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Technical Note

1976-29

J. D. Bridwell

A Terminal Access Control System for FLEETSAT

22 November 1976

Prepared for the Department of the Navy
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Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS



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FOR THE COMMANDER

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LINCOLN LABORATORY

A TERMINAL ACCESS CONTROL SYSTEM FOR FLEETSAT

J. D. BRIDWELL
Group 66

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ABSTRACT

Lincoln Laboratory's Terminal Access Control System (TACS) provides demand assigned time division multiple access TDMA to GAPSAT or FLEETSAT 25 kHz channels. TACS is centrally controlled by a multiple access controller (MAC), nominally located at a shore station. Users of TACS who can be on shore-based or mobile platforms, enter requests for service via a Terminal Access Controller (TAC). The TAC provides error control and data buffering functions in addition to demand assignment control. The MAC automatically responds to the user request with an assignment or busy indication.

TACS initially will utilize WSC-3 radios and modems, modified for 19,200 symbol per second operation and for rapid turn around time. TDMA frame formats are designed to maximize system efficiency and utility. For example, a mobile platform equipped with one half duplex WSC-3 has use of two 2.4 kbps circuits simultaneously. A platform with a full duplex radio has use of four such circuits.

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1.0 INTRODUCTION

Lincoln Laboratory is developing earth terminal equipment to demonstrate the ability to upgrade the FLEETSAT system to a demand assigned TDMA (time division multiple access) system. The experimental upgraded system is called TACS, for Terminal Access Control System. Potential users of TACS are Navy and other tactical users. TACS, consisting of new demand assigned TDMA equipment and suitably modified existing terminal hardware, will make use of 25 kHz FLEETSAT or GAPSAT channels. TACS will provide 25 kHz channel throughput several times higher than the single net, 2.4 kbps of the currently planned system, and will accommodate more than one 2.4 kbps net with a single transceiver. A small ship equipped with one half duplex transceiver could, for example, operate in one voice net and one data net simultaneously. TACS will also provide error control for the severe RFI environment. Initial TACS system tests are expected to begin in early 1977.

The Laboratory is building two types of equipment to demonstrate the centrally controlled Terminal Access Control System. The minicomputer based central controller, designated the Multiple Access Controller (MAC), generates the TDM time base and manages demand assignment. A single MAC would control up to eight FLEETSAT channels, and would nominally be installed at a Communications Area Master Station (CAMS). Each mobile platform would have a microprocessor based Terminal Access Controller (TAC). The TAC is programmable to accommodate evolutionary changes in the transmission system and operating protocols.

The Laboratory is building two TACS and one MAC. This equipment, supplemented by a simulation, will be used to demonstrate a Fleet-wide TACS system. Demand assigned TDMA can thus be tested against putative operating scenarios. The system described in this report is the Fleet-wide system.

In parallel with Lincoln Laboratory's TACS development, the Navy is procuring the DAMA, or Demand Assigned Multiple Access, system.¹ The DAMA system, also for use with FLEETSAT, will provide TDMA in an initial phase, and demand assignment in a follow-on phase. The DAMA system includes a binary 19.2 kbps modem, and utilizes rate 3/4 coding, for a burst rate of 14.4 kbps.* The TACS experiment is expected to influence the evolving DAMA system, especially in the error control and demand assignment areas.

The introduction of this report discusses TACS and its environment with the objectives of telling how the system works, why it is structured the way it is, how it performs, and how it can evolve. Technical details are given only when they are essential for a general understanding. Each subsection of the introduction has a counterpart in Section 2. The subsections in Section 2 build upon the introduction, providing the detail needed for a more complete understanding of the system. Corresponding subsections in Section 3 described a possible application of TACS. The report does not attempt to be complete in technical detail. Other documents, some completed and others in progress, are needed for the technical detail required for the system implementation. The system described in this report is an iteration of the one presented in Reference 2.

* In this report, sps means symbols per second, and bps means bits per second. Hence, rate 3/4 coding of 14.4 kbps data requires 19200 binary channel symbols per second. Consideration is also being given to raising the DAMA modem's data rate to 32 kbps.

1.1 Operating Conditions and Requirements

Potential users of the system will be located on mobile platforms (ships, aircraft and other vehicles) and at Naval Communications Area Master Stations, or CAMS.* Potential users are in other Services than the Navy. Because of such differences as antenna gains among the various types of platforms, the nominal link signal-to-noise ratios vary over a 16 dB range. The system must provide bit error rate performance of 10^{-5} for data and 10^{-3} for vocoded speech over the entire range. The bit error rate and operational performance levels should be maintained not only during nominal transmission conditions, but also when links are disturbed by RFI and other short interval degradations.

In addition to the requirements on link performance, two operational requirements strongly impact on system design. These are talker to listener turn around delay and system response time. A practical limit on talker to listener turn around delay of about 4 seconds places an upper limit of about 2 seconds on TDM frame length.† System response time can be thought of as the number of elapsed frames between a user request for service and a system response, where system response means assignment, busy signal, and so forth. For most purposes, a 10 second response time is sufficient, hence the demand assignment control system should provide response within 5 two second TDM frames. In those instances which require tighter system response time than the demand assigned system can provide, a circuit can be dedicated.

* formerly called COMMSTAS.

† The DAMA system specification limits the frame length to a maximum of 1.5 seconds.

1.2 System Evolution

A key feature of the TAC is field programmability. This feature is provided so that inexpensive field modifications can be made (1) to accommodate transmission system improvements (such as from GAPSAT to FLEETSAT), and (2) to facilitate the evolution of system operation in harmony with improved transmission capability and with experience gained (such as with demand assignment).

Evolution of the transmission system will be marked by increases in the transmission system capacity, which is defined in this report to be the number of 2.4 kbps circuits which the system can support under nominal conditions. The transmission system capacity thus defined depends upon the number of channels available and the multiplexing factor, or the number of accesses per channel. Another important factor, demand assignment gain, leads to an increased utilization of capacity. Demand assignment gain, discussed later, is the average number of 2.4 kbps nets that can share a 2.4 kbps circuit. The current system consists of one wideband and two narrowband GAPSAT channels, and earth terminal equipment limited to 9.6 kbps or lower. RFI may preclude satisfactory operation at rates much greater than 2.4 kbps, since the current system does not use forward error control. The capacity is then about 8 circuits, which results from frequency division multiplexing about six 2.4 kbps, on the wideband channel, and one on each of the narrowband channels. Introduction of TACS or DAMA would permit TDMA, since those systems would use forward error control. Assuming that the TDMA system used the equivalent of three 25 kHz GAPSAT channels, and that modems were modified for at least 19.2 ksps operation, DAMA would

provide a multiplexing gain of about 3 and TACS would provide a gain of about 5. Hence the GAPSAT transmission system capacity would be about 9 circuits with DAMA or about 15 with TACS.

Using DAMA or TACS with the seven 26 dBw, EIRP,[†] 25 kHz, channels of FLEETSAT would yield a capacity of about 21 circuits for DAMA or 35 for TACS. Most ship and shore links are bandlimited. Hence, replacement of existing modems by advanced high rate modems* would approximately double the capacity (to about 70 circuits) with TACS.

Corresponding to the increase in capacity of the space segment is an increase in the capacity of a half duplex transceiver. With the current plan, such a transceiver could be used for only one 2.4 kbps circuit, unless it is manually switched. With TDMA and a modified modem in the GAPSAT era, a half duplex transceiver could be used for two circuits (one data and one voice, say) with TACS, or one with DAMA. With FLEETSAT and TACS, three circuits can be used, if one of them is transmit only. Supplemented with an advanced modem, a half duplex transceiver could be used for four 2.4 kbps circuits with TACS. In addition to accommodating transmission system improvements, the field programmability of the TAC will also accommodate changes in operating protocols that will be desirable as experience is gained from use of the system. Operational changes will take place in several interrelated dimensions, and in ways that cannot be predicted with certainty until experience is gained with

[†] It is assumed that such disadvantaged platforms as aircraft and submarines would use the 28 dBw channels. Use of the 26 dBw channels by such platforms would lead to lower utilizations than suggested above.

* See, for example, Reference 2. The initial version of TACS had a Terminal Access Controller and Modem, or TACM, which was to include an advanced modem. Another example is the high rate Navy modem currently under development [3].

readily available tactical satellite communications. One dimension is average net population. Initially, there will be a few nets, each with a large number of members. As the number of available circuits grows, the number of nets will grow, and the average membership of nets will decrease.

Another dimension of change will be demand assignment. Initially, nets having large populations will have high duty factors, and will use dedicated circuits. Reducing the population by increasing the number of nets will reduce the average duty factor. A demand assignment system can serve many more low duty factor nets than can a dedicated circuit system of equal capacity. Though the potential demand assignment gain is high, the evolution to demand assignment is expected to be a gradual one. At first, demand assigned circuits will be used experimentally. As experience is gained, efficient protocols will be developed, and demand assignment may eventually account for the majority of satellite circuit usage. There will probably always, however, be certain special purpose nets which require dedicated circuits.

An important effect - reliability - stems from the growth of demand assignment. Disabled channels are removed from the demand assigned system, assuring that only high quality circuits are assigned. In contrast, reassignment of a user of a disabled circuit in a dedicated system can have a traumatic effect. In short, the demand assigned system degrades gracefully.

1.3 System Structure

The system requires control circuits to achieve and maintain TDM timing, and for management of demand assignment. Only a few such circuits are needed to control a large number of communications circuits. This section discusses

the issues involved with control and communications slots, and suggests possible applications of the system as the transmission system and demand assignment evolve. Each slot, whether a control slot or a communications slot, has the same basic structure: an acquisition sequence followed by data. The acquisition sequence provides for the acquisition of phase, frequency, symbol, and burst synchronization. The data portion contains the coded data which a user generated within the last frame time. The fine structure is discussed in more detail in Section 2.

1.3.1 Control Circuits

A control circuit is in effect a star net of TACs with the MAC at the center, as depicted by Fig. 1-1a. Figure 1-1b shows the control portion of a TDM frame.* The MAC-to-TAC transmissions, in the control slot (C), include system timing and demand assignment information. The ranging slot (RANG) is TAC-to-MAC transmission used for initial system entry. Each platform typically has a number of potential users of satellite communications circuits. For demand assignment purposes, the users on a particular platform form a star network centered on the platform's TAC. Requests for circuits, initiated by the users, are forwarded by the TAC to the MAC in the request slots (R). The displacement of the C and R slots by at least 290 msec in the satellite transponder (the sum of round trip propagation delay and receive-to-transmit turnaround time of the transceivers) allows a half duplex transceiver to receive C, switch to the transmit mode, and transmit in R in the same frame.

* The DAMA system restricts a transceiver to a given channel, hence has separate control on each channel. TACS controls the transceiver tuning electronically, such that control on one channel can serve the control needs of several channels. Also, control can be expanded to other channels as needed (for example, to support increases in user request rates).

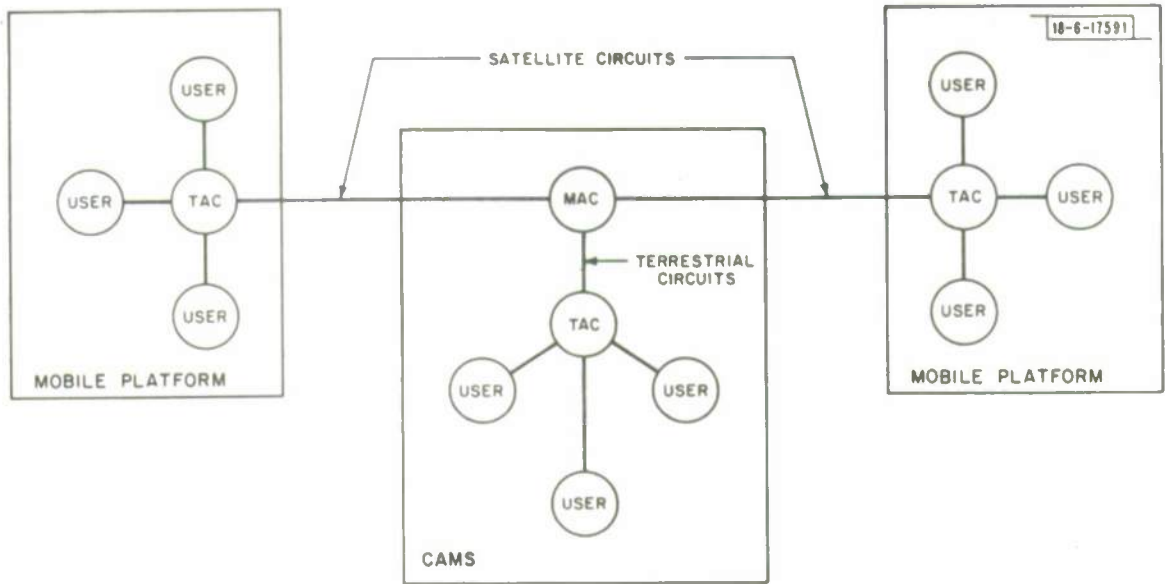


Fig. 1-1a. System Control Configuration.

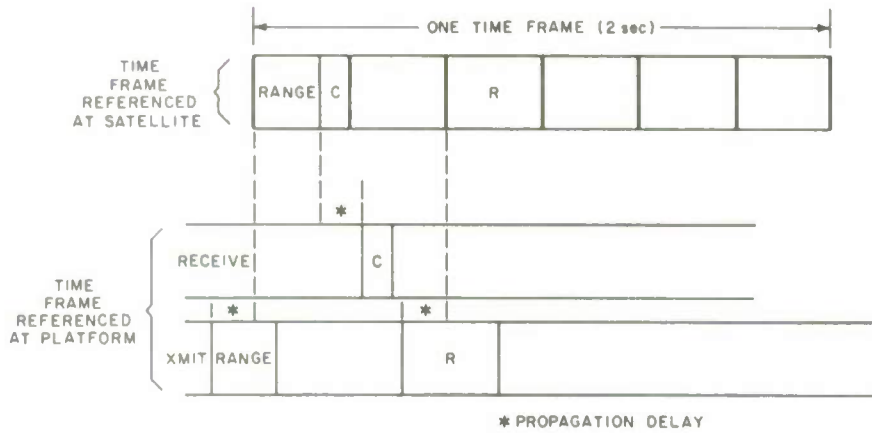


Fig. 1-1b. Control Structure of TDM Time Frame.

1.3.2. Communications Circuits

The control functions require only a small portion of the capabilities of the TAC, just as the control circuits require only a small portion of the satellite capacity. The majority of the TAC, of course, is used for communications. For this discussion, the control circuits are not considered; control and communications circuits are integrated into one frame structure in the following subsection.

Figure 1-2 shows an example of communications circuits and the corresponding frame structures. The burst rate is assumed to be ~ 15.4 kbps if a 2 second frame is subdivided into six equal $1/3$ second slots. Four platforms are shown, in four different circuit configurations. Each platform is assumed to have one half duplex transceiver. The communications circuits can be star configured or can be fully connected. Star configured circuits can be broadcast or report back. Figure 1-2a shows a broadcast circuit (B) in which platform 1 transmits and the other platforms receive. Time slot 1 is used for this circuit. Since each slot duration exceeds 290 msec, a half duplex transceiver can, say, receive in slot 1 and transmit in slot 3. Figure 1-2b shows a report back circuit (RB), which is the inverse of the broadcast circuit. occupying time slot 3. Platforms 2, 3 and 4 can receive B and transmit RB. The broadcasting platform (assumed also to be half duplex), however, cannot receive in slot 6, the slot preceding the broadcast slot, nor can it transmit in slot 4, the slot following the report back slot.

Figure 1-2c shows platforms P_2 , P_3 and P_4 in a fully connected net. Such a configuration is typical of voice nets, hence the designation V_1 . V_1 is in slot 4. Platforms P_2 , P_3 and P_4 can also operate in net V_2 , as shown in

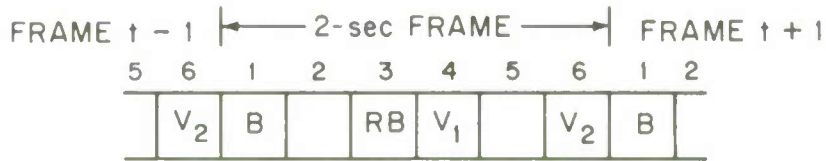
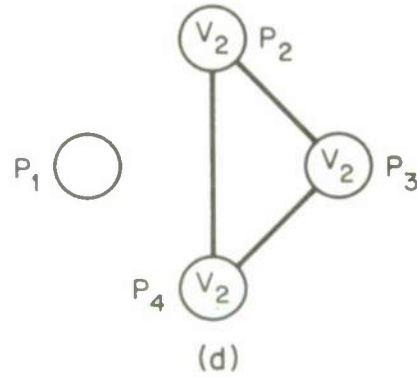
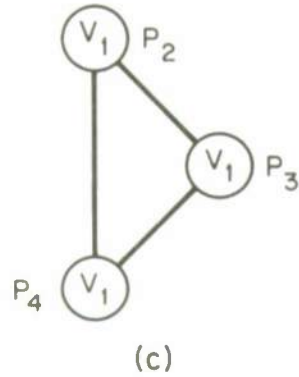
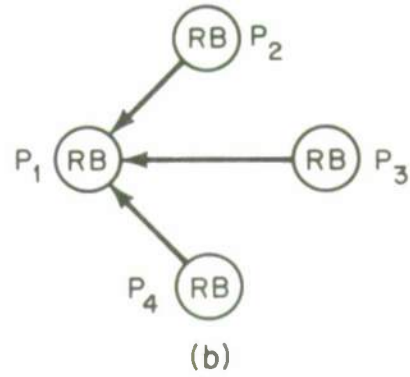
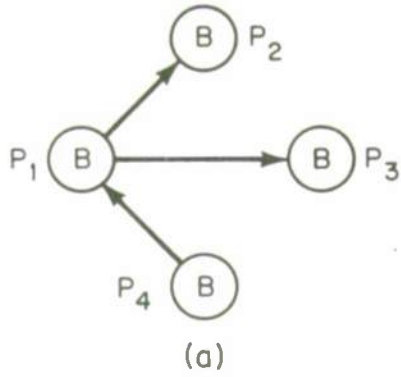


Fig. 1-2. (a) Broadcast Circuit (B), (b) Report Back Circuit (RB), (c) Fully Connected Net (V₁), (d) Fully Connected Net (V₂), (e) Communications Slot Structure of TDM Time Frame.

Fig. 1-2d. Since V_2 uses slot 6, platform P_1 cannot participate in this net. In summary, then, P_2 , P_3 and P_4 can receive in B, transmit in RB, and transmit or receive in V_1 and V_2 . The total throughput of each half duplex transceiver is 9.6 kbps. Platform P_1 can transmit B and receive RB for a total half duplex transceiver throughput of 4.8 kbps.

Platform P_1 , however, serving as a broadcasting platform, would usually be a large platform. Large platforms typically have more than one half duplex transceiver. Figure 1-3 shows the impact on the structure of Fig. 1-2 if platform 1 is equipped with two half duplex transceivers coupled to form a full duplex one. Platform 1 can now operate in V_1 and V_2 and further, can operate in V_3 and V_4 with other full duplex platforms. As Fig. 1-3b shows, this completely uses up the time frame. Structures for more than one channel are covered in Sections 2 and 3. Any 2.4 kbps communications slot can be subdivided into a number of 75 bps slots.

1.4 System Operation

Ease of use is a major system objective. Automation of the synchronization and other system control procedures, channel switching, and of certain net control procedures helps to achieve that objective. Automatic synchronization, designed to minimize operator interaction, begins immediately after an operator (on a mobile platform, say) initializes the antenna and transceiver and switches on the TAC (initialization includes setting of channels to be used). The TAC achieves receive synchronization from the framing sequence (in the control slot) from the MAC. It then transmits a ranging signal in the ranging slot. The MAC then transmits a timing correction (again, the control slot) providing the

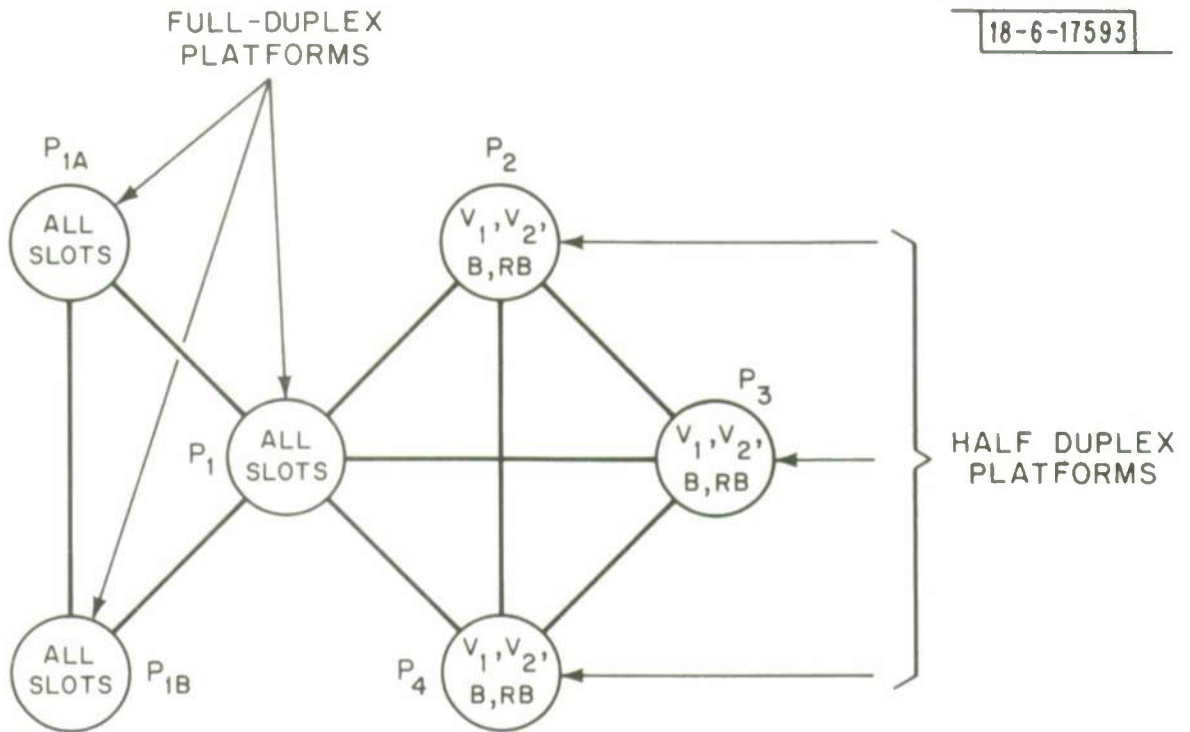


Fig. 1-3a. Circuit Usage of Half Duplex and Full Duplex Platforms.

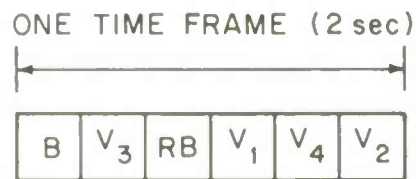


Fig. 1-3b. Communications Slot Structure for Half Duplex and Full Duplex Platforms.

TAC with transmit synchronization. Synchronization is maintained at the TAC by tracking the framing sequence and by periodic timing updates.

Another automated system control procedure is establishment of link burst rates. Each mobile platform monitors the control slot, and periodically sends a quality measure to the MAC. The MAC also measures the quality of these periodic transmissions. Hence, the MAC can maintain a data base of uplink and downlink quality for each platform. The MAC uses this database to calculate the link burst rate for any prospective circuit.

The automatic calculation of link burst rates for a given circuit eliminates the need for the user to recognize degraded transmission conditions. Other system control procedures are provided to simplify system use. For example, the MAC can recognize congestion in request slots and subsequently create more such slots.

Once transmit timing is attained, users can enter the system. The entry procedure depends upon the state of evolution of demand assignment, but in all cases is designed for ease of use.

To enter a net already in progress or to begin a communication with all members of a net not in progress, a member of a voice net simply pushes a key on his telephone set. The TAC then automatically sends a request in a request slot. Requests can be made in two kinds of slots: shared request slots and dedicated report slots. Shared request slots are used for rapid response, while dedicated report slots are used for non-real time requests (Dedicated slots are also used for the timing updates mentioned above as well as for a safety valve for requests in case of system overload.) After receiving a request, the

MAC returns an assignment in the control slot. The TAC then automatically uses this slot assignment for the conversation. The user can then enter or initiate the net conversation.

The TAC design can also accommodate user-to-user addressing. To address a particular user on a particular net, a calling user keys in the user address, and the call then proceeds the same as for an all-net call. This direct user-to-user addressing capability is not presently used in most operational environments, hence operational procedures for its use are not defined. It is assumed, however, that all-net addressing and user-to-user addressing would not both be used for a given net.

1.5 System Components

Upgrading the FLEETSAT system to a demand assigned TDMA system requires new equipment (the MAC and TACs) and modifications to existing equipment (principally the modem).

1.5.1 Terminal Access Controller

Figure 1-4 shows the small platform TAC configuration. The user interface has two parts. The data interface is at 2.4 kbps, the assumed standard for vocoded speech or automated record traffic, although several 75 bps interfaces are also provided. The control interface provides for signaling between users throughout a platform and the TAC. For dedicated circuits, this signaling is simply the push to talk indication from the user. For demand assigned circuits, the signaling includes addressing (specifying the user or net to be called) and alerting (indicating an incoming call).

All circuits, whether control or communications circuits, are encrypted. Communications circuits are assumed to be encrypted by external crypto units, associated with the vocoder or message processing machine, which can operate in the Message Indicator or Synchronous mode. The synchronous mode is best suited for TDM applications, since long preambles are unnecessary. The interface will, however, provide for a relatively efficient Message Indicator mode, with a foreshortened preamble. Control circuits require a separate external crypto which, for purposes of efficiency and response time, must be synchronous. The control crypto is used to encrypt requests and decrypt control information except for timing information, which is sent in the clear. While the TACS design would accommodate cryptos for control circuits, the initial demonstrations will not use control cryptos.

User data is input to the buffer at 75 bps or 2.4 kbps, stored until the designated time, and then coded, interleaved, and transmitted at the designated channel burst rate. This rate would be up to ~ 15.4 kbps for the GAPSAT and FLEETSAT systems with upgraded WSC-3 modems, and up to ~ 32 kbps for a FLEETSAT system with an advanced modem. Interleaving is pseudo-random, with a block length of ~ 256 symbols to randomize RFI and other clustered errors. Incoming bursts from the channel follow the opposite course, and the data is buffered, then clocked to the user at the 75 bps or 2.4 kbps data rate.

WSC-3 modems are now capable of operating at 75, 300, 1200, 2400, 4800 or 9600 sps. Investigations into providing an increased TDM rate are now in progress. One possibility would be to operate at 19.2 kbps and to use a rate 4/5 code, for a burst rate of 15.36 kbps. Another possibility which would yield

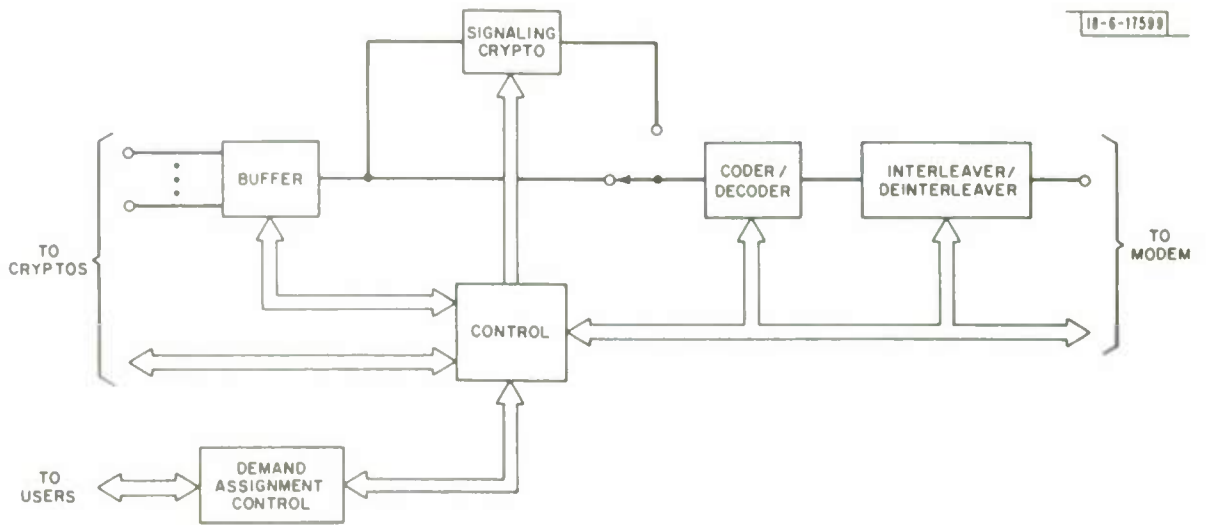


Fig. 1-4. Half Duplex Platform TAC Configuration.

the same burst rate is 20.48 ksps and a rate 3/4 code.* While the higher symbol rate would result in slightly more channel (bandlimiting) degradations, the performance improvement of the rate 3/4 code against RFI would be more than offsetting. The channel symbol rate and code rate actually used for the implementation will be chosen to yield the highest performance possible, subject to constraints on implementation cost and complexity. The DAMA modem could also be incorporated into TACS.

The operation of the TAC for a large platform is identical to that for the small platform, except that the equipment can transmit and receive simultaneously. Hence, the coder and decoder, and the interleaver and deinterleaver must operate simultaneously. In this report a large platform is assumed to be one with two WSC-3s, configured as one full duplex transceiver. This decision is based on the decoder speed as a limiting element. While slightly more flexibility would result from two half duplex transceivers, this arrangement would require the decoder to decode two received sequences simultaneously, resulting in a more complicated and unnecessarily expensive design.

* Data rates are typically a power of 2 times 75 bps. There is, therefore, strong reason to provide such standard data rates as 75 bps and 2.4 kbps. There is no reason, however, for the burst rate or symbol burst rate to be of such form.

1.5.2 Multiple Access Controller

Figure 1-5 shows the CAMS configuration. (This could also be a large ship.) The MAC is implemented with a minicomputer and associated peripherals. The MAC controls the TDMA system over the control circuits. It transmits the time base, timing corrections, and assignments in the control slot. It monitors the ranging slot and request slots for signals. Because CAMSs are major users of the communications circuits, the demand assignment control lines are connected directly to the MAC, rather than over satellite circuits.

1.5.3 Modifications to Existing Equipment

Efficient TDMA operation requires changes in acquisition time, turn around time, and symbol rate of existing modems. The WSC-3 was designed for more or less continuous operation at rates up to 9.6 ksps. The 40 msec acquisition preamble required for each transmission has little impact on the overall efficiency in this type of operation. TDMA, however, requires operation in the burst mode. A 40 msec preamble would use up 12% of a 1/3 second slot. Further, half duplex operation requires switching between the transmit and receive modes. It would be desirable in some cases for such switching to be done much faster than the present 40 msec. Finally, the 9.6 ksps limit is far below the capabilities of the typical link.

Electronic Communication, Inc., or ECI, has done preliminary investigations into these TDMA modifications for the WSC-3. Although further work is required, the investigations indicate that (1) a 10 msec acquisition time seems feasible, (2) turnaround time of 2 milliseconds can be met, and (3) operation at 19.2 ksps or somewhat higher is possible. An Engineering Change

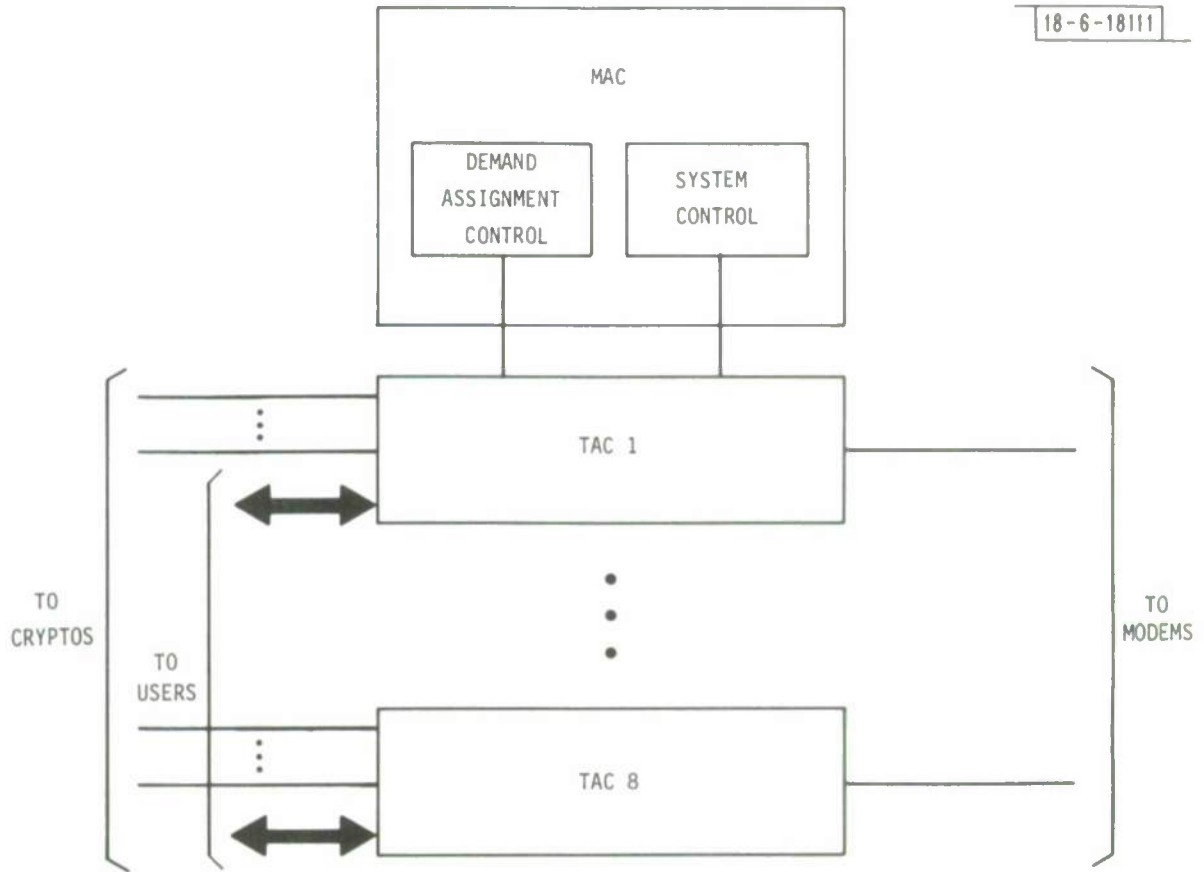


Fig. 1-5. CAMS Configuration.

Proposal for ECI to carry out the further work is now in progress. Lincoln Laboratory is now experimenting with WSC-3 acquisition at 9.6 ksp/s, and will experiment with acquisition at 19.2 ksp/s or higher in the future. It is assumed throughout this report that TACS will include WSC-3s with the modifications indicated above. In addition, the WSC-3 can be remotely tuned to any preset channel by use of the presently available remote channel selector. Hence, operation over several channels requires no specific changes to the WSC-3.

Two other changes in the WSC-3 are needed to improve link performance. One is provision of the pulse blanker output to indicate symbol erasures caused by RFI. The other is eight level symbol decisions for near-optimal coding gain.

2.0 TDMA SYSTEM DESCRIPTION

This section builds upon the background given in the Introduction. The operating conditions and requirements for the system are first expanded, following which system evolution is discussed. The overall and detailed system structure, followed by system operation, are then given. Finally, system components are discussed.

2.1 Operating Conditions and Requirements

A given satellite coverage area might have as many as 120 ships, 10 aircraft, and 40 submarines as users of satellite communications. Most of these platforms may be candidates for demand assigned TDMA. In addition to these Navy platforms, Ground Mobile Forces and Air Force platforms might be included in the system. In this report, such users are assumed to have roughly the same properties and requirements as some corresponding Navy platform. The standard user data rate is 2.4 kbps; however, there may be some 75 bps users. In addition to mobile platforms, each coverage area contains two CAMSs, one of which is an alternate, or standby, for the principal CAMS.

The characteristics of Navy platforms, with respect to EIRP, antenna gains, number and types of transceivers and so forth, are documented in Reference 2. The matrix of effective P_r/N_0^* for each possible link is shown in Table 2-1.

* Signal to noise ratio that would be measured at the 70 MHz IF of the receiving platform's transceiver. See Appendix for detailed link calculations and assumptions.

TABLE 2-1

SIGNAL TO NOISE RATIOS FOR GAPSAT AND FLEETSAT 25 kHz LINKS
(All Entries in dB)

RECEIVING PLATFORM	CAMS			SHIP			AIRCRAFT			SUBMARINE		
	28	26	23	28	26	23	28	26	23	28	26	23
SATELLITE EIRP ^A												
DOWNLINK P _r /N _o	65.4	63.4	60.8	59.4	57.4	54.8	47.4	45.4	42.8	44.4	42.4	39.8
TRANSMITTING PLATFORM												
UPLINK P _t /N _o												
CAMS	57.0 (55.0)	56.1	53.9	54.9	54.1	41.7	46.9	44.9	42.2	44.0	42.0	39.3
LARGE SHIP	55.5	55.2	53.1	54.3	53.4	51.2	46.6	44.8	42.1	43.9	42.0	39.2
SMALL SHIP	59.8 (57.8)	58.2	56.0	56.5	55.4	52.9	47.1	45.5	42.5	44.2	42.2	39.6
AIRCRAFT	55.3	55.1	52.9	54.1	53.4	51.1	46.6	44.8	42.1	43.8	41.9	39.2
SUBMARINE	46.7 (44.8)	46.7	44.6	46.5	46.3	44.1	43.1	41.9	38.9	41.2	39.6	36.5

NOTES: A) 28 dBW and 26 dBW are for FLEETSAT 25 kHz Channels. 23 dBW is for 25 kHz GAPSAT channel or 25 kHz portion of 500 kHz GAPSAT channel.

B) From Table A-2 (includes 6 dB downlink margin).

C) From Table A-1 (includes 6 dB uplink margin). Number in parentheses is GAPSAT; other number is FLEETSAT.

The 23 dBw GAPSAT channels are either narrowband channels or 25 kHz portions of the wideband channel. The P_r/N_0 calculations for all links assume 6 dB of margin on each uplink and downlink. The 6 dB margin absorbs a host of possible losses, including modem implementation loss and unfavorable departures from nominal of any portion of the RF link. The aggregate departure from nominal for the entire link has two components, one steady state and one time varying. If the steady state component is less than the 6 dB margin, then the margin can absorb some portion of the time varying component. In some cases, though, extra margins must be provided for the time varying losses. The time varying component of transmission degradations results from RFI and channel fading. Such fading might result from ship's roll, multipath, or scintillation. The limits of channel fades within which TACS will function are discussed later in this section.

Pulsed RFI from shipboard radars causes burst errors, in which several consecutive symbols are corrupted (possibly erased) when the radar pulses. One measure of the severity of RFI is the percentage of symbols corrupted. This percentage would typically be about 5% or less for a single radar or some multiple of about 5% for more than one radar. Each ship would have only one radar which would be harmful at UHF; however, a given ship could be affected by other radars on other ships. In such a case, the radar from another ship would be most harmful when sweeping past the ship. It seems unlikely, then, that there would be more than two interfering radars at one time for a given platform; one located on the platform itself, and one on another platform. Worst case RFI, then, would be about 10% (and this value may be overly cautious).

Since the actual values are unknown, the system should be robust enough to combat up to, say, 10%.

Fading also causes burst errors, but of substantially greater time duration than does RFI. Multipath and ship's roll cause fades of duration on the order of seconds. (Ship's roll causes fades because the directive antenna, lacking elevation stabilization, points away from the satellite during roll.) Scintillation may cause fades of tens of seconds in duration.

As noted in Section 1, such conditions of deep fades preclude interactive communications with rapid turn around time requirements. For example, deep fades preclude voice conversations, since the 4 second turn around requirement cannot be met. If a particular circuit cannot deliver the desired error rate performance (10^{-5} for data and 10^{-3} for voice), it cannot be used. Rather, an adjustment must be made to improve the performance to the required level. For example, the burst rate could be lowered. This implies that the system be able to measure the performance of a given circuit.

There are, of course, limits beyond which the TDMA system simply will not perform as required. This limit is roughly the point at which a link can no longer support a burst rate of ~ 4.8 kbps, for then, not even 2 circuits of 2.4 kbps each can be time division multiplexed on the channel. A value of channel fade that will just permit a 4.8 kbps burst rate for a link is the fading limit for that link.

2.2 System Evolution

Early phases of the TDMA system will be marked by a shortage of satellite channels. The GAPSAT phase could benefit from demand assignment but integra-

tion of demand assignment into operations is likely to take considerable time. The approach suggested here is to begin to introduce rudimentary demand assignment in the earliest phases. This should accelerate the development of demand assignment through operational experience. The subsequent availability of a mature demand assignment system in the FLEETSAT era will provide a substantial level of service. TACS will accommodate both demand assigned and dedicated circuits.

The first links available for TACS demonstration will probably be 25 kHz portions of the 500 kHz GAPSAT channel. Three 25 kHz channels each with EIRP of ~ 23 dBw could be derived from the wideband channel. TDMA burst rates for such channels are shown in Table 2-2. These rates are based on the P_r/N_0 from Table 2-1. Coded links would be needed both for RFI protection and for realizing high burst rates.

Two principal conclusions are: (1) submarine links, with burst rates of 5.8 kbps or less, are only marginally viable candidates for TDMA, and (2) coded ship- or aircraft-to-shore and shore-to-ship links, with burst rates of at over 25 kbps, are strong candidates for TDMA. A 20.5 ksps symbol rate combined with a rate 3/4 code would provide a burst rate of ~ 15.4 kbps, consistent with the weakest ship-shore-ship GAPSAT link. Rate 3/4 coding, in conjunction with interleaving, would protect against at least 5% RFI.⁴ Uncoded links, of course, would not provide RFI protection at the TDM burst rates.

TABLE 2-2

BURST RATES FOR 23 dBW GAPSAT CHANNELS
(All Entries in kbps)

RECEIVING PLATFORM →	CAMS		SHIP		AIRCRAFT		SUBMARINE	
	UNCODED	CODED ^A	UNCODED	CODED	UNCODED	CODED	UNCODED	CODED
TRANSMITTING PLATFORM ↑								
CAMS	24.6	49.1 ^B	14.8	29.6	1.7	3.3	0.9	1.7
LARGE SHIP	20.4	40.8 ^B	13.1	26.2	1.6	3.2	0.8	1.7
SMALL SHIP	39.6 ^B	79.0 ^B	19.6	39.1 ^B	1.8	3.5	0.9	1.8
AIRCRAFT	19.7	39.2 ^B	12.8	25.5	1.6	3.2	0.8	1.7
SUBMARINE	2.9	5.8	2.6	5.1	0.8	1.5	0.4	0.9

NOTES: A) Uncoded links have $E_b/N_0 = 10$ dB. Coded links have $E_b/N_0 = 7$ dB, and RFI is assumed to be no worse than 5%.

B) Exceeds channel bandwidth for BPSK.

Table 2-3 shows burst rates for 25 kHz FLEETSAT channels. Coded ship- or aircraft-to-shore and shore-to-ship links can support burst rates in excess of the channel bandlimit. This is roughly twice the maximum burst rate with modified WSC-3 or DAMA modems. Hence an advanced modem would roughly double the number of 2.4 kbps FLEETSAT TDMA circuits. Submarines are marginal candidates for TDMA with FLEETSAT.

2.3 System Structure

As indicated in Section 1, fleet communications is expected to progress from dedicated circuits to demand assigned TDMA during the GAPSAT and FLEETSAT programs. Changes both in equipment and in operating procedures can be expected during that time. The demand assigned TDMA system, interfacing as it does both with users and with existing equipment, must be flexible enough to accommodate and provide for such changes. The system must also adapt to changing link conditions. Finally, it is desirable for the system to be readily upgraded for use with programs which follow FLEETSAT.

The structure described in this section is intended to provide the necessary flexibility for the desired growth and adaptability. The flexibility is achieved by using a modular architecture and programmable hardware. In this subsection, we first present the overall system structure, and second, the detailed structure. The stage will then be set for a description of system operation in Subsection 2.4.

2.3.1 Overall Structure

Both the MAC and the TAC will accept basic frame parameters as program inputs. These parameters include frame length, number of slots, and the location of the control, ranging, and request slots. Figure 2-1 depicts a typical

TABLE 2-3

BURST RATES FOR FLEETSAT 25 kHz CHANNELS
(All Entries in kbps)

RECEIVING PLATFORM → TRANSMITTING PLATFORM	CAMS ^A		SHIP		AIRCRAFT		SUBMARINE	
	UNCODED	CODED ^B	UNCODED	CODED	UNCODED	CODED	UNCODED	CODED
CAMS	40.4 ^C	80.6 ^C	25.6	51.1 ^C	4.7	9.5	2.5	5.0
LARGE SHIP	33.4 ^C	66.6 ^C	22.5	44.9 ^C	4.6	9.1	2.4	4.9
SMALL SHIP	66.0 ^C	131.6 ^C	34.3 ^C	68.5 ^C	5.1	10.1	2.6	5.2
AIRCRAFT	34.0 ^C	67.9 ^C	25.9	51.8 ^C	4.5	9.1	2.4	4.8
SUBMARINE	4.7	9.4	4.2	8.4	2.1	4.1	1.3	2.6

NOTES: A) Links involving submarines and aircraft are assumed to utilize 28 dBW channels. All other links utilize 26 dBW channels.

B) Uncoded links have $E_b/N_o = 10$ dB. Coded links have $E_b/N_o = 7$ dB, and RFI is assumed to be no worse than 5%.

C) Exceeds channel bandwidth for BPSK.

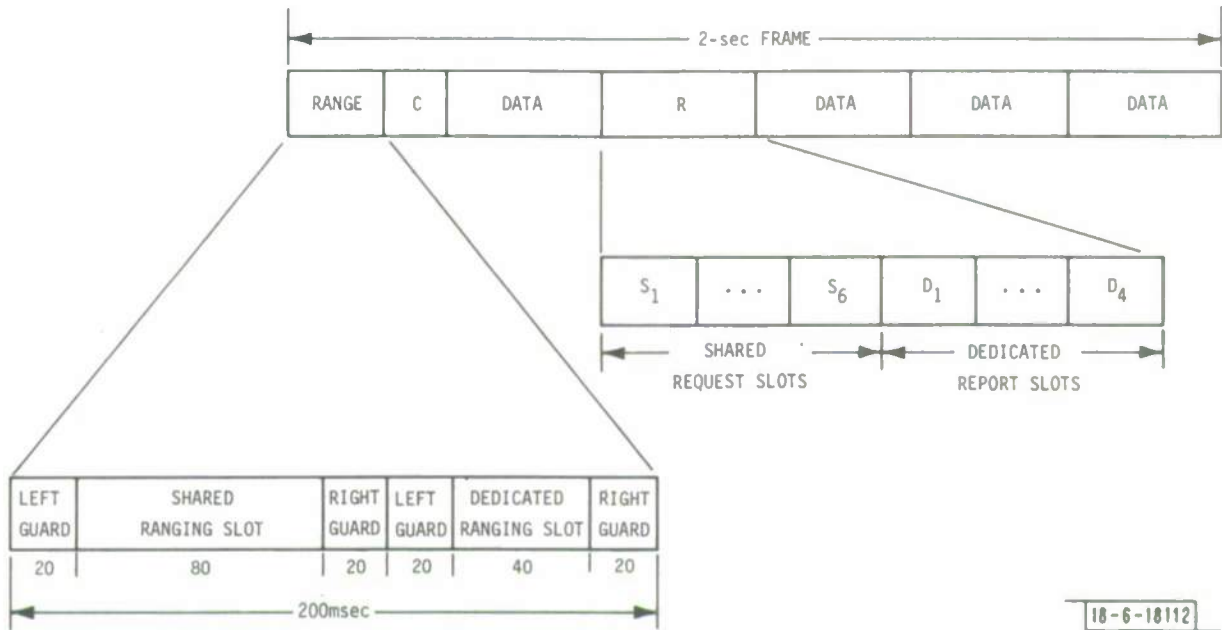


Fig. 2-1. Typical Frame Structure for Channel with Control.

frame organization. The control slot contains MAC-to-TAC control transmissions, while the request slots and ranging slot contain TAC-to-MAC control transmissions. The programmable frame structure will accommodate future changes in code rate, modem acquisition time, and burst rate, as well as operational changes.

Two types of slots may be used for user requests: dedicated report slots and shared request slots. In the figure, there are 4 dedicated and 6 shared slots in each 2 second frame. (Operation is discussed in Section 2.4.) The cycle time for dedicated slots is one minute. With 4 dedicated slots per frame, the system will accommodate 120 platforms. These slots are used for transmit timing updates (re-ranging) and for non-realtime requests. Realtime requests are made in shared request slots (or in dedicated slots, if such slots are due within, say, 2 frames). The six slots will service a new request rate of approximately one request per second ($0.9 \times 3 \text{ slots per second}/e \approx 1$).^{*}

Two ranging slots are shown, one shared and the other dedicated. The shared ranging slot shown is 120 msec long. Each ranging signal is 40 msec long, including a 20 msec acquisition sequence. Each ranging slot has 20 msec of guard at each end. This allows complete positional uncertainty, hence no manual range input is needed. The 120 msec ranging slot services a new system entry rate of about 0.5 entry per frame.[†]

* As shown in Reference 3, the capacity of "slotted ALOHA" systems is $1/e$ times the number of slots. Operation too close to capacity will cause saturation, hence, the 0.9 safety factor.

† This is because there are effectively three 40 msec ranging slots, which are asynchronously accessed, as in unslotted ALOHA.³ The capacity is $1/2e$ times the number of slots. With a 0.9 safety factor, the capacity is $0.9 \times 3/2e \sim 0.5$.

The dedicated slot is 80 msec long, allowing for the 40 msec ranging signal and the ± 20 msec of timing uncertainty. The MAC polls inactive platforms, commanding them to range in the dedicated ranging slot. The dedicated slot provides a means for initial system entry in event of congestion in the shared ranging slot.

2.3.2 Detailed Structure

Each burst, whether data or control, has 1 msec guard time to prevent overlap of consecutive bursts. Each burst also has modem acquisition and burst acquisition sequences. The modem acquisition sequence of 20 msec^{*} allows the modem to acquire phase, frequency, and symbol synchronization. The burst acquisition sequence is a unique 25 symbol sequence which the TAC recognizes as the beginning of a burst after symbol synchronization has been achieved.

All bursts, whether control or communications, are formatted in the same manner with respect to guard time and modem and burst acquisition sequences. Individual control bursts (ranging, shared requests, dedicated reports, and control slot) are transmitted at a symbol burst rate of 1/2 the normal symbol rate, and rate 1/2 coded, for a burst rate of 4.8 kbps.

The control slot structure is shown in Fig. 2-2. The initial part of the frame is concerned with system control. The framing sequence of 25 symbols provides acquisition within one 2-second frame with probability .99, assuming

* The 20 msec figure is thought to be conservative. Decreasing the modem acquisition sequence is under study.

FRAMING SEQUENCE	CLOCK	FORMAT CODE	INITIAL TIMING CORRECTIONS	TIMING UPDATES	COMMANDS	ASSIGNMENTS	PREEMPTIONS	CALL PROGRESS INFORMATION
SYSTEM CONTROL					DEMAND ASSIGNMENT CONTROL			
			TYPICAL					
			NO. BITS	NO. WORDS/FRAME	NO. BITS/FRAME			
SYSTEM CONTROL								
FRAMING SEQUENCE			25	1				25
TIME OF DAY CLOCK			16	1				16
FORMAT CODE			21	1				21
INITIAL TIMING CORRECTION								
PLATFORM CORRECTION			9					
			<u>10</u>					
TOTAL			19	1				19
TIMING UPDATE								
PLATFORM CORRECTION			9					
			<u>4</u>					
TOTAL			13	4				52
COMMANDS								
PLATFORM COMMAND CODE			9					
SLOT CHANNEL			3					
			7					
			<u>3</u>					
TOTAL			22	2				44
DEMAND ASSIGNMENT CONTROL								
USER-USER ASSIGNMENT								
CALLED PLATFORM			9					
CALLING PLATFORM			9					
NET MESSAGE INFORMATION			7					
			7					
			3					
			<u>3</u>					
			<u>5</u>					
TOTAL			46	1				46
ALL-NET ASSIGNMENT								
NET MESSAGE INFORMATION			7					
			21					
(same as user-user)			<u>21</u>					
TOTAL			28	1				28
PREEMPTION								
SLOT CHANNEL			7					
			3					
			<u>3</u>					
TOTAL			13	1				13
CALL PROGRESS INFORMATION								
PLATFORM NET MESSAGE			9					
			7					
			<u>3</u>					
TOTAL			19	1				19
TOTAL NO. BITS/FRAME								283

Fig. 2-2. Detailed Structure of Control Slot.

$P_r/N_o \geq 45$ dB and RFI no worse than 10%. False acquisition probability is $\leq 10^{-5}$ at any P_r/N_o .⁵ The 16-bit clock provides a unique sequence in each frame over a 24-hour day.

The number of system control and demand assignment control words in the latter part of the control slot varies with traffic activity. The quantity of each such word included in the current control slot is given by the format code. The 3-bit code for each word type permits from 0 to 7 words of each type.

System control word types include timing corrections and commands. Timing corrections can be initial corrections or timing updates. An initial timing correction is a 19-bit response to a ranging signal (9 bits for platform address and 10 bits to reduce the platform's timing uncertainty from ± 40 msec to ± 40 μ sec). A timing update is a 13-bit response to a dedicated report (9 bits for platform address and 4 bits to reduce timing error from ± 400 μ sec to less than ± 40 μ sec). A third system control word type is a command. The command has a variety of potential uses. One important use is polling of inactive platforms commanding them to range in the dedicated ranging slot. This procedure provides entry for a platform attempting to enter the system during periods of congestion in the shared ranging slot.

The latter portion of the control slot contains demand assignment control messages, which are of three basic types: assignments, preemptions, and call progress information. Assignments are of two types: user-to-user or all net. In a user-to-user call, the assignment specifies the 9 bit called and calling user addresses, the 7 bit net address, and 21 bits of information pertinent to the specific call, for a total of 46 bits. An all net call provides the same

information except for the user addresses, for a total of 28 bits. A preemption merely specifies the slot and channel to be vacated, and the number of frames that the current user has in which to terminate. This requires a total of 13 bits. A user request cannot always be honored, in which case call progress information is provided. Examples are "called user busy," "all circuits busy," "called platform inactive," or "called platform cannot transmit." Each call progress message has 12 bits -- 9 for the calling user and 3 for the message.

The number of bits in the control slot for a typical level of activity is shown to be 283. The 113 msec control slot shown provides for 576 bits at 5.1 kbps. This number should accommodate peak traffic requests and provide spares for system control features to be added later.

The request slot structure is shown in Fig. 2-3. User-to-user and all-net request are formatted alike. (In an all-net request, the user addresses are not pertinent.) A request transmitted in a shared request slot has the 9 bit user addresses, and 7 bit net address, and 10 bits of message information for a total of 35 bits. A request transmitted in a dedicated report slot has the same information, except that the calling user address is implicit in the location of the dedicated report slot. Each dedicated report also contains a link quality in indication. This is derived from the Viterbi decoding metric from the decoded control slot. A termination request simply indicates the channel and slot, which requires 10 bits.

2.3.3 A Possible Evolution of Frame Structures

As noted earlier, TACS provides for a phased evolution of demand assignment. Figure 2-4 shows a frame structure for two GAPSAT channels. In

SHARED REQUEST	
CALLING PLATFORM	9
CALLED PLATFORM	9
NET	7
MESSAGE INFORMATION	
PRECEDENCE	3
LENGTH	5
CONVERSATIONAL	1
VOICE/DATA	<u>1</u>
TOTAL	35
TERMINATION	
CHANNEL	3
SLOT	<u>7</u>
TOTAL	10
DEDICATED REPORT	
CALLED PLATFORM	9
NET	7
MESSAGE INFORMATION	
(same as shared request)	10
QUALITY INDICATION	<u>9</u>
TOTAL	35

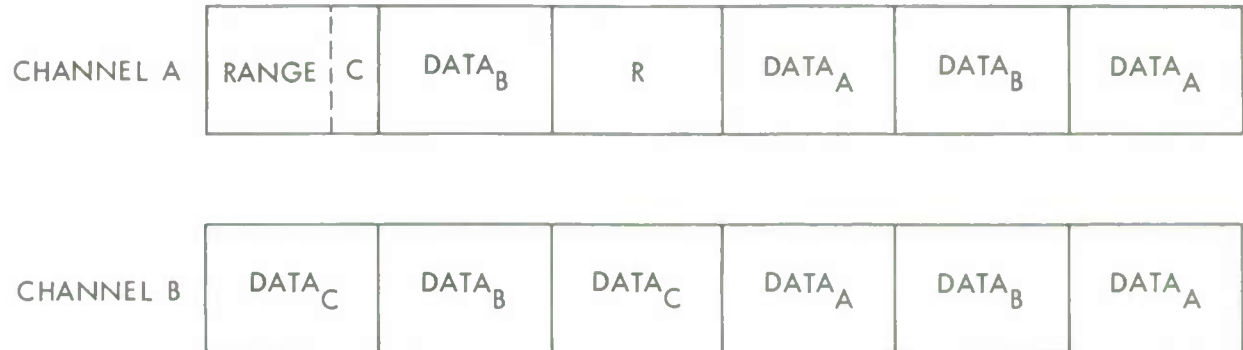
Fig. 2-3. Detailed Structure of Request Slots.

this example, and in the two others which follow, objectives in the frame structure design are to maximize satellite channel and half duplex transceiver throughput. The GAPSAT example is based on a 15.4 kbps burst rate with upgraded WSC-3 modems. One sixth of the capacity is given to control. Average channel throughput is five circuits, or 12 kbps. Each half duplex platform has use of two circuits at once, for a throughput of 4.8 kbps. A full duplex platform has use of four circuits at once, for a throughput of 9.6 kbps. Slots 1 and 3 in channel 2 can be used by platforms with more than one full duplex transceiver.

Figure 2-5 shows frame structures for FLEETSAT with upgraded WSC-3 modems. The burst rate here is 15.4 kbps as with the GAPSAT example. One third of each of two channels is used for control. This amounts to about 10% of the capacity of 7 channels. If needed, control could be added on other channels. As with GAPSAT, a half duplex transceiver has two circuits, a full duplex transceiver four. Channel throughput on channels with control is four circuits, and throughput on other channels is six circuits.

Figure 2-6 shows a frame structure for FLEETSAT with advanced modems. An advanced modem is one with higher than binary (probably quaternary) modulation to achieve higher throughput through bandlimited channels than is feasible with binary modulation. The frame length is 1.8 seconds,* and the burst rate is

* For interoperability between platforms with binary and advanced modems in a transitional period, the frame duration could be 2 seconds. The 1.8 second time shown reduces turn around time.



C = CONTROL

R = REQUESTS

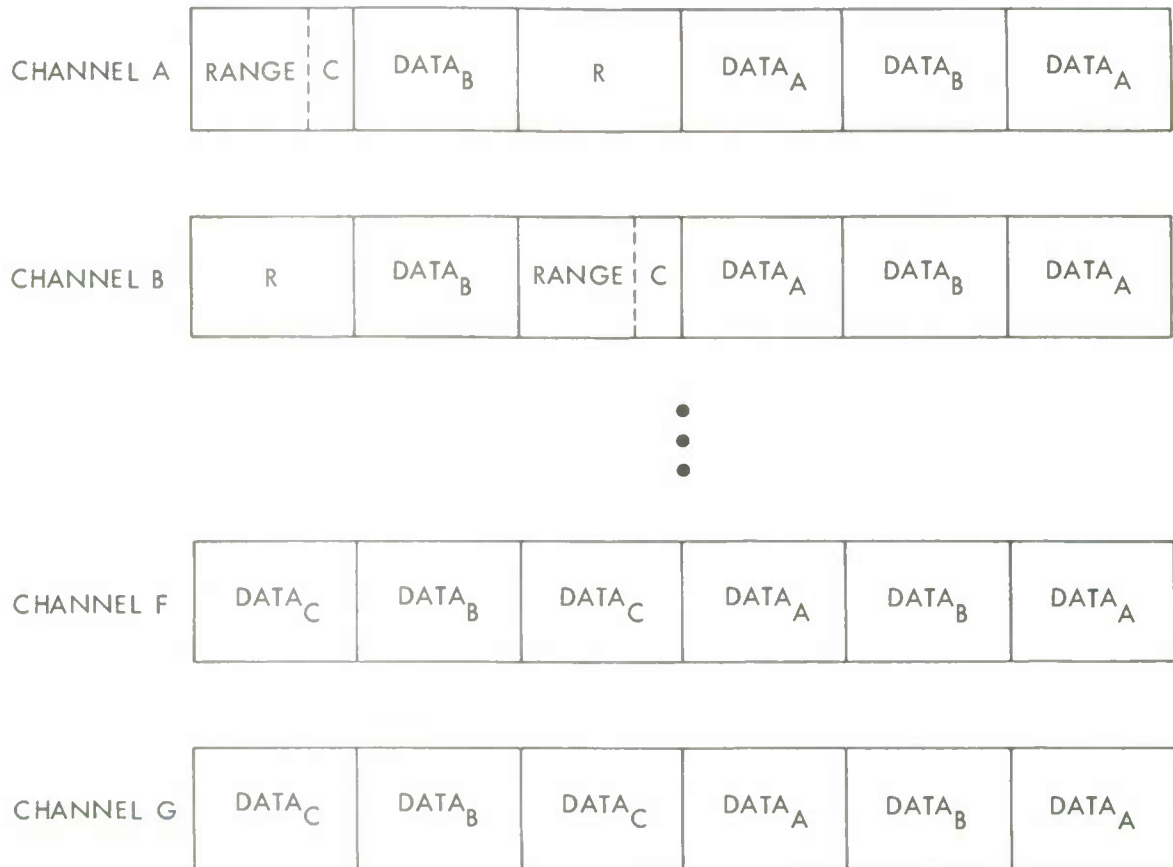
RANGE = RANGING

DATA_A = SLOT USED BY ANY PLATFORM

DATA_B = SLOT USED BY FULL DUPLEX PLATFORM

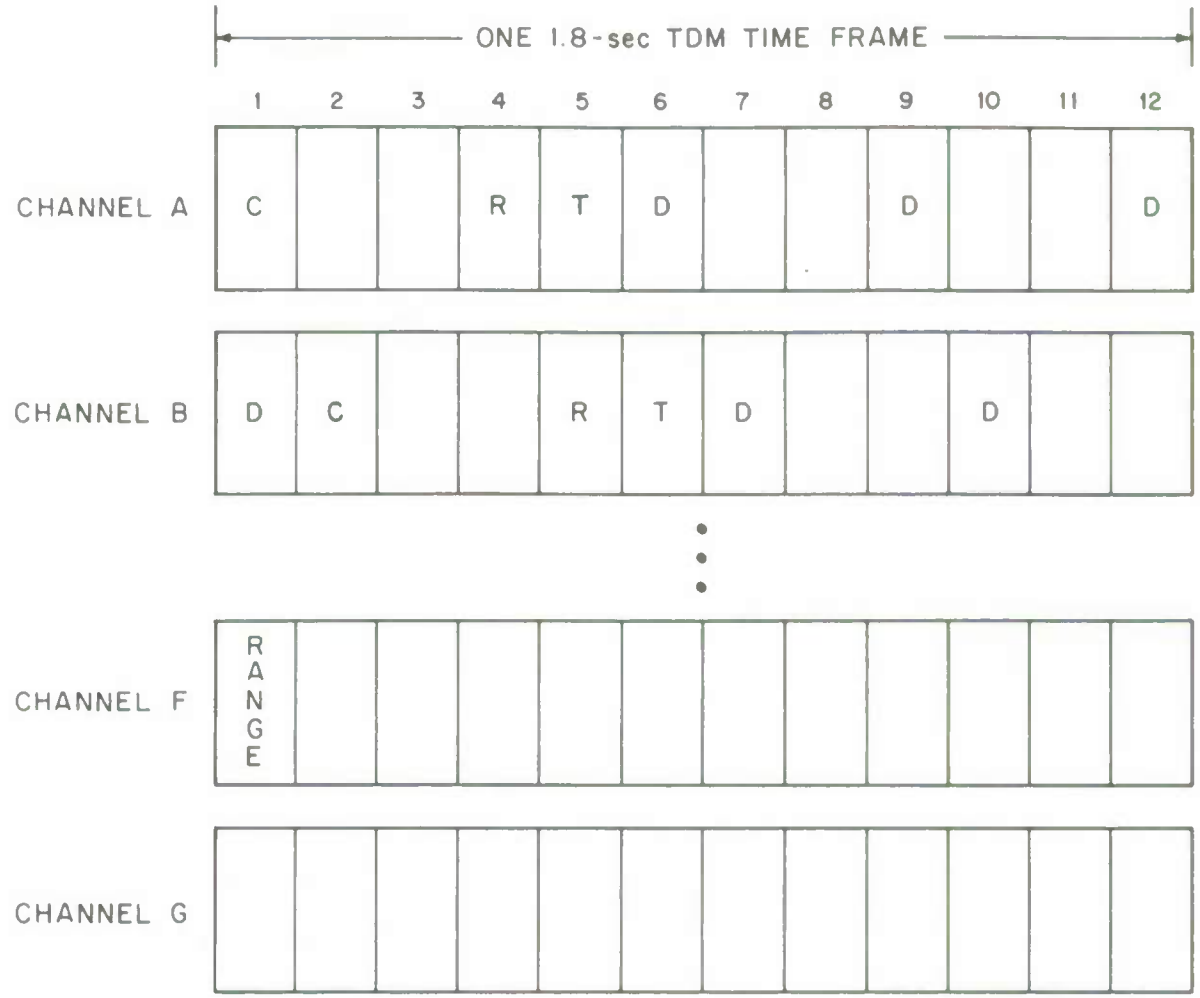
DATA_C = SLOT USED BY PLATFORM WITH MORE THAN
ONE FULL DUPLEX RADIO

Fig. 2-4. Possible Frame Structure for Two TDMA GAPSAT Channels.



C = CONTROL
 R = REQUESTS
 RANGE = RANGING
 DATA_A = SLOT USED BY ANY PLATFORM
 EXCEPT HALF-DUPLEX PLATFORM
 USING CHANNEL B FOR CONTROL
 DATA_B = SLOT USED BY ANY PLATFORM
 EXCEPT HALF-DUPLEX PLATFORM
 USING CHANNEL A FOR CONTROL
 DATA_C = SLOT USED BY PLATFORM WITH MORE
 THAN ONE FULL DUPLEX RADIO

Fig. 2-5. Possible Frame Structure for Seven TDMA FLEETSAT Channels.



T= TRANSMIT ONLY
D= VOICE
R= REQUESTS
C= CONTROL
RANGE= RANGING

Fig. 2-6. Possible Frame Structure for Seven TDMA FLEETSAT Channels with Advanced Modems.

throughput on other channels is twelve circuits. A half duplex platform has simultaneous use of three voice circuits, and one transmit only circuit.

In any of the structures, one of the 2.4 kbps slots can be used for a number of 75 bps slots. A 2.4 kbps GAPSAT or FLEETSAT circuit with upgraded WSC-3 modems yields eleven, and a FLEETSAT and advanced modem yields about 15 (assuming 5 msec acquisition time with the advanced modem and 20 msec with upgraded WSC-3 modems).

2.4 System Operation

Assuming that TACS is in operation, we now consider the entry of a platform into the system. A radioman sets the preselected frequencies in the transceiver for the 25 kHz channels in which the platform will operate. An operator also initializes the TAC. The TAC then automatically searches for the framing sequence within the designated channel. After synchronization is achieved, requests for service may be made.

2.4.1 Automatic Operation

For simplicity of design, it is desirable to maintain a constant symbol rate throughout a burst. The control information is transmitted at 4.8 kbps, and is rate 1/2 coded for a symbol rate of 9.6 ksps. The modem and frame synchronization symbols are thus sent at 9.6 ksps for the control burst. The TAC places the WSC-3 modem in the 9.6 ksps mode. Through the interface provided for remote operation, the TAC switches the WSC-3 to the channel containing the system timing sequences. A unique sequence is used for modem synchronization, followed by the burst synchronization sequence. The WSC-3 modem acquires its phase and frequency, and generates symbol timing from the

modem synchronization sequence. The modem signals symbol timing acquisition to the TAC, whereupon the TAC searches for the burst synchronization sequence (a unique 30 symbol sequence) followed by the framing sequence (unique 50 symbol sequence). Acquisition of the framing signal constitutes receive synchronization. The user can then receive data bursts. Acquisition of a data burst requires only a subset of frame acquisition. The beginning of each data burst is known to $\pm 400 \mu\text{sec}$. Under the same conditions defined for frame acquisition, the TAC will detect a 25 bit burst acquisition sequence that begins within $\pm 400 \mu\text{sec}$ of its nominal start time with probability $1-10^{-5}$.

Before users can make requests or transmit data, the TAC must achieve transmit synchronization. The transmit synchronization procedure is shown in Fig. 2-7. A ranging signal is sent after frame synchronization is achieved. Since the ranging slots are shared, the TAC selects a slot at random to minimize the probability of conflict when more than one platform range within the same frame. The ranging signal includes the slot number for which it was intended, so that the MAC can readily measure the time offset from nominal. Upon receipt of the timing correction from the MAC, the TAC synchronizes its transmit clock and users can then initiate requests.

If the MAC fails to interpret the ranging signal, either because of conflict or transmission errors, the TAC does not receive the correction and must retransmit. The probability of conflict is much greater than the probability of error. There is a good chance, then, that more than one reranging attempt is necessary. Assuming that the three ranging slots have capacity of

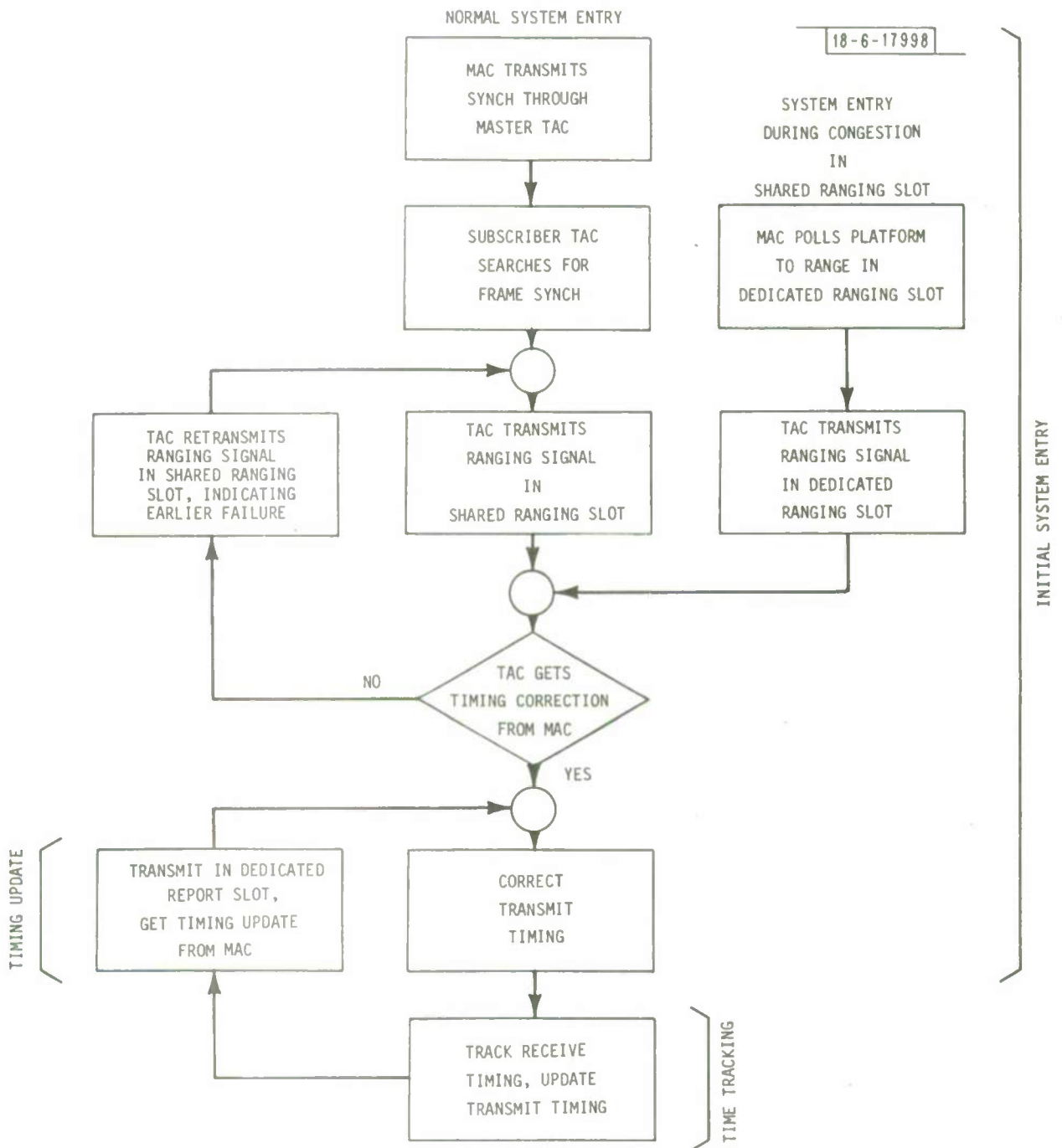


Fig. 2-7. Timing Synchronization Procedure for TAC.

0.5, it is not desirable for two platforms to rerange in the same frame. Therefore, each TAC simply generates a random number (between 1 and 4, say) to select the frame in which it will retransmit, and then transmits at random in one of the slots in that frame. Because each frame can accommodate up to three ranging signals, four consecutive frames can accommodate up to 12 ranging signals. The (unslotted ALOHA) capacity of the ranging slots in four frames is 2. Hence with high probability, the reranging attempts will be successful. If such an attempt is unsuccessful, a retransmission is made. If many platforms are attempting to range at once, reranging attempts all end in failure. For this reason, the MAC polls one inactive platform with a command in the control slot, inviting that platform to range in the dedicated ranging slot in the next frame. If that platform has been attempting unsuccessfully to range in the shared ranging slots, entry will be achieved through the dedicated ranging slot.

Transmit timing is maintained by tracking the framing sequence and by making periodic updates by use of the dedicated report slot. Each platform transmits a dedicated report once each minute. The MAC transmits a timing update to the platform after measuring the timing offset of dedicated report. An oscillator with accuracy of 1 part in 10^6 would cause at worst a 120 μ sec change in transmit timing in one minute.* The dedicated report from the platform or the resulting timing update from the MAC might be invalidated by transmission

* The 60 μ sec change appears to the TAC to be a change in receive synchronization, hence the TAC adjusts its receive clock by 60 μ sec. It also adjusts its transmit clock by 60 μ sec in the opposite direction. Hence the transmit timing inaccuracy increases by at worst 120 μ sec in one minute.

errors. Under most transmission conditions, a timing update would be achieved with very high assurance every two or three minutes. Assuming 3 minutes as a worst case requires $800 \mu\text{sec}$ of guard time for each burst* for transmit timing inaccuracy.

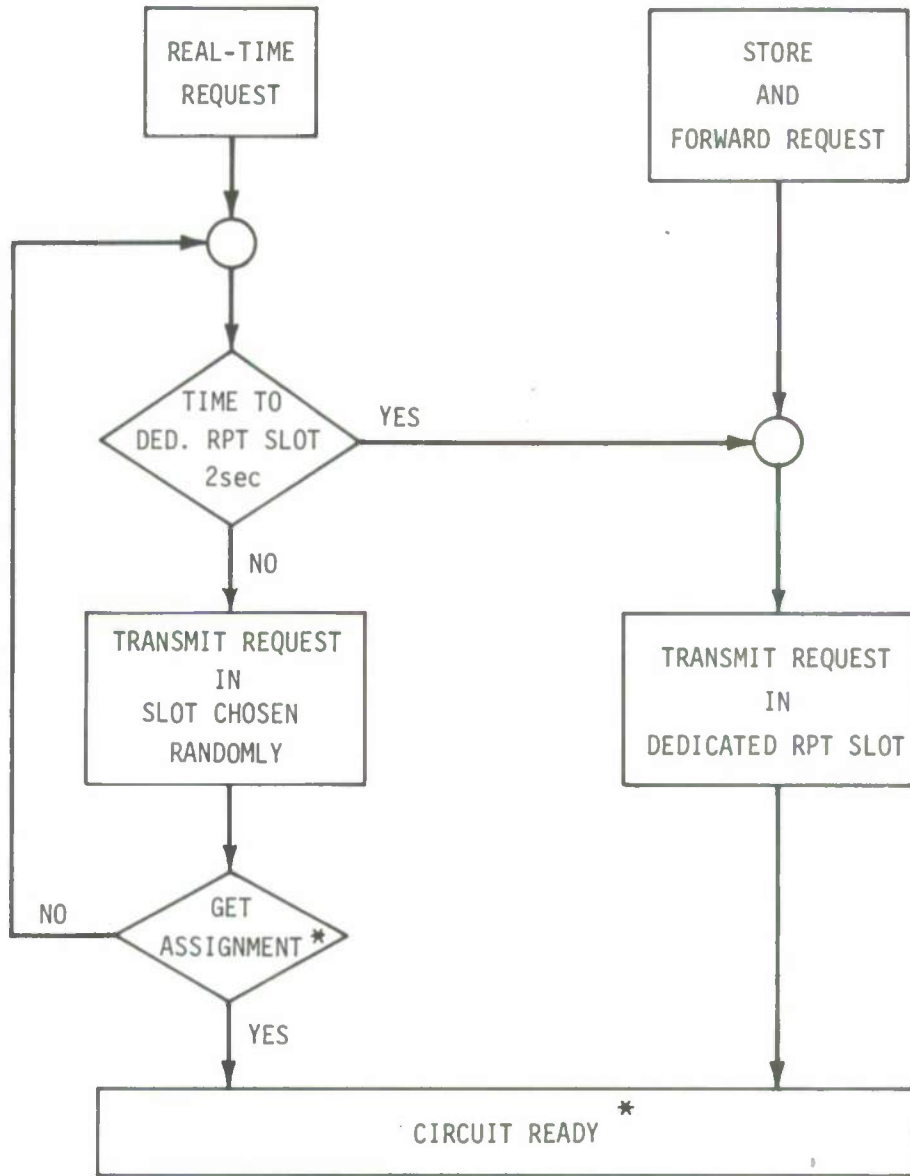
As long as the TAC has transmit synchronization, a user may enter requests. The request procedure is shown in Fig. 2-8. A user need not specify whether a shared request slot or dedicated report slot should be used. Rather the user specifies the precedence of the message. If the precedence is high enough to require a response time of less than one minute, or if the message requires human interaction as for voice or interactive data, then shared request slots are used (except when the dedicated report slot is available within the expected response time of the shared slots, in which case it is more efficient to use the dedicated slot).

The current example assumes 6 shared request slots. The TAC transmits a request in one of the 6 shared slots chosen at random. It either receives a response from the MAC in the next control slot or it doesn't. If not, the TAC retransmits at random in the next frame.

2.4.2 System Use

TACS accommodates star nets (which may be broadcast, report back, or both) and fully connected nets. The automated procedures just discussed permit relatively simple demand assignment protocols for the assignment of a circuit to a net and the release of the circuit on completion of net communications.

* $(120 \mu\text{sec of inaccuracy/minute} \times 3 \text{ minutes} + 40 \mu\text{sec of initial inaccuracy after the update})/\text{platform} \times 2 \text{ platforms}$.



*OR OTHER OUTCOME, IF ASSIGNMENT CANNOT BE MADE

Fig. 2-8. Request Procedure for TAC.

TACS performs the important functions of alerting called users and providing calling users with call progress information. A fundamental assumption in the TACS design is that a net using a circuit may be preempted by a net with higher precedence traffic. This assumption requires that a user indicate the traffic precedence when making a circuit request.

Before discussing the implications of precedence entry, it is useful to consider the various types of net communications available with TACS. One type is the traditional fully connected net in which each net member participates, either as talker or listener, in every net communication. A second type is the traditional star net; a broadcast is sent to all net members, and messages are sent back from specified net members to the broadcasting platform. A third type is a nontraditional net which provides user-to-user communications. In this net operation, one (of many) users specifies a called user in a request. No other users except the called and calling users are involved in the net communication (except optionally for a net controller). A given net is assumed to be one of the three types; the system does not permit a mixture. In the discussion which follows, calls are referred to "all-net" calls for the traditional types of nets, and "user-to-user" calls for the nontraditional nets.

To this point, a need has been identified for entry of message precedence and in some cases, called user address. In addition, called users must be alerted of incoming calls, and calling users provided with certain call progress information. The required complexity of the demand assignment interface depends upon the type of net. The simplest net is a traditional net for which all traffic has the same precedence. For this type of net, a calling user can

initiate a request by depressing the push to talk key on his telephone set. A visual or audible indication could indicate circuit readiness to the calling user. The speech from the calling user could serve adequately to alert the called users.

At the other extreme, a user-to-user call requires precedence and address inputs, as well as call progress information (called user busy, circuit ready, etc.). Figure 2-9(a) is a conceptual illustration of an interface to satisfy requirements of the most complex net operation. The interface, called the TIC for Terminal Input Controller, consists of a 12-character digital display and a numerical keyboard. (The TIC is not needed for an automated data net interface, however. Rather a simple handshaking arrangement will be used.) Figure 2-9(b) shows a flow chart of operation with the TIC. The operation includes both all-net and user-to-user calls. The time required for the user to input the necessary data for user-to-user call is about five seconds. The automatic request procedure takes from a few seconds to several seconds, depending on traffic conditions. Hence the circuit setup time is on the order of ten seconds -- roughly comparable to the time required for a long distance call setup in the commercial dial network. The interface between the TAC and automated data nets is functionally the same as the voice user interface.

A call can be terminated in one of three ways. First the request can be made for a given duration: from one to 32 frames for record transmission, or from 10 to 320 seconds for voice. Second, the last user to communicate simply pushes the terminate button on the TIC, after which the terminate request is automatically sent by the TAC. This second method has the problem of requiring

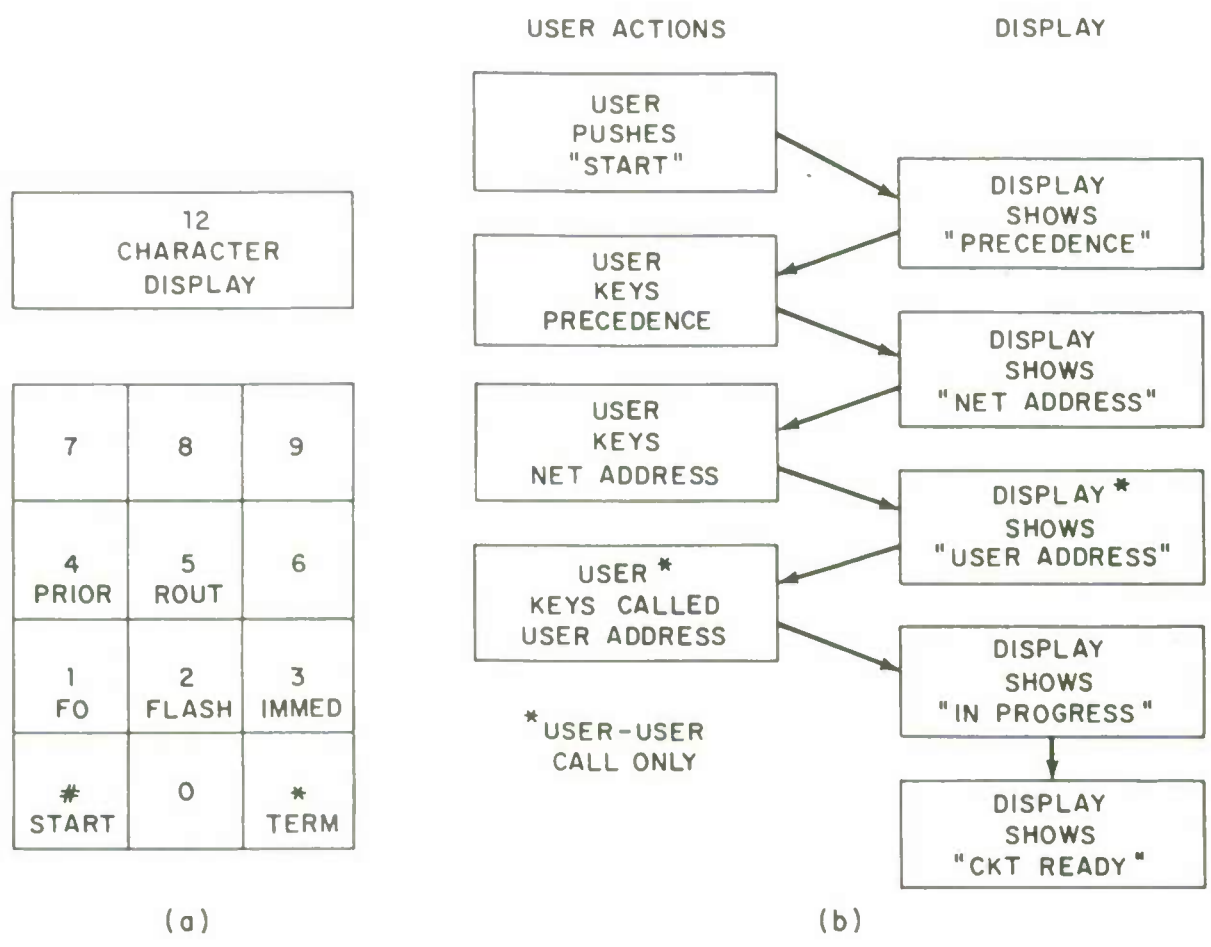


Fig. 2-9. (a) Conceptual View of Terminal Input Controller (b) User Interaction with Terminal Input Controller.

human action which cannot be depended upon with certainty. For this reason, the MAC searches all slots for activity, automatically terminating demand assigned slots after n consecutive frames of inactivity. The parameter n is variable, and will be different for voice and record nets. The programmability of the TAC and MAC permits changes in n as desired.

The buffering strategy in TACS is as follows: User data generated within one time frame period prior to the end of a slot (less the preamble and one interleaving block) is transmitted in that slot. At the receive end, once the preamble and an interleaving block is received, the data is output to the user at the I/O rate. This strategy leads to a talker to listener turnaround time of about twice the frame time.

2.5 System Implementation

The two major equipments needed to upgrade the current FLEETSAT system to a demand assigned TDMA system are the MAC (at a COMMSTA) and TACs (for each CAMS or mobile platform). In addition, certain changes in existing terminal hardware are needed.

Figure 2-10 illustrates the TAC in functional form. The TAC performs three basic functions: TDM, demand assignment, and error control. The time division multiplexing function buffers data input from users, formats the data (with the proper burst acquisition sequences), and transmits at the proper rate at the proper time. The error control function encodes and interleaves the data bits (not the acquisition symbols) prior to transmission. The demand assignment function monitors the control slot for incoming control messages, and accepts user requests. Users initiate requests from a terminal input controller (TIC) colocated with their telephone set or other I/O device. Of course, the reverse procedure is followed for received data.

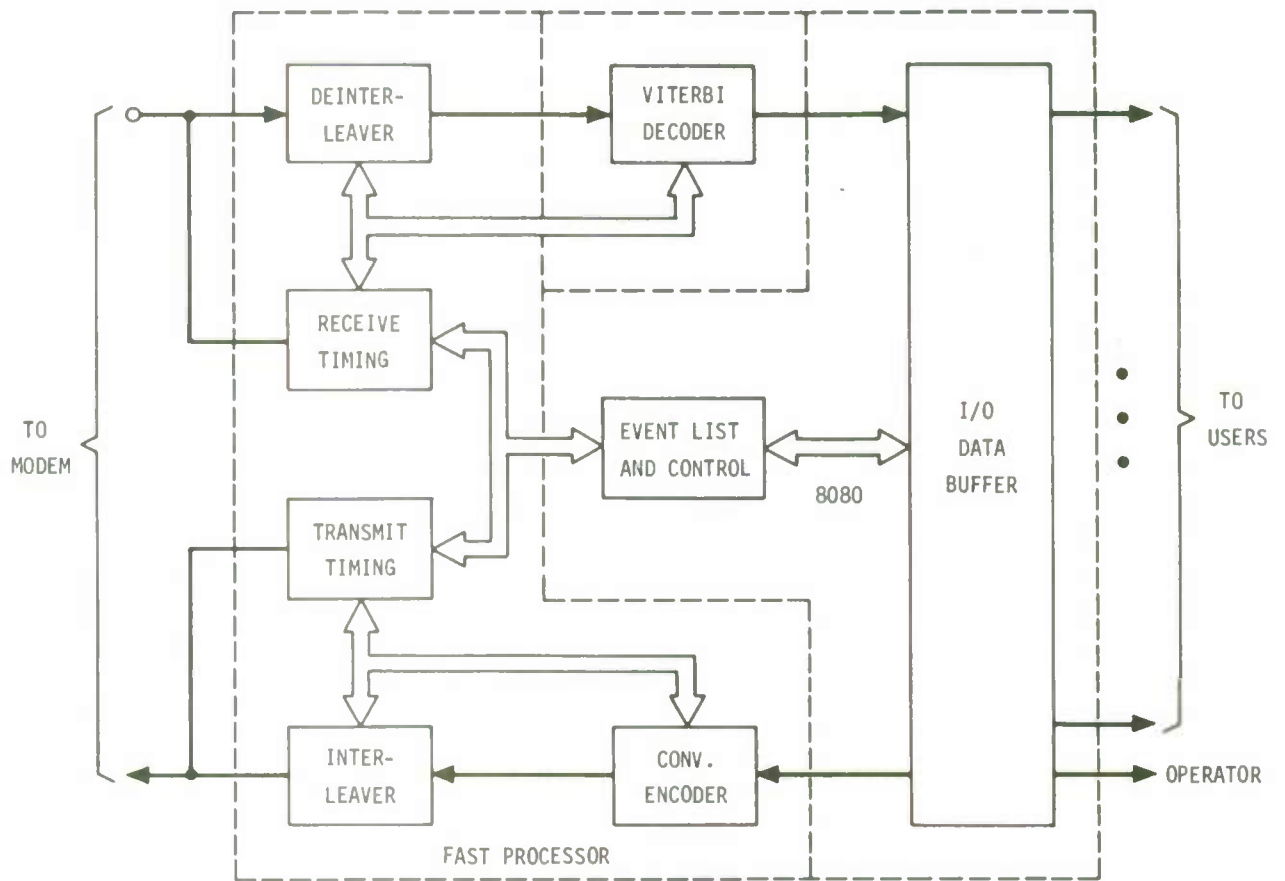


Fig. 2-10. Functional View of Terminal Access Controller.

The TAC consists of three modules, as indicated in the Figure. A general purpose microprocessor (Intel 8080) provides I/O buffering, the operator interface, and an event list, which controls the TAC synchronization and error control functions. The synchronization, deinterleaving, interleaving, and convolutional encoding functions are performed by the fast processor, which is a special purpose microprocessor (based on the 2901 ALU). This machine was selected for the real time or near-real time operations that require higher speed than the 8080 can provide.

The event list in the 8080 is a key to the programmability of the TAC. The event list is simply a list of instructions and the time at which the instructions are to be performed. The fast processor performs the functions (interleaving, rate 1/2 encoding, rate 3/4 coding, and so forth) as instructed. The event list can be changed by transmission from the MAC, in response to an assignment or preemption, for example. Other features in the event list can be changed by the operator, for example, major frame format changes.

The fast processor controls the Viterbi decoder by indicating the appropriate code rate and constraint length. Any one of a given set of four combinations of code rate (R) and constraint length (k) can be selected (by the fast processor). The constraint length can be 6, 7, 8, 9 or 10. The code rate is of the form $\frac{q}{p}$, where $q < p$, $q \leq 4$, and $p \leq 5$. A typical set of values for a given phase (say FLEETSAT with upgraded WSC-3 modems) might be: $k=10, R=4/5$; $k=9, R=3/4$; $k=8, R=2/3$; and $k=7, R=1/2$. The symbol rate would be 9.6 kbps or 19.2 kbps, also under control of the fast processor. The Viterbi decoder can easily accommodate rates as high as 32 kbps, to upgrade to the advanced modem. The TAC includes approximately 330 ICs.

Figure 2-11 illustrates the MAC, which is being implemented with a Varian 620/L-100 minicomputer.* The MAC controls system timing and manages demand assignment. Both of these control functions are exercised through one of the TACS at the CAMS. This TAC, designated the master TAC, receives control slot information from the MAC and transmits it to mobile platforms, and forwards ranging signals and requests from mobile platforms to the MAC. The master TAC also forwards requests from local users (connected by terrestrial facilities to the CAMS) directly to the MAC.

The MAC has an executive routine which coordinates the transfer of data to and from the master TAC and the operator. The sequence of operation is as follows: The TDM time base is generated with the time code generator from a crystal oscillator. The executive routine formats the control slot, which contains the TDM time base, and causes it to be transmitted to mobile platforms. New platforms entering the system transmit ranging signals, from which the MAC ranging routine calculates initial transmit timing corrections. Platforms already in the system transmit periodic dedicated reports, from which the ranging routine calculates transmit timing updates. The timing corrections are transmitted in the next control slot. Requests for service are input to the scheduling routine, which searches the data base for available capacity, both in the transceivers of the platforms involved and in the satellite channels.

* The choice of the Varian was based on its availability (it was "left over" from a past project), on the available support and on its capability to do the job. The MAC could also be implemented on a UYK-20.

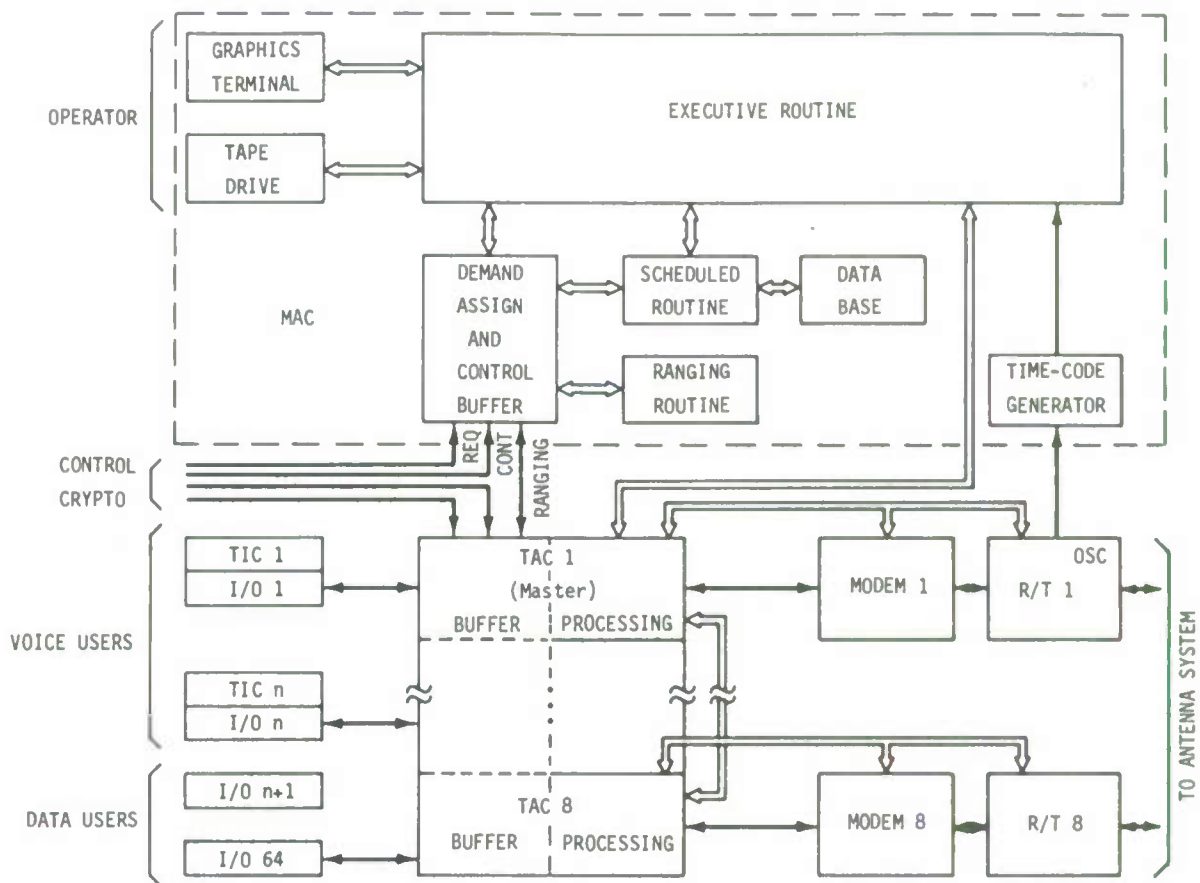


Fig. 2-11. Multiple Access Controller and Terminal Access Controllers at CAMS.

The scheduling routing then makes the necessary assignments and preemptions in the next control slot, and updates the data base. If for some reason the request cannot be honored, the user is given the appropriate call progress indication.

The TACS at the MAC^{*} are slightly different from the TAC at a mobile platform, although the TAC is being designed such that a mobile platform TAC can be upgraded readily to the MAC TAC configuration. One difference has already been mentioned: users at the CAMS (or large platform serving as the MAC) enter requests directly to the master TAC. This avoids unnecessary congestion in the request slots. Another difference is the contiguous nature of the buffer memory in the TACS. This is done to prevent unnecessary blockage between the users at the CAMS and the capacity of the TACS.

Each TAC at the CAMS has an associated full duplex transceiver. Since there is one TAC for each of eight channels, and since there is full connectivity between CAMS users and TAC capacity, each TAC can operate exclusively on only one channel (TAC 1 on channel A, and so forth). This scheme is in keeping with the currently proposed connection of CAMS antenna systems to minimize harmful intermodulation products.

* The principal MAC location is the primary or alternate CAMS. A large platform can be equipped to serve as a MAC in event of failure of the principal and alternate shore based MACS.

3.0 TDMA SYSTEM APPLICATION

The actual demand assigned TDMA system in a given stage of the FLEETSAT evolution will depend upon many factors, some of them unforeseen. The applications of TACS given in this section are therefore intended as examples. The programmability of the TAC and MAC would permit upgrading as the system evolves, as well as changes in frame structures and protocols within any given evolutionary stage. The purpose of this section is to provide a coordinated set of examples to demonstrate how TACS can evolve, beginning with the current state of the FLEETSAT program.

3.1 Operating Conditions and Requirements

The currently planned FLEETSAT traffic includes a number of LXSs, or Information eXchange Systems. The Common User Digital Information eXchange System, or CUDIXS, is an automated, star configured, record traffic net. Another is a secure voice circuit, which links together the bridges of all ships within a coverage area. This net is called FLTCOMMON in this report. All TDMA-equipped ships will be members of the FLTCOMMON and CUDIXS nets. Another secure voice net, called ICOM in this report, will link among major ships' Flag Plots. Although other systems are planned, the three mentioned above suffice to discuss the examples.

Ships which belong to the HICOM net will have at least two WSC-3s. Most ships, which are members of only the FLTCOMMON and CUDIXS nets, will have only one WSC-3. A constraint on the frame structures in the examples given is that a platform be able to participate in all the nets of which it is a member at one time.

3.2 System Evolution and Structure

The evolution of demand assignment might begin with GAPSAT. The system will be dominated by nets which already exist, including the 1XSSs and perhaps some 75 bps circuits. Figure 3-1 shows the functional configurations of small and large platforms assumed throughout the FLEETSAT era.

Before discussing the frame structure for each of the three stages, it is desirable to consider the operation of high duty factor voice nets (particularly FLTCOMMON). FLTCOMMON would tie together the bridges of satellite-equipped platforms in the coverage area. The number of such active platforms would be in the 50-100 range. The net control protocol on such a large voice net limits throughput or response time or both. The availability of more circuits by TDM helps to relieve voice net congestion. Figure 3-2 shows an example of restructuring of FLTCOMMON around operational functions (screen, anti-air warfare, and carrier/plane guard). Each new FLTCOMMON net would have far fewer members, and would be designed for duty factor of about 30%. The flagship of an operational group would be in the net controller, would be a large platform, and would also have access to a HICOM net. Each HICOM net is assumed to have a duty factor of about 10%.^{*}

Figure 3-3 shows a slot assignment scheme for two 25 kHz GAPSAT channels. The 2 second time frame is subdivided into 6 equal slots. Slots 1 and 3 of channel 1 are used for control circuits. Control can be expanded to slots 1

* This suggested structuring of Fleet satellite communications was derived from operational information provided by LCDR George A. Burman of PME-106 in NAVELEX.

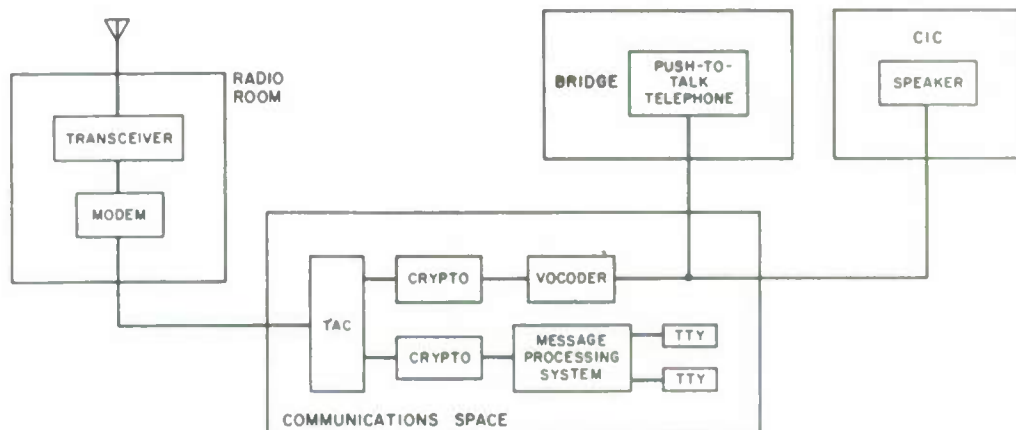


Fig. 3-1a. Small Platform Configuration.

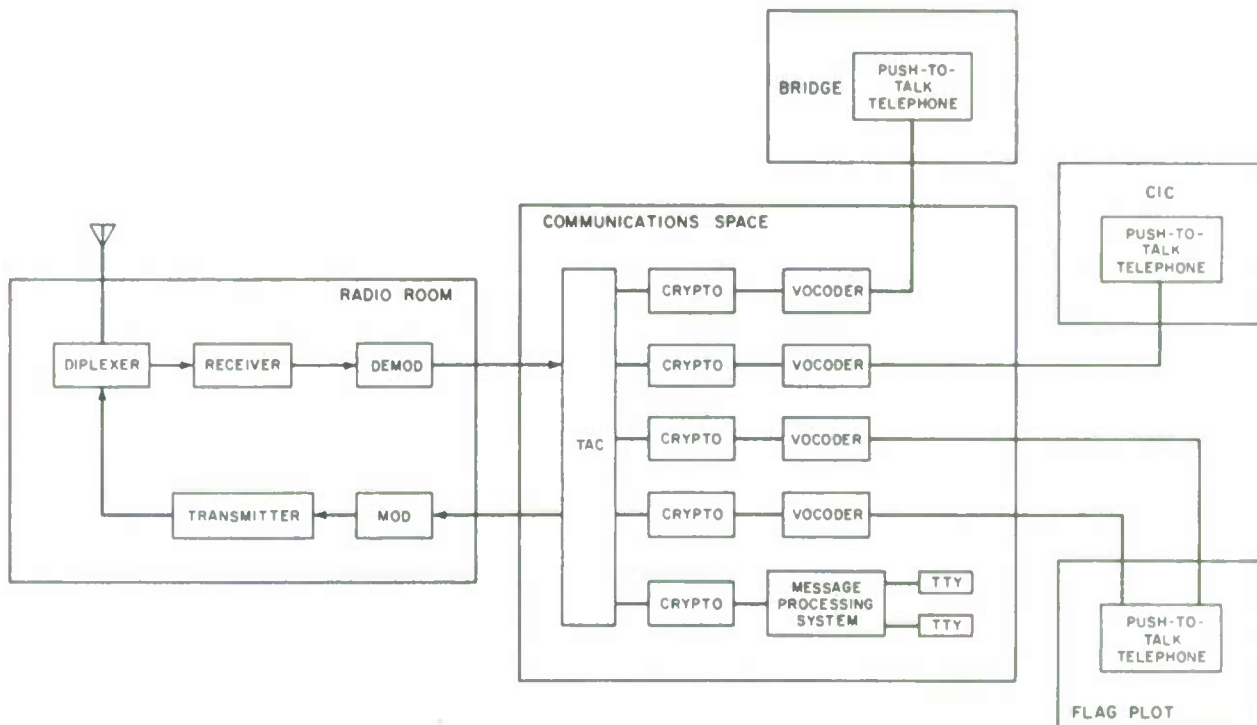


Fig. 3-1b. Large Platform Configuration.

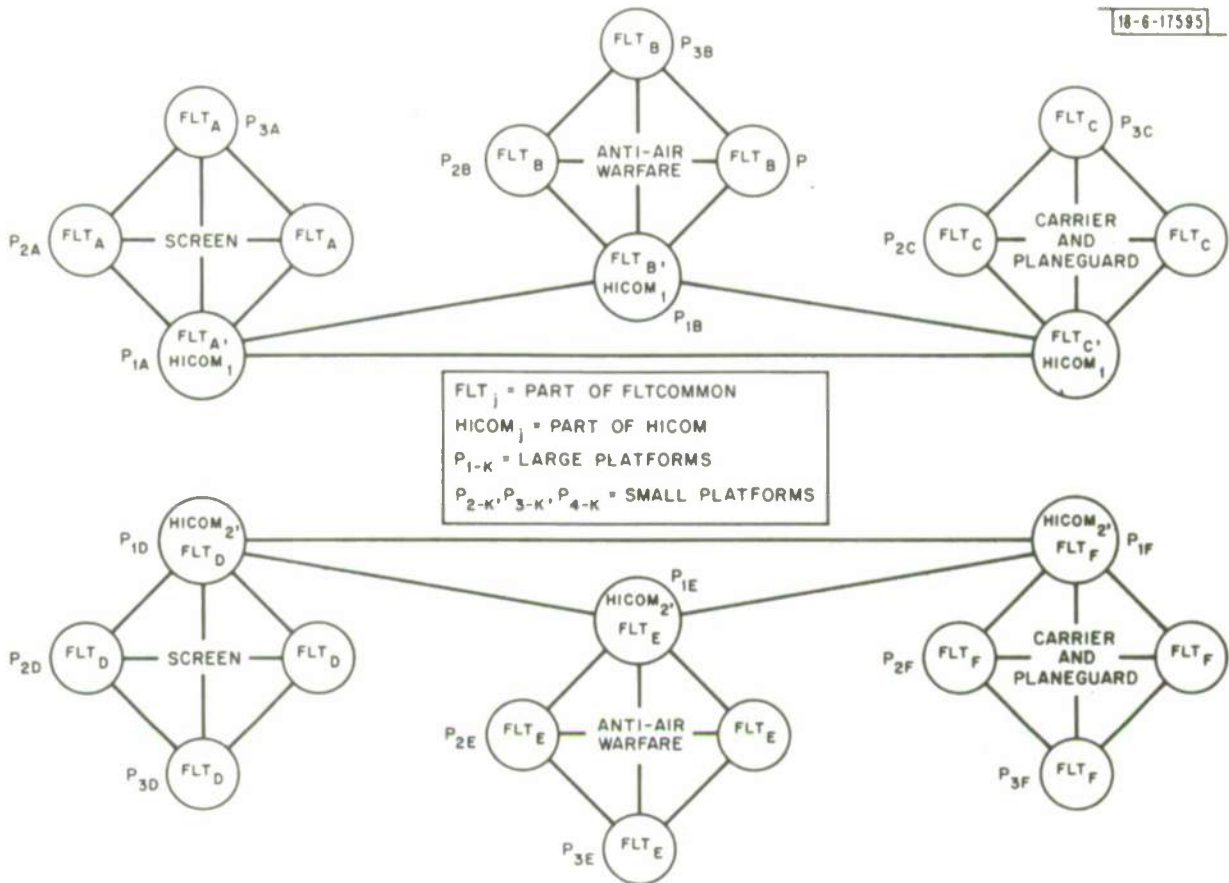
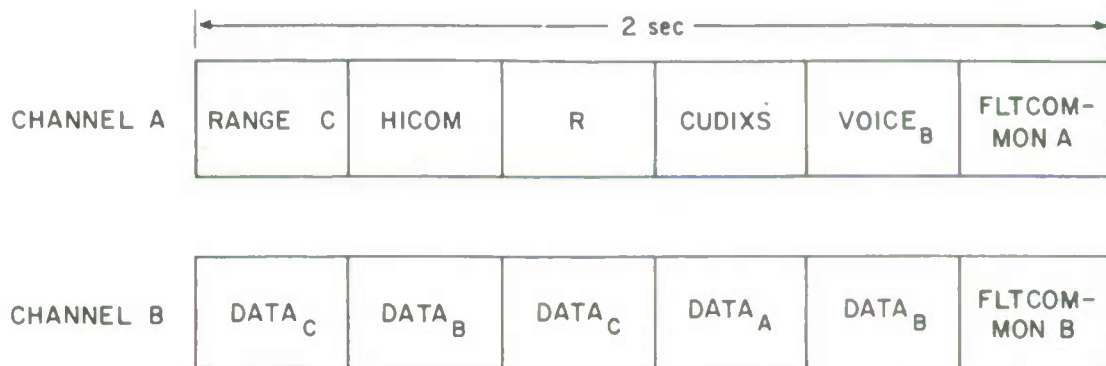


Fig. 3-2. Partitioning of HICOM and FLTCOMMON Nets.



C = CONTROL

R = REQUESTS

RANGE = RANGING

VOICE_A = SLOT USED BY ANY PLATFORM

VOICE_B = SLOT USED BY FULL DUPLEX PLATFORM

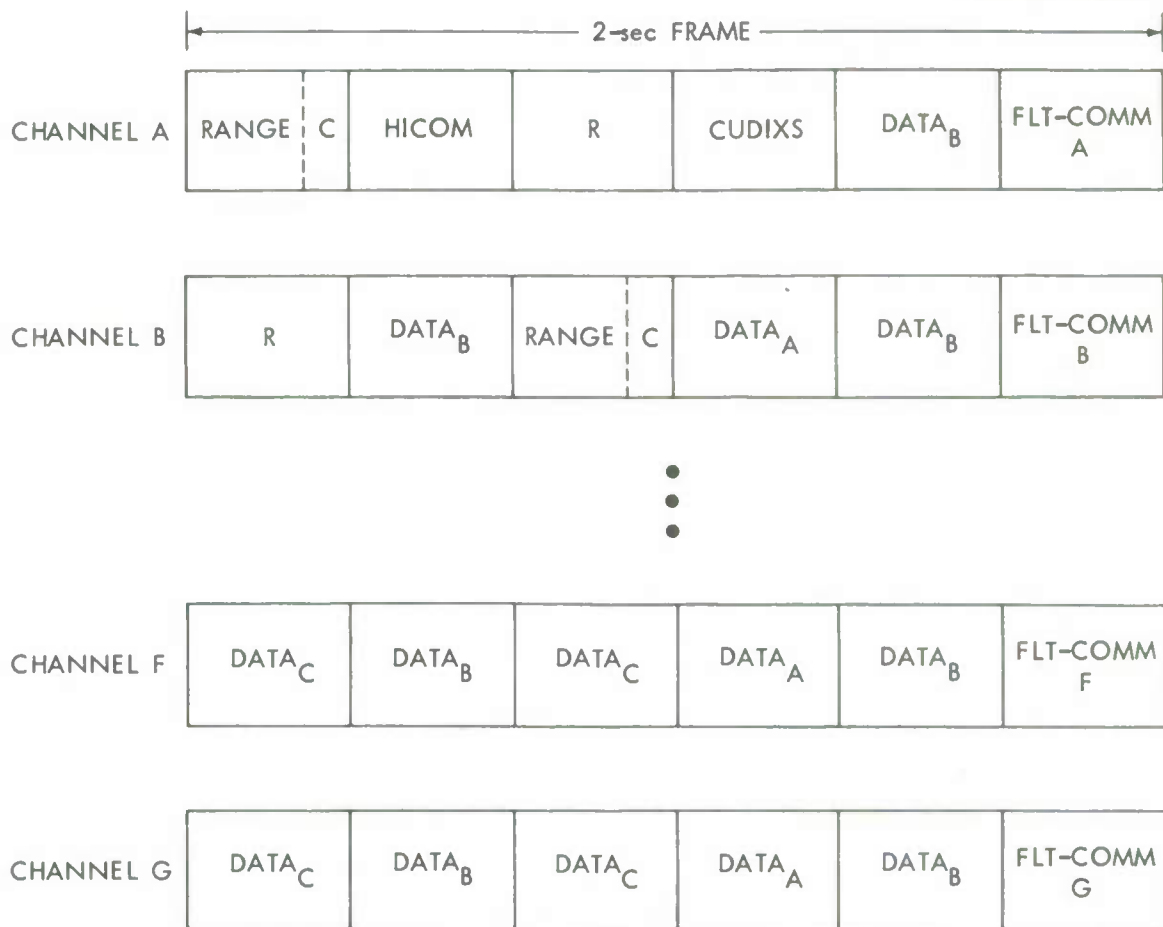
VOICE_C = SLOT USED BY PLATFORM WITH MORE THAN
ONE FULL DUPLEX RADIO

Fig. 3-3. Possible Assignments for Two TDMA GAPSAT Channels.

and 3 of channel 2 if necessary. Users on a small platform would simultaneously use the CUDIXS circuit (slot 4 of channel 1) and one FLTCOMMON circuit (slot 6 of either channel), only two FLTCOMMON nets would be available. The control circuits, CUDIXS, and the FLTCOMMON nets use dedicated circuits. The HICOM nets also use a dedicated circuit, but since there are more than one HICOM nets, the HICOM users share the circuit by demand assignment. Users on a large (full duplex) platform could have simultaneous use of 4 communications circuits and the control circuits. Six additional 2.4 kbps circuits would also be available. Any one of these could alternately be used for about eleven 75 bps circuits.

Figure 3-4 shows a slot assignment scheme for 7 FLEETSAT channels. As in the GAPSAT example, the 2 second time frame is subdivided into 6 equal time slots. Individual platforms would have the same capability as for GAPSAT with TDM. The .3 duty factor of the FLTCOMMON nets makes them attractive candidates for demand assignment. The circuits could be dedicated in early states of FLEETSAT, then gradually merged into the demand assignment system. For example, slot 6 of, say, three channels could be set aside for the six FLTCOMMON nets.

As shown in the Figure, slot 1 of channel B is used for requests and slot 3 is used for control and ranging. This permits a set of half duplex platforms to use a set of data slots complementary to those used by the half duplex platforms with control in channel A. That is, half duplex platforms with control in channel B would have simultaneous use of slots 2 and 5, just as half duplex platforms with control in channel A have use of slots 4 and 6.



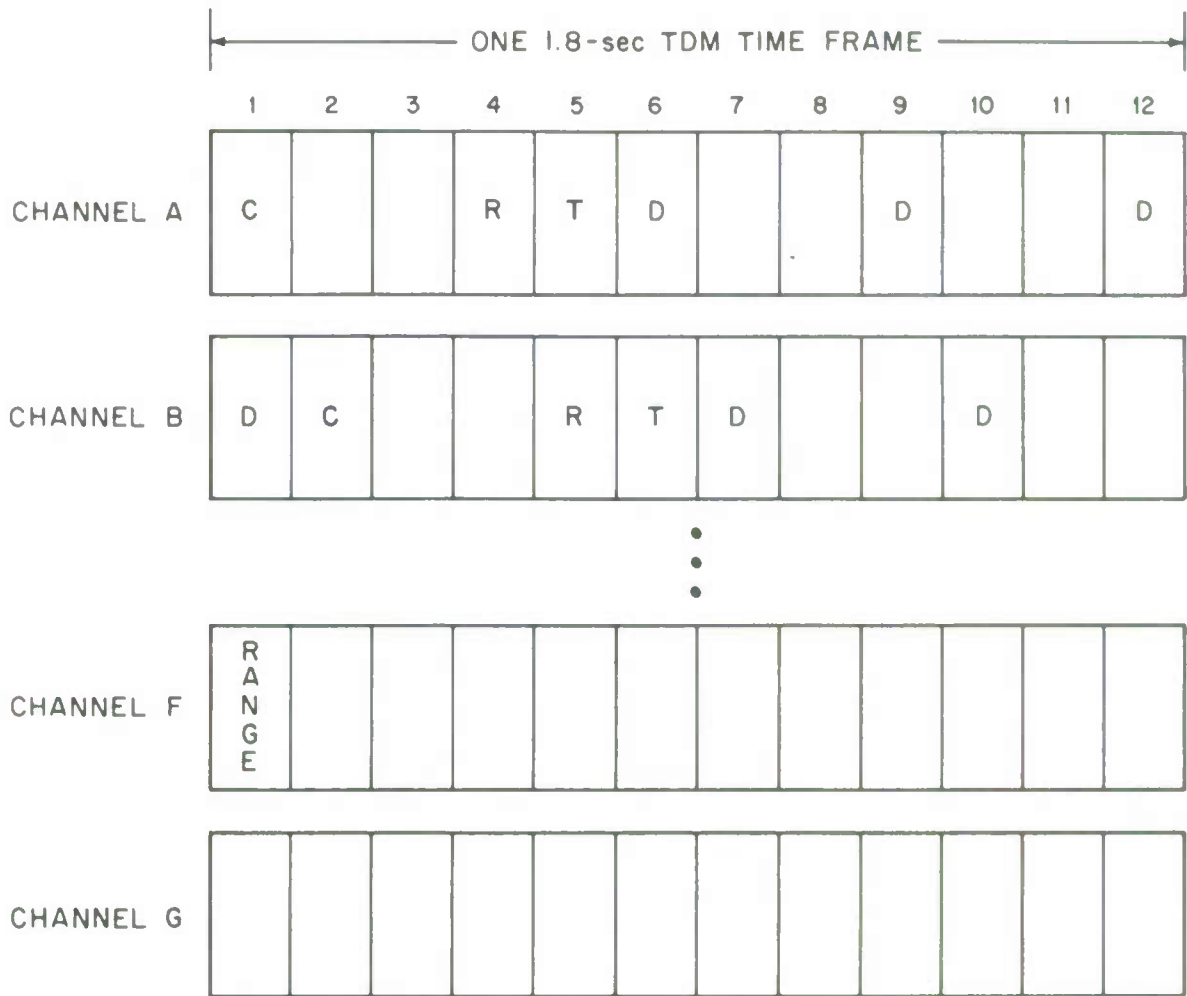
- C = CONTROL
 R = REQUESTS
 RANGE = RANGING
 DATA_A = SLOT USED BY ANY PLATFORM
 EXCEPT HALF-DUPLEX PLATFORM
 USING CHANNEL B FOR CONTROL
 DATA_B = SLOT USED BY ANY PLATFORM
 EXCEPT HALF-DUPLEX PLATFORM
 USING CHANNEL A FOR CONTROL
 DATA_C = SLOT USED BY PLATFORM WITH MORE
 THAN ONE FULL DUPLEX RADIO

Fig. 3-4. Possible Assignments for Seven FLEETSAT TDMA Channels.

Readers are encouraged to tailor other arrangements to operating scenarios. The programmable frame structures permit rapid reconfiguration as scenarios change.

The control and request slots can be expanded as necessary to slots 1 and 3 of channels C through G. This permits long term as well as short term accommodations of changes in request rates and other operating statistics. For example, short term peaks in request rates can be met by creating request slots in slot 3 of channel C for the duration of the peak need. Such "dynamic control," as noted in reference 4, leads to an optimum allocation of control and communications capacity.

Figure 3-5 shows the third phase, FLEETSAT plus an advanced modem. The 1.8 second time frame has 12 equal slots. A small platform using slots 1 and 4 of channel 1 for control circuits can simultaneously use slot 5 for ship-to-shore transmissions and slots 6, 9 and 12 for voice circuits. Hence, if the demand assignment function of CUDIXS were transferred to the TDMA system, small platforms could use slot 5 for CUDIXS transmissions. This capability of one ship-to-shore data (record) circuit simultaneous with three voice circuits would be sufficient for most platforms. Large platforms would have simultaneous use of 10 circuits. Hence, small platforms would have substantial capability with only one half duplex transceiver. Large platforms would have more than twice the capability with one full duplex transceiver than was originally planned for the largest (four half duplex transceivers) shipboard installation. Hence, Fig. 3-5 shows the third phase, FLEETSAT plus an advanced modem. The 1.8 second time frame has 12 equal slots. Control and request



T= TRANSMIT ONLY
 D= VOICE
 R= REQUESTS
 C= CONTROL
 RANGE= RANGING

Fig. 3-5. TDM of 7 FLEETSAT Channels with Advances Modem.

slots are shown as staggered in order to create complementary sets of data slots for complementary sets of half duplex platforms. A half duplex platform with control in channel A would have full use of slots 6, 9 and 12, and transmit only use of slot. In this phase, the demand assignment function of CUDIXS could be transferred to TACS, hence slot 5 would suffice for ship-to-shore record traffic (the shore-to-ship CUDIXS traffic could also be sent in slot 5, since this traffic is intended for full duplex platforms). In addition to the record capability, a half duplex platform would have simultaneous use of three voice or tactical data circuits. One possible set of nets for such circuits would be FLTCOMMON, tactical data, and a net linking Combat Information Centers.

As a final note, the increased number of slots provided by advanced modems makes the system far more flexible and robust than TACS or DAMA with simple modems. For example, it is much easier to adapt to degraded conditions by simply assigning two slots to a disadvantaged net. Under normal link conditions, a half duplex platform could have simultaneous use of four nets, including CUDIXS. This is comparable to the capability of a large platform with four WSC-3s without TDMA. Full duplex platforms have use of as many as 10 nets. Such increased capabilities would probably have a strong impact on operational flexibilities.

APPENDIX

As in Reference 2, the effective link P_r/N_o is calculated as

$$\left(\frac{P_r}{N_o}\right)_{\text{eff}} \approx \frac{\left(\frac{P_r}{N_o}\right)_{\text{up}} \left(\frac{P_r}{N_o}\right)_{\text{down}}}{\left(\frac{P_r}{N_o}\right)_{\text{up}} + \left(\frac{P_r}{N_o}\right)_{\text{down}} + W}$$

where $W = 25$ kHz and both uplink and downlink P_r/N_o include 6 dB of margin. Table A-1 shows details of calculations of $(P_r/N_o)_{\text{up}}$ and $(P_r/N_o)_{\text{down}}$ for FLEETSAT and GAPSAT 25 kHz channels. Assumptions are shown as footnotes to the Tables.

One assumption which may be optimistic is that 23 dBW of ERP is available for 25 kHz channels derived from the 500 kHz GAPSAT channel. The losses associated with frequency division multiple access through a hard-limiting transponder will tend to require more than the usual 6 dB margin. The fact that the specified EIRP (28 dBW) of the wideband channel is for limb of earth and end of life at least partially offsets the hard-limiting losses, at least for a large geographic region. Further, additional margin is available for most links operating at 15.4 kbps, as noted in Table 2-2. For example, large ship-to-CAMS links operating at 15.4 kbps have 4.2 dB of margin available.

TABLE A-1

UPLINK CALCULATIONS
(All Entries in dB)

	CAMS	LARGE SHIP	SMALL SHIP	AIRCRAFT	SUBMARINE
RF POWER	20	20	20	26 ^B	20
- MULTICOUPLER LOSS	3.8 ^A	3.8	0	0	0
- LINE LOSS	3	4	4	2	2
+ ANTENNA GAIN	<u>12</u>	<u>12</u>	<u>12</u>	<u>0</u>	<u>-3</u>
PLATFORM EIRP	25.2	24.2	28.0	24.0	15.0
- MARGIN	6.0	6.0	6.0	6.0	6.0
BOLTZMANN'S CONST	228.6	228.6	228.6	228.6	228.6
- PATH LOSS ^C	174.8	174.8	174.8	174.8	174.8
GAPSAT G/T	<u>-18.0</u>	<u>-18.0</u>	<u>-18.0</u>	<u>-18.0</u>	<u>-18.0</u>
GAPSAT (P_r/N_o) _{up}	55.0	54.0	57.8	53.8	44.8
FLEETSAT G/T	<u>-16.0</u>	<u>-16.0</u>	<u>-16.0</u>	<u>-16.0</u>	<u>-16.0</u>
FLEETSAT (P_r/N_o) _{up}	57.0	56.0	59.8	55.8	46.8

NOTES: A) The CAMS transmit antenna configuration is assumed to have a pair of transmitters coupled through one multicoupler stage to one OE-82-like (12 dB) antenna.

B) Assumes 400 W power amplifier under development.

C) Slant range at 311 MHz.

TABLE A-2

DOWNLINK CALCULATIONS
(All Entries in dB)

	CAMS			SHIP			AIRCRAFT			SUBMARINE		
	28	26	23	28	26	23	28	26	23	28	26	23
SATELLITE EIRP												
- PATH LOSS ^A	173.6	173.6	173.2	173.6	173.6	173.2	173.6	173.6	173.2	173.6	173.6	173.2
- MARGIN	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
+ ANTENNA GAIN	18.0	18.0	18.0	12.0	12.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0
- N _o (1000°K)	+199.0	-199.0	-199.0	-199.0	-199.0	-199.0	-199.0	-199.0	-199.0	-199.0	-199.0	-199.0
(P _r /N _o) _{down}	65.4	63.4	60.8	59.4	57.4	54.8	47.8	45.4	42.8	44.4	42.4	39.8

NOTES: A) FLEETSAT downlink calculated at 270 MHz, GAPSAT at 257.55 MHz; both slant range.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Lincoln Laboratory's Terminal Access Control System (TACS) provides demand assigned time division multiple access TDMA to GAPSAT or FLEETSAT 25 kHz channels. TACS is centrally controlled by a multiple access controller (MAC), nominally located at a shore station. Users of TACS who can be on shore-based or mobile platforms, enter requests for service via a Terminal Access Controller (TAC). The TAC provides error control and data buffering functions in addition to demand assignment control. The MAC automatically responds to the user request with an assignment or busy indication. TACS initially will utilize WSC-3 radios and modems, modified for 19,200 symbol per second operation and for rapid turn around time. TDMA frame formats are designed to maximize system efficiency and utility. For example, a mobile platform equipped with one half duplex WSC-3 has use of two 2.4 kbps circuits simultaneously. A platform with a full duplex radio has use of four such circuits.		

