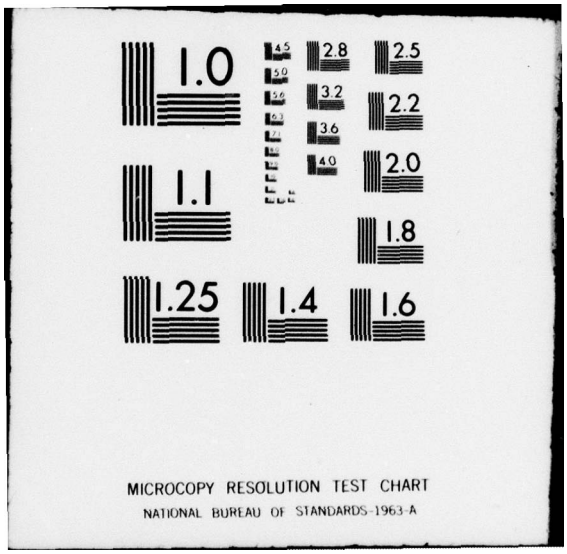
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Volume 1 Executive Summary

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This final report presents the results of the Demand-Assignment Techniques Study (DATS). The objective of this one-year study is to evaluate demend assignment (DA) techniques for military satellite communications. Demand-assignment provides an effective way to meet growing DOD requirements for satellite communications by enabling many users to share satellite and earth terminal resources. The study is divided into the following four major tasks:

a. Establishment of Selection Criteria;
b. Trade-off Investigation of Candidate DA Techniques; → next page

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c. Detailed Investigation of Preferred DA Techniques, and
d. Evaluation of Earth Terminal Reliability and Cost.

Results of all study task as well as overall conclusions and recommendations are presented.

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Volume 1 Executive Summary

Demand Assignment Techniques Study (DATS) for Military Satellite Communication Applications

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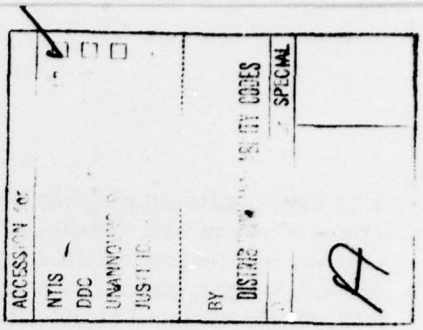

EXECUTIVE SUMMARY

Objective and Scope

This final report presents the results of the Demand-Assignment Techniques Study (DATS). The objective of this one-year study is to evaluate demand assignment (DA) techniques for military satellite communications. Demand-assignment provides an effective way to meet growing DOD requirements for satellite communications by enabling many users to share satellite and earth terminal resources.

The study is divided into the following four major tasks:

a. Establishment of Selection Criteria
b. Trade-off Investigation of Candidate DA Techniques
c. Detailed Investigation of Preferred DA Techniques
d. Evaluation of Earth Terminal Reliability and Cost

Results of all study tasks as well as overall conclusions and recommendations are presented in two report volumes. Volume 1 consists of the Executive Summary while Volume 2 contains the main body of the report plus technical appendixes.

Demand-Assignment Definition

Demand assignment (DA) deals with techniques to provide efficient matching between the time-varying user demands for service and the available system capacity. The benefits of DA may be realized in terms of supporting more users, requiring less satellite capacity, or both. For a given capacity, a DA system can serve a larger population than a fixed assignment system, provided the user duty-cycle is relatively low. Conversely, a fixed user population can be served by a smaller amount of satellite capacity when using a DA system as opposed to a fixed-assignment system.

Demand-assignment can be divided into two categories as considered in this study: demand-assignment multiple access (DAMA) and baseband demand assignment (BDA). DAMA refers to matching the available satellite capacity to the time-varying user needs. A DAMA system involves a demand-assignment technique and a satellite multiple-access technique. BDA refers to matching the available terminal capacity associated with a single rf carrier to the time-varying local user needs. A BDA system involves a DA technique and a baseband multiplexing technique. With DAMA, satellite channel capacity is demand assigned directly to the total user population, whereas, with BDA, satellite channel capacity is fixed assigned among the terminals and the terminal channel capacity is then demand assigned to the user population. Both DAMA and BDA, either separately or in a hybrid DAMA/BDA form, may be used to achieve maximum utilization of the SATCOM system.

Study Background and Ground Rules

Current and planned military satellite communications (SATCOM) systems can be broadly classified into UHF and SHF systems, in accordance with the user communities they serve in these two frequency bands. Examples of UHF satellite systems are GAPFILLER, FLEETSATCOM, and AFSATCOM. SHF satellite systems include DSCS I, II, and III, the British SKYNET and NATO series.

The community employing UHF SATCOM consists of a large number of low-duty-cycle users, many of whom are mobile. Their communications requirement is primarily for netting, that is, for communication between net members and designated shore or control stations. Power, weight, size, and cost constraints of these users dictate simple terminals typically with single-channel transmitting and receiving capabilities.

Accommodation of a large UHF military user population in the overcrowded UHF frequency band will be difficult if all users are provided with dedicated channels. Furthermore, dedicated assignments are inefficient in the use of the limited satellite resources available. A demand-assignment approach, where channels are assigned temporarily to users when they need to communicate and are then reassigned to other users when idle, will allow better utilization of satellite resources. In this manner, communication capability will be provided to a much larger number of users within the limited bandwidth available at UHF.

The SHF frequency band has been used in the past primarily for trunking to support the strategic long-haul communication requirements of the Defense Communications System (DCS). The high duty-factor and the large volume of traffic involved in trunking requires full-time dedicated links. In the past few years, however, the user community requiring SHF SATCOM has grown considerably. The new SHF users require tactical trunking and netting communications. Entrance of the new users and their differing communication needs requires that SHF systems provide both strategic and tactical trunking and netting capabilities. Recognition of this fact necessitates investigation of demand-assignment techniques at SHF to provide rapid and responsive service to all users.

Several key ground rules have been incorporated into the DATS study to ensure that efforts focus on the near-term needs of the user communities who will derive the most benefit from demand assignment.

The four major ground rules are as follows:

a. Consider only the general purpose user community
b. Consider only digital traffic (voice and data)
c. Consider only earth terminals now in inventory or planned for inventory by the early 1980's
d. Consider only operational satellites or near-term programmed satellites

Specific users and satellites consistent with these ground rules are listed in table 1. The list of terminals is too extensive for inclusion here, but covers the range from single-channel, UHF shipboard terminals to large, fixed SHF trunking terminals.

Table 1. Users and Satellites Considered in DATS Study.

	UHF	SHF
User Communities	Fleet Operations Ground Mobile Forces	Fleet Operations Ground Mobile Forces Defense Communication System
Satellites	FLEETSAT GAPSAT	DSCS II

Study Approach

Accomplishment of DATS objectives is based on a comprehensive technical approach that includes the following:

a. Development of unified capacity assignment theory
b. Development of user models
c. Analysis of practical candidates for DA efficiency
d. Detailed analysis of preferred DA candidates for cost and radio spectrum assignment limitations
e. Preparation of system recommendations

One of the major results of this study is the classification of capacity assignment systems and unified development of demand assignment theory. The theory covers both voice traffic (appendix A) and data traffic (appendix B). The theory then is applied to representative user models in order to establish a ranking of practical candidate systems against the first selection criterion, DA efficiency. Included in the user models are the earth terminal parameters and message traffic statistics unique to each user community identified in table 1. Sources of traffic models utilized during the study are listed in table 2.

After initial ranking, the most efficient systems are selected for detailed evaluation of two additional criteria, cost and radio spectrum assignment limitations. These latter factors provide a check on the viability of DA systems based on economic and international radio spectrum regulatory considerations. The theoretical basis for radio spectrum evaluation is derived from previous results presented by Long.[5] Results of the detailed analysis are then assessed to prepare final system recommendations.

Table 2. Source of Traffic Models for DATS Study.

TYPE	USER	REFERENCE SOURCE
UHF	Fleet Operations (FLTOPS)	Lincoln Labs Study[1]
	Ground Mobile Forces (GMF)	INTACS[2]
SHF	Fleet Operations (FLTOPS)	COMSAT Study[3]
	Ground Mobile Forces (GMF)	INTACS[2]
	Defense Communication System (DCS)	A. D. Little, Inc.[4]

Demand-Assignment Candidate Systems

A SATCOM capacity-assignment system is composed of several functional entities. In describing a system, it is convenient to specify the purpose or type of system and the techniques by which each major function is accomplished. Table 3 depicts the composition of assignment systems as considered in this report. Listed are the categories of system types, assignment techniques, and control-channel techniques from which assignment systems can be constituted.

Table 3. Composition of Assignment Systems.

SYSTEM TYPES	MESSAGE-CHANNEL ASSIGNMENT TECHNIQUES	CONTROL-CHANNEL TECHNIQUES
Fixed assignment	Preassigned (fixed)	Not applicable
Demand assignment multiple access (DAMA)	Random Polled Reservation	Fixed Random Polled None
Baseband demand assignment (BDA)	Random Polled Reservation	Fixed Random Polled None

The several possible combinations of each message-channel assignment technique with each control-channel technique listed in table 3 for DAMA and BDA have been considered during the study. Several combinations were ruled out from further investigation because the assignment and control techniques were inconsistent or impractical.* The remaining (valid) combinations are listed in table 4.

General comments on the combinations are included in the table. The combinations apply, in principle, to both DAMA and BDA systems, although a particular combination may be more effective for a DAMA application than for BDA, or vice versa. In addition, fixed assignment of the message-channel capacity was also evaluated to serve as a reference candidate.

*For example, a fixed-assignment control-channel technique is inconsistent in a system employing random assignment of the message-channel capacity because the latter does not utilize any control channel, by definition. As another example, it is impractical to devise a polled message-channel assignment system utilizing polled assignment for the control channel, since this implies that the user would be polled to determine if it needed to be polled. The first polling activity suffices to permit transmission of messages.

Table 4. Practical Combinations of Techniques Applicable to BDA and DAMA Systems.

MESSAGE-CHANNEL ASSIGNMENT TECHNIQUE	CONTROL-CHANNEL TECHNIQUE	COMMENTS
Random	None	Examples: pure random, pure ALOHA, slotted ALOHA
Polled	Fixed	
Reservation	Fixed	Examples: UMSTEAD, SPADE
Reservation	Random	
Reservation	Polled	Similar to reservation-fixed

Demand Assignment Candidate Evaluation

The key evaluation criteria identified by the DATS study are DA efficiency, cost and radio spectrum assignment constraints. Each criterion is calculated numerically, based on the theory and system models developed during the study. In the tables that follow, DA efficiency is indicated quantitatively as the number of satellite channels needed to satisfy the communication requirement of the various users. The most efficient systems are those requiring the fewest number of channels. Cost numbers are estimated basic production costs for the supplementary hardware required to implement the DA functions in existing terminals. The number of terminals included in the cost estimates is shown with each table. Because of varying conditions of deployment and logistic support, costs of installation and life-cycle maintenance are not included. Radio spectrum assignment constraints have proven difficult to quantify. A factor has been derived that provides a measure of the constraint impact on the candidate systems imposed by current spectrum assignment criteria. This factor indicates the fraction of the total possible frequency assignments (bandwidth) that must be available to the particular service being analyzed, for example, FLTOPS, such that the system will achieve a standard probability (0.5) of obtaining the required frequency assignments. Detailed analysis of the spectrum availability in the locale of each existing or planned earth terminal was not undertaken as part of the DATS study. Instead, frequency assignment availability factors have been categorized as shown in table 5 for the purpose of comparing systems. Category boundaries are based on subjective evaluation of general band occupancy and prevailing frequency management policies.

Comparison of SHF Candidates

During the study, each practical DA system listed in table 4 has been evaluated for applicability to FLTOPS, GMF, and DCS requirements for SHF SATCOM. Only reservation systems were found to be adequately efficient to support the voice traffic that is predominant at SHF. Results of applying the DATS evaluation criteria to the reservation DA candidates are listed in tables 6 through 8.

Table 5. Frequency Assignment Constraint Categories.

FRACTION OF TOTAL FREQUENCY ASSIGNMENTS THAT MUST BE AVAILABLE AS PREREQUISITE FOR ACCEPTABLE PROBABILITY OF OBTAINING DA SYSTEM ASSIGNMENT	FREQUENCY ASSIGNMENT CONSTRAINT LEVEL
0 to 0.5	Low
0.5 to 0.9	Moderate
0.9 to 0.99	High
0.99 to 1	Severe

Table 6. Demand Assignment Options for SHF SATCOM for Fleet Operations.*

DA SYSTEM	SATELLITE CHANNELS	BASIC PRODUCTION COST ($ X10^6)			FREQUENCY ASSIGNMENT CONSTRAINTS ON UP-LINK	
		TDMA	FDMA		TDMA	FDMA
			FDM	TDM		
BDA-reservation						
Without TASI	133	1.3	2.1	4.6	Moderate	Low
With TASI	122	1.4	2.0	4.2	Moderate	Low
DAMA-reservation	41	1.3	2.2		Moderate	Moderate

*Representative model consisting of 22 shipboard terminals with G/T of 18 dB/K.

Table 7. Demand Assignment Options for SHF SATCOM for Ground Mobile Forces (GMF).*

DA SYSTEM	SATELLITE CHANNELS	BASIC PRODUCTION COST ($ X10^6)			FREQUENCY ASSIGNMENT CONSTRAINTS ON UP-LINK	
		TDMA	FDMA		TDMA	FDMA
		TDM	FDM	TDM		
BDA-reservation						
Without TASI	2304	4.4	23.7	40.9	Severe	Low
With TASI	1302	5.8	16.2	36.8	Severe	Low
DAMA-reservation	1388	4.4	25.7		High	High
*Representative model consisting of 60 transportable terminals with G/T of 18 dB/K.						

Table 8. Demand Assignment Options for SHF SATCOM for the Defense Communications System (DCS).*

DA SYSTEM	SATELLITE CHANNELS	BASIC PRODUCTION COST ($ X10^6)			FREQUENCY ASSIGNMENT CONSTRAINTS ON UP-LINK	
		TDMA	FDMA		TDMA	FDMA
		TDM	FDM	TDM		
BDA-reservation						
Without TASI	1176	1.7	11.9	16.0	High	Low
With TASI	622	2.1	7.5	14.1	High	Low
DAMA-reservation	784	1.7	12.6		High	Moderate
*Representative model consisting of 21 terminals with G/T from 26.5 to 39 dB/K.						

The FLTOPS network includes relatively few terminals, with light traffic generation per terminal. As shown in table 6, DAMA requires only one third the number of satellite channels required by BDA with or without TASI.* Since both the production cost and frequency assignment constraints are comparable between BDA and DAMA, DAMA is the clear choice for FLTOPS, with TDMA having a slight cost advantage over FDMA.

*Time-assignment speech interpolation (TASI) is a dynamic form of BDA in which baseband channels are reassigned to active circuits during pauses in the speech of a given individual. When that individual resumes speaking, he is assigned to any idle channel.

Results for the GMF are listed in table 7. Based on number of satellite channels, both BDA-TASI and DAMA require only 60 percent of the channels required by BDA-reservation. BDA-TASI and DAMA have comparably low costs when TDMA is employed, however spectrum availability constraints eliminate the BDA-TDMA combination. The remaining viable system choices are DAMA-TDMA and BDA-TASI using FDM-FDMA.

The DCS network is made up of relatively few large, fixed terminals, each having heavy traffic. Referring to table 8, BDA-TASI is superior to all other candidates in requiring the fewest number of satellite channels. In addition, BDA has equal or better frequency assignment probability than DAMA. Both TDM-TDMA and FDM-FDMA are considered viable systems. The trade-off between the two systems is cost versus frequency assignment risk.

Comparison of UHF Candidates

During the DATS study, each practical DA system listed in table 4 has been evaluated against FLTOPS and GMF requirements for UHF SATCOM. In contrast to SHF, traffic at UHF is composed largely of store-and-forward data messages. For the specific message statistics and user characteristics encountered, only DAMA-reservation systems were found to be efficient. Results of applying DATS evaluation criteria to DAMA-reservation candidates are shown in tables 9 and 10. These tables include columns for control channel technique and priority protocol. Both factors were also evaluated at SHF but had negligible impact on evaluation criteria because data traffic is an insignificant portion of total traffic at SHF.

The FLTOPS network at UHF includes a total of 160 terminals with relatively light traffic per terminal. As shown in table 9, cost and frequency assignment criteria are nearly identical for all systems, thus selection can be based on number of satellite channels. Accordingly, DAMA with priority protocol is the most favorable choice. The priority protocol advantage is significant because it avoids the necessity of considering all messages to be of the highest priority.

The GMF network at UHF includes a total of 210 terminals, both transportable and vehicular. As in the FLTOPS case, cost and frequency assignment factors are nearly identical for all candidate systems. Again, the viable system is DAMA with priority protocol. It should be noted that severe frequency assignment constraints are expected for the GMF.

Recommendations and Conclusions for Demand Assignment

The DATS study has identified and evaluated viable demand-assignment techniques for military satellite communications. The study has concentrated on the current and near-term requirements of the general purpose SATCOM user community. When applied as recommended below, demand assignment of satellite capacity yields significant savings of satellite resources compared to current fixed-assignment techniques.

The DA systems recommended for each user community have been chosen for minimum satellite channel requirements, consistent with cost and frequency assignment availability criteria. In evaluating various candidate systems, the following general conclusions have been reached:

Table 9. Demand Assignment Options for UHF SATCOM for Fleet Operations.*

DA SYSTEM	CONTROL TECHNIQUE	PRIORITY PROTOCOL	SATELLITE CHANNELS	BASIC PRODUCTION COST ($ X10^6)	FREQUENCY ASSIGNMENT CONSTRAINTS ON UP-LINK
DAMA-reservation	Fixed/TDMA	No	4	9.3	High
		Yes	2	9.5	High
	Random/slotted ALOHA	No	3	9.3	High
		Yes	2	9.9	High

*Representative model consisting of 10 large, 50 medium and 100 small shipboard terminals with G/T of -20 dB/K.

Table 10. Demand Assignment Options for UHF SATCOM for Ground Mobile Forces (GMF).*

DA SYSTEM	CONTROL TECHNIQUE	PRIORITY PROTOCOL	SATELLITE CHANNELS	BASIC PRODUCTION COST ($ X10^6)	FREQUENCY ASSIGNMENT CONSTRAINTS ON UP-LINK
DAMA-reservation	Fixed/TDMA	No	21	8.1	Severe
		Yes	14	8.3	Severe
	Random/slotted ALOHA	No	20	8.1	Severe
		Yes	14	8.3	Severe

*Representative model consisting of 210 vehicular/transportable terminals with G/T of -22 kB/K.

a. Reservation-type demand assignment systems are significantly more efficient than either polled or random systems for the general purpose SATCOM user.
b. Priority protocol reduces the required satellite channels by a factor of 1.5 to 2 for the UHF user.
c. Production costs are dependent on the baseband and multiple access technique chosen, but are relatively independent of the choice between BDA and DAMA.

d. SHF frequency assignment constraints are low for BDA-FDMA systems and range from moderate to severe for all other candidate systems. Constraints for all candidate UHF systems are high or severe.

DATS evaluation criteria have been applied to candidate DA systems for each user community. Based on these results, the following DA system recommendations are presented for SHF users:

a. FLTOPS

DAMA-reservation, using either TDMA or FDMA for satellite multiple access. Both methods are considered viable.

b. GMF

BDA-TASI, using FDM for baseband multiplexing and FDMA for satellite multiple access.

DAMA-reservation, using TDMA for satellite multiple access.

Both systems are considered viable, with final selection dependent on cost versus frequency assignment risk.

c. DCS

BDA-TASI, using either FDM-FDMA or TDM-TDMA for baseband multiplexing and satellite multiple access. Both methods are considered viable with final selection dependent on cost versus frequency assignment risk.

The recommendations resulting from applying evaluation criteria to the UHF user community are as follows:

a. FLTOPS and GMF

DAMA-reservation with either slotted ALOHA or fixed-TDMA control channel with priority protocol feature. Both methods are considered viable.

Recommendations for Further Study

The general conclusions and system recommendations above are based on ground rules, theoretical analyses, user models, and evaluation criteria developed during the DATS study. Important factors such as communication security and user interoperability were not considered. Therefore, an additional study is recommended to assess the impact of these operational goals and constraints on the present DATS conclusions. Further, frequency assignment constraints in the SATCOM bands must continue to be identified and studied because of the crucial part they play in the selection and implementation of demand assignment systems to meet the growing DOD needs for satellite communications.

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