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DEMAND ACCESS COMMUNICATIONS FOR TDRSS USERS

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Mr. David Zillig
NASA GSFC, Code 531
Goddard Space Flight Center
Greenbelt, MD 20771

Dr. Aaron Weinberg
Mr. Robert McOmber
Stanford Telecommunications, Inc.
1761 Business Center Drive
Reston, VA 22090

ABSTRACT

The Tracking and Data Relay Satellite System (TDRSS) has long been used to provide reliable low- and high-data rate relay services between user spacecraft in Earth orbit and the ground. To date, these TDRSS services have been implemented via prior scheduling based upon estimates of user needs and mission event timelines. While this approach may be necessary for large users that require greater amounts of TDRSS resources, TDRSS can potentially offer the planned community of smaller science missions (e.g., the small explorer missions), and other emerging users, the unique opportunity for services on demand. In particular, innovative application of the existing TDRSS Multiple Access (MA) subsystem, with its phased array antenna, could be used to implement true demand access services without modification to either the TDRSS satellites or the user transponder, thereby introducing operational and performance benefits to both the user community and the Space Network.

In this paper, candidate implementations of demand access service via the TDRSS MA subsystem are examined in detail. Both forward and return link services are addressed and a combination of qualitative and quantitative assessments are provided. The paper also identifies further areas for investigation in this ongoing activity that is being conducted by GSFC/Code 531 under the NASA Code O Advanced Systems Program.

1.0 INTRODUCTION

For over a decade, the Tracking and Data Relay Satellite System (TDRSS) has been providing reliable, low- and high-data rate, two-way relay services between low-earth orbit user spacecraft and the ground. To date, these TDRSS services -- both single access (SA) and multiple access (MA) -- have been provided to users via structured scheduling. The scheduling is completed days in advance of the actual service event, and based upon estimates of user needs and mission event timelines. This approach has historically been, and may continue to be, necessary for certain classes of users and operational scenarios (e.g., real-time relay of time-critical, wideband science data). On the other hand, newly emerging users and operational scenarios may be capable of taking advantage of certain TDRSS services on demand. Such users may include emerging small-satellites and certain non-space users (e.g., aircraft).

Toward this end, Code 531 at NASA/GSFC, under the sponsorship of the Code O Advanced Systems Program, has been identifying and assessing a variety of Demand Access (DA) concepts that reflect the following Statement of Need:

Dramatically enhance user accessibility to TDRSS, by accommodating service requests on demand. The new DA services should:

- **Support the broadest possible range of users, with particular emphasis on emerging small-sats and other unique users (e.g., NASA aircraft).**
- **Emphasize low-data-rate TT&C services.**
- **Ensure low-cost Space-Network (SN)/user operations.**

Within the framework of SN operations, the above DA service needs are addressed here by focusing on the innovative utilization of the TDRSS Multiple Access (MA) Forward and Return services. The rationale for MA utilization -- in contrast to Single Access (SA) -- is due to the unique nature of the electronically steerable MA antenna, its amenability to very rapid configuration, and its much higher availability than SA (especially on the MA Return link). Further insights into MA service utilization for DA are provided via subsequent discussions in the body of the paper.

The purpose of this paper is to provide representative, interim results of ongoing DA study activities that are being conducted by GSFC Code 531. The organization of this paper is as follows. Section 2 provides an overview of DA operations, including an architectural definition and a description of candidate DA service applications. Sections 3 and 4 follow with respective descriptions and unique features of candidate Forward and Return link DA operations concepts; qualitative and quantitative performance results are also presented. Section 5 concludes with a Summary and Observations.

2.0 DEMAND ACCESS OVERVIEW

A first logical question to ask is: **What is meant by "ideal" Demand Access?** Within the present SN framework, this question is addressed in Figure 1. As seen, the key ingredients of interest, for both the Forward and Return links, may be summarized as follows:

- No NCC scheduling.
- Essentially immediate SN reaction to a user service request.
- No contention with other users (i.e., 100% service satisfaction).

Given that "ideal" DA is not achievable via the SN, the second question that arises is: **How close to "ideal" DA can be achieved via innovative utilization of MA service capabilities?** As will be shown in Sections 2 and 3, the answer to this question is: **Remarkably close to "ideal" DA is achievable via: suitable user operations concepts, modest ground augmentations, and appropriate applications of the highly capable MA resources!** To be emphasized is the fact that the proposed DA capabilities are achievable with the **existing** on-orbit TDRSS spacecraft and **existing** user spacecraft transponders.

Prior to proceeding with the detailed discussions it is useful to gain some insight into potential applications of DA. A listing of candidate DA services and relevant observations is given in Table 1. As seen, the DA services can benefit both SN operations (e.g., BRTS) and user communications and tracking, by introducing simplicity, flexible and efficient use of resources, robustness, enhanced performance, and the accommodation of new/unique applications.

To complement Table 1, Figure 2 illustrates a few candidate DA scenarios. As seen, the applications are diverse, and the Forward and Return portions may be applied either separately or jointly. It should also be noted that a conscious effort is being made here to include the potential for a direct, real-time INTERNET interface between the user spacecraft and the Principal Investigator.

It is apparent that a variety of system-level, cost, performance, and technology considerations must be addressed in assessing candidate DA concepts.

Representative considerations and evaluation criteria being applied as part of the GSFC Code 531 study are as follows:

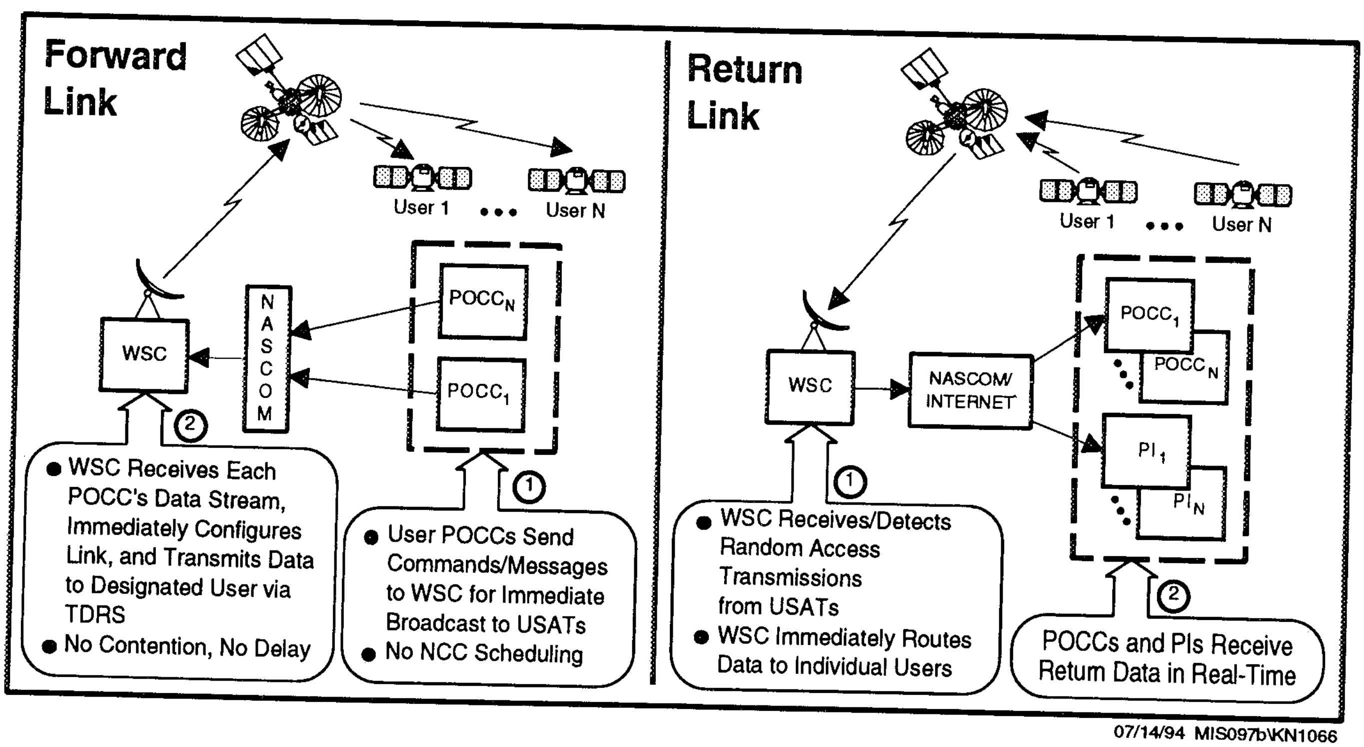

Figure 1: What is "Ideal" Demand Access?

Table 1: Candidate DA Services

DA Service	Observations
TDRS tracking; BRTS no longer scheduled for nominal TDRS tracking	• SN benefit • Potentially improved tracking performance
User one-way return tracking	• Via single TDRS with sufficiently stable oscillator • Differenced doppler for portion of user orbit, cancels oscillator drift • Potential to eliminate coherent turnaround and reduce transponder power consumption
Low-rate command load	• Multiple times per day • As desired by user
Low-rate telemetry	• As desired by POCC and/or PI • Echoes or ACKs of DA CMDs • Immediate access to on-board problems (via transmission initiated by spacecraft) • Immediate access to data on unexpected Targets of Opportunity • Potential E-mail interface to PI via WSC/INTERNET interface
User or SN testing without loading SN scheduled services	• FWD and RTN user tests • SN SMA FWD/RTN tests via BRTS, or via cooperative spacecraft, or via non-ops spacecraft (e.g., COBE)
• Apply inner TDRSs for DA and outer TDRSs for scheduled service • Option: DA augmentation via GRTS	• Would provide near-global, 24 hour DA service • Would simplify DA/WSC operational interface (may enhance automation potential) • May simplify supporting HW/SW upgrades required at WSC • Low complexity DA operations may be ideal application of GRTS
Provide FWD messages to user community whenever MA FWD is not otherwise being used	• Maximizes utilization of MA FWD resource • Can be used to periodically provide entire user community with useful housekeeping data; e.g.: – Time of day – SN schedule information that is unclassified – Clock/oscillator corrections; periodic synchronization to WSC CTFS – TDRS and USAT state vector updates (effectively eliminates need for on-board nav)
FWD/RTN DA can also accommodate unique ground users (e.g., polar)	Take advantage of increased inclination of aging TDRSs (e.g., F1)

- FWD/RTN link availability (user satisfaction; waiting time).
- FWD/RTN link data throughput.
- SN impacts -- implementation and cost (e.g., White Sands Complex (WSC); new elements and interfaces; application of 1 vs 2 vs 3 TDRS constellation nodes for DA).
- User impacts -- implementation and cost (e.g., POCC; transponder).
- Operational risk and robustness (e.g., prime/backup; transition; robust accommodation of an expanding user population that desires DA service).
- End-to-end cost per bit (overall NASA perspective).

3.0 MA FORWARD DEMAND ACCESS (MAFDA)

Preliminaries

The TDRSS MA capability relies on a unique, 30 element phased array antenna on each TDRSS spacecraft, with each element providing a conical 26° beamwidth (i.e., greater than earth coverage from geostationary orbit). The MA capability provides both FWD and RTN link services. The FWD capability, and its application to DA, is addressed in this section.

The MA FWD capability involves application of 8 - 12 of the 30 elements, which are phased via ground control, to point to and service a single user at a time.

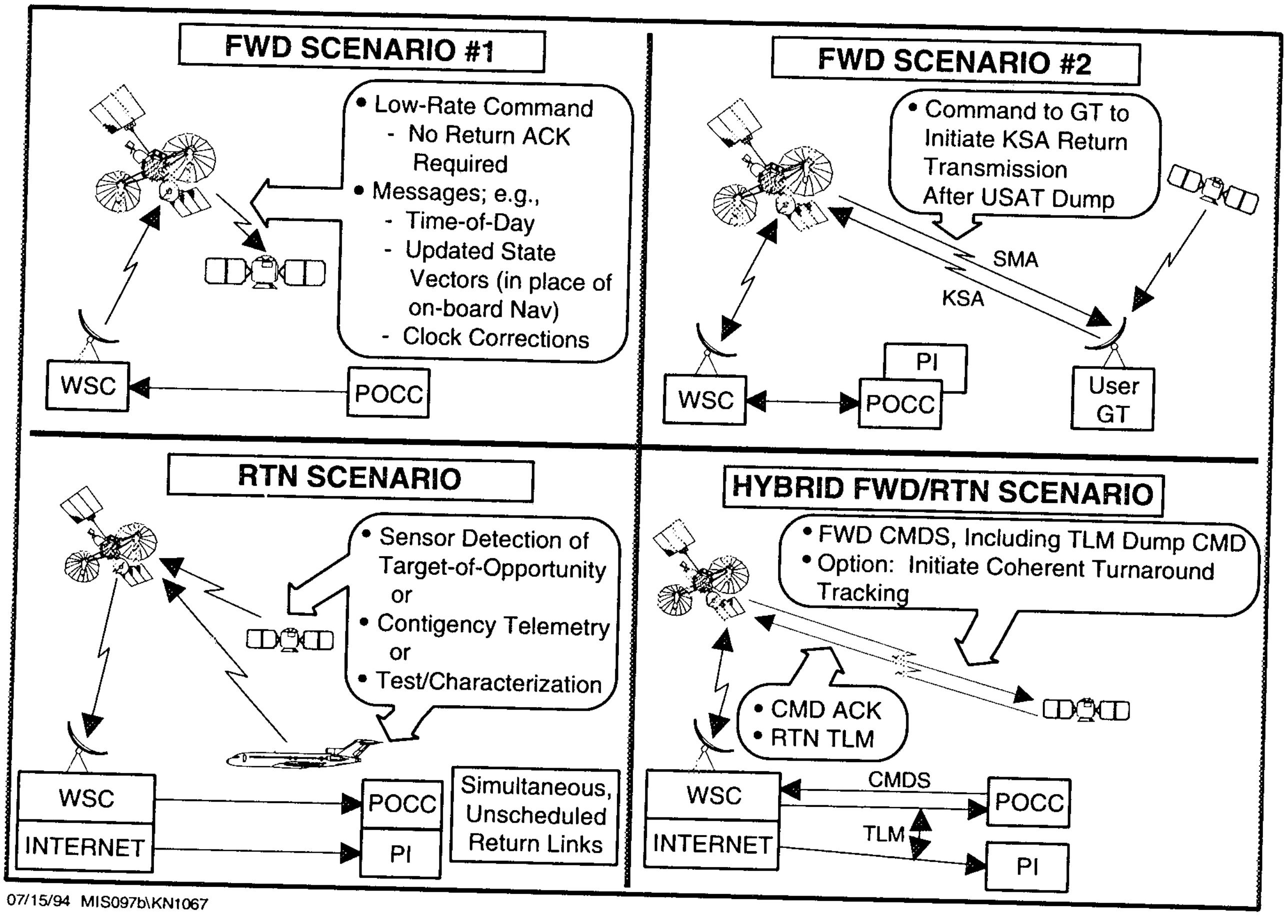

Figure 2: Candidate Demand Access Scenarios

As such, the MA FWD link is generally considered "a scarce resource" and must be applied wisely to maximize its applicability to DA. The TDRS MA FWD EIRP is 34 dBW, which accommodates .5 - 1 kbps, via a user near-omni antenna, if the FWD data is convolutionally encoded.

Because of the "one user at a time" feature, an appropriate quantitative performance assessment of MAFDA requires explicit utilization of a user mission model. For the purpose of this paper, the mission model employed reflects the seven baseline SN users for the year 2000, augmented with 10 hypothetical users that reflect a diversity of current and planned small-sat characteristics (Table 2). The rationale for this augmentation is to "stress" the proposed MAFDA system, and determine how robustly the system performs under high loading conditions, and ultimately what the system capacity is.

Description and Assessment of Candidate MAFDA Concept

As part of the Code 531 study activity, several candidate MAFDA concepts have been addressed to date. The present paper addresses a concept that appears to be a leading contender. The high level architecture, and associated operations concept ingredients, are illustrated in Figure 3. In this figure, the circled numbers represent the order time sequence of events. Of particular importance is the ability of each POCC to send messages, as desired, to its respective user spacecraft via the TDRSS ground terminal (WSC). Note that the NCC is not in the service request path, but does receive associated status information, as it must. Also to be noted is that the POCC transmissions are relayed to WSC via a preprocessor that:

- Queues messages on a first-come-first-serve basis (i.e., the proposed DA scheme precludes priorities).

Table 2: Representative Small-Sat Orbital Characteristics

#	Basis of Orbit	Eccentricity	Inclination (deg)	Period (minutes)	Altitude (km)	Argument of Perigee (deg)	Right Ascension (deg)	Spacecraft Altitude Rotation Axes
1	TIMED Elliptical	0.3089	95	152	--	0	0	Pitch Axis
2	TIMED Circular	0	49	92	400	0	40	Pitch Axis
3	SAMPEX	0.0089	82	97	612	0	80	Pitch Axis, Yaw Axis
4	TIMED Circular	0	49	92	400	0	100	Pitch Axis
5	SAMPEX	0.0089	82	97	612	0	225	Pitch Axis, Yaw Axis
6	TIMED Elliptical	0.3089	95	152	--	270	180	Pitch Axis
7	Low Inclination	0	28.5	92	400	0	100	Pitch Axis
8	Low Inclination	0	28.5	97	600	0	200	Pitch Axis
9	Critical Inclination	0.1	63.4	120	--	270	0	Pitch Axis
10	Critical Inclination	0.1	63.4	120	--	90	180	Pitch Axis

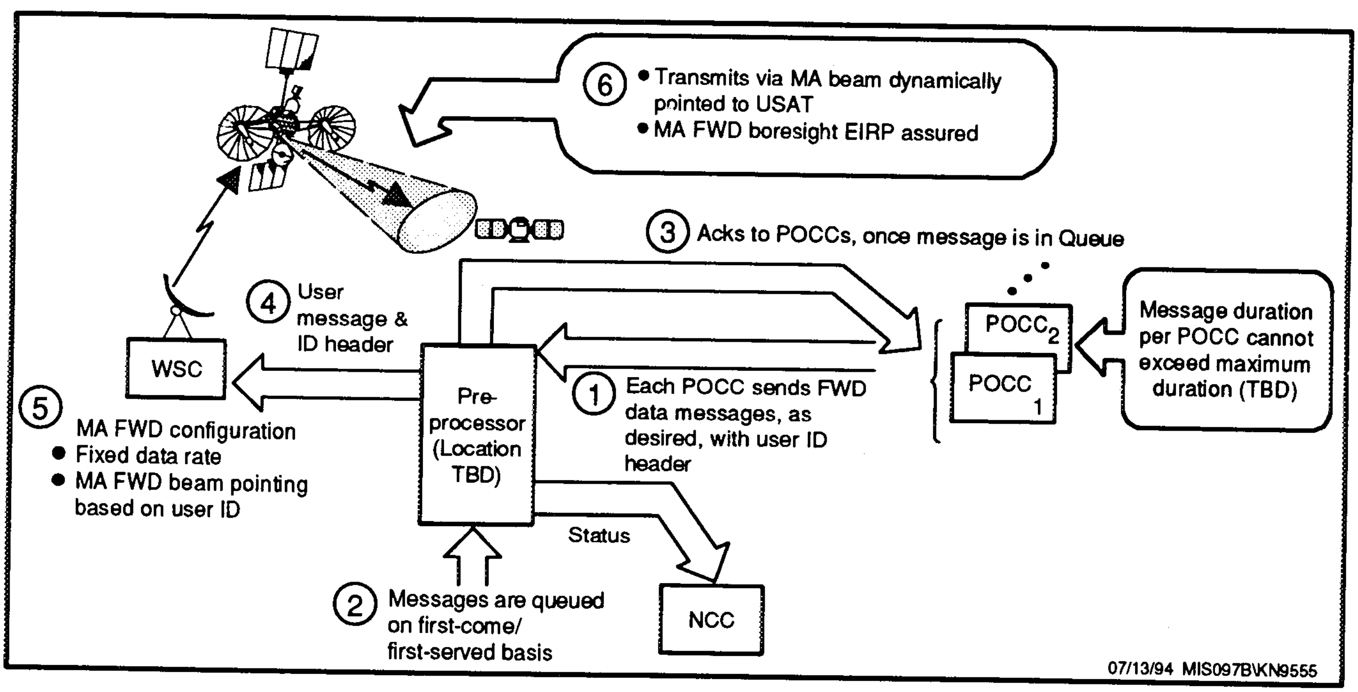

Figure 3: Candidate MAFDA Approach

- Sends acknowledgement to the POCC, once the message is successfully queued.
- Identifies the POCC's ID and sends the appropriate information to WSC for rapid link configuration.

Within this framework, WSC can configure and establish the MA FWD link within 30 seconds. As such, almost immediate service accommodation is provided, **as long as the queue is empty when a POCC transmits a message**. Queue contents vs time is addressed in more detail shortly.

More insight into the ground interface is presented in Figure 4. The middle block shown represents the preprocessor of interest, which is anticipated to be an automated/low-rate/low-complexity processor, that perhaps can be embedded in a small workstation. Its physical location, yet to be established, is currently not envisioned to be a critical system factor. Several additional points of interest are as follows:

- For simplicity, the present concept assumes that the MAFDA data rate is the same for all users.
- The message duration per DA service is assumed to be fixed (e.g., 2 minutes).
- WSC, as currently implemented, contains all necessary user database information to permit rapid extraction of key user link parameters (e.g., state vectors and oscillator frequency).

Figure 4 also illustrates a representative structure for a user message. The duration of each such message, and the transmission duty cycle per POCC, are key system design parameters. Discussion follows.

Given that a single MA FWD link exists per TDRS, it is clear that the user satisfaction, via the proposed DA service concept, will be high only if the message duration and transmission duty cycle per POCC are reasonably sized. To gain quantitative insight into these matters, as well as insight into how many TDRSS constellation nodes should be allocated to MAFDA, a comprehensive and flexible simulation capability has been developed. The simulation propagates all user orbits of interest, permits variation of message duration and duty cycle, and randomly inserts POCC messages into the queue. The simulation can also assess DA operations via one, two or three TDRSS constellation nodes.

Figure 5 provides one illustrative set of simulation results, wherein the 10 small-sats of Table 2 are treated as DA users and are accommodated via the single TDRS node at 85°E; BRTS is also included in the simulation as a priority user, given the requirement for TDRS orbit determination. All other TDRSS users -- i.e., the nominal year 2000 users (such as HST) -- are accommodated as regularly scheduled users via the other two TDRS constellation nodes. The following key observations result:

- Messages of up to 2.5 minute duration per orbit can be accommodated with little or no queue waiting time; < 1% probability that waiting time exceeds 2.5 minutes.

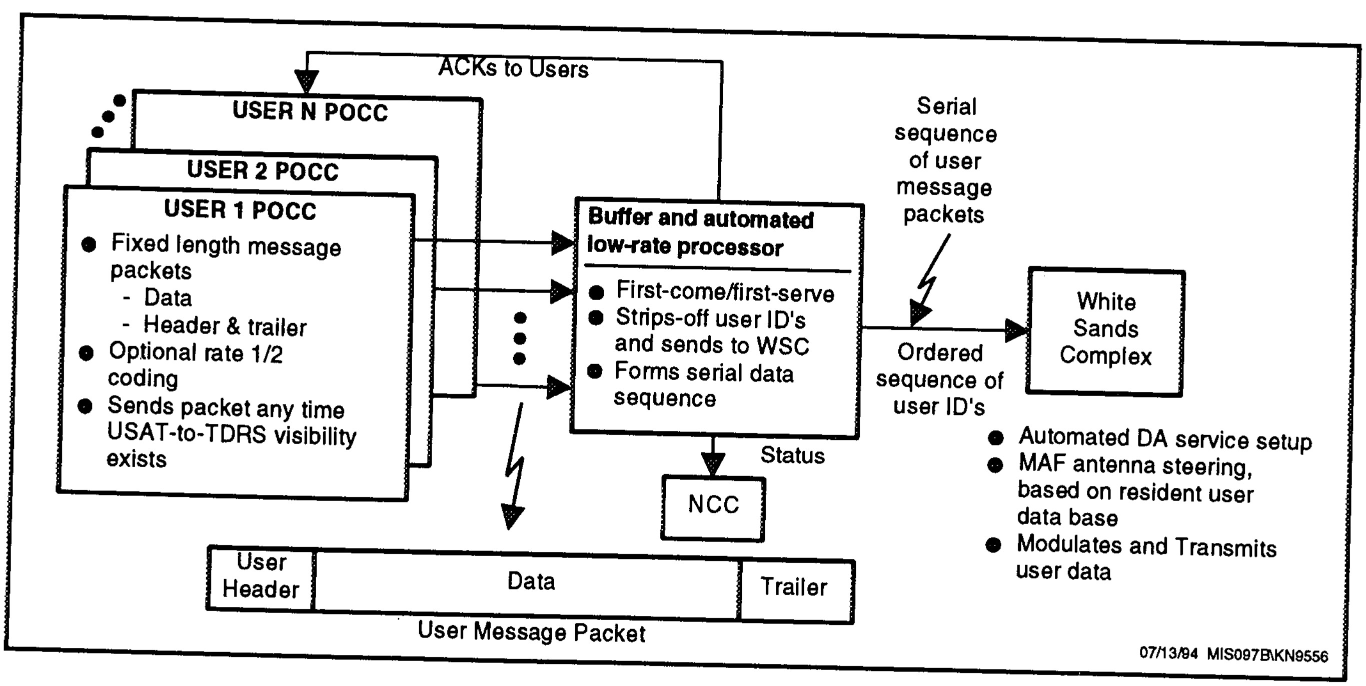

Figure 4: Candidate User Ground Interface for MAFDA

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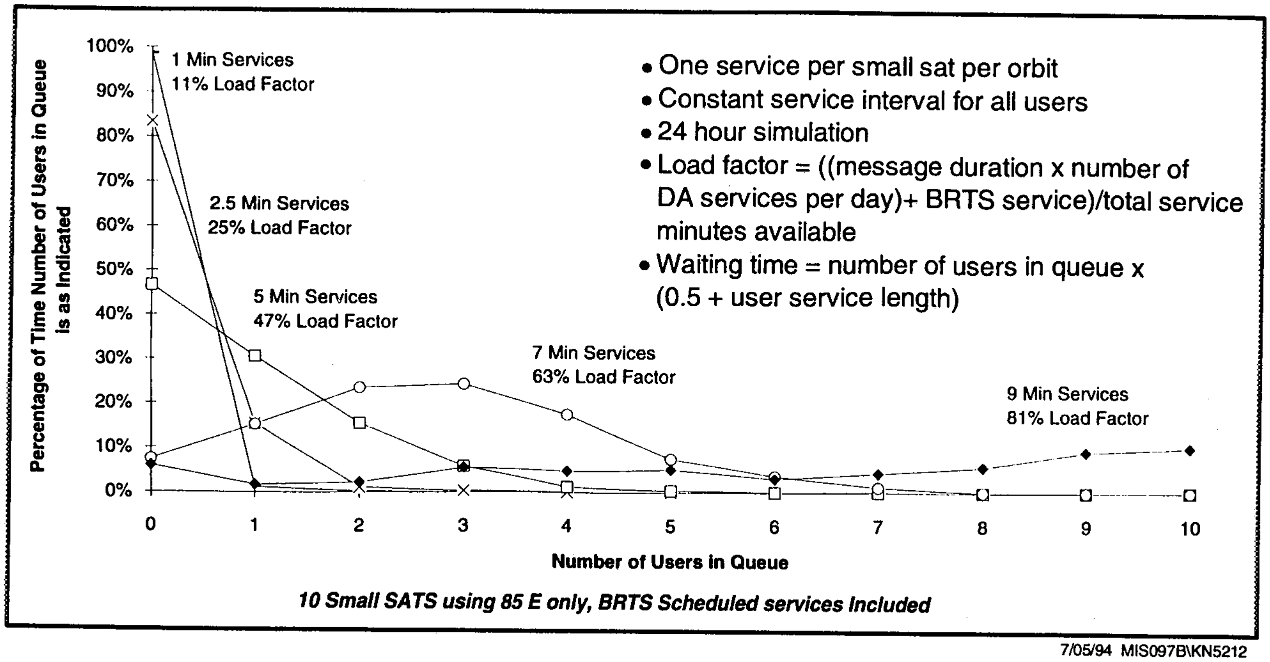

Figure 5: MAFDA Simulation Results

- Waiting time increases to a maximum of 15 minutes for 5 minute message duration per orbit.
- The queue grows unacceptably for message durations > 5 minutes, and instability occurs for message durations exceeding 8 minutes.

Additional simulation results were generated for DA services via 2 and 3 nodes, including results that combine scheduled and DA services per constellation node. General conclusions, to date, include:

- High DA service satisfaction and extremely short waiting times are achievable, even for a significant user population, subject to a reasonably designed DA operations concept; e.g.,
  - One POCC message per unit orbit.
  - Message duration on the order of 2 - 5 minutes, with larger durations acceptable if more than one TDRS node allocated to DA.
- Load factor determines DA performance, regardless of number of nodes allocated to DA.
  - Negligible waiting time for ≤ 25% load factor.
  - Maximum weighting time increases to ~ 3 x message length for load factor ~ 50%.
  - Instability occurs for load factor > 75%.
- Dedication of node(s) to DA leads to slightly higher satisfaction with reduced operational flexibility, than integration of scheduled and DA users on a node.

4.0 MA RETURN DEMAND ACCESS (MARDA)

For the MA RTN link, all 30 elements of the phased array are employed, and a unique ground-based beamforming capability is applied to enable support of many users simultaneously; the formed-beam G/T is on the order of 0 dB/°K, which supports at least 1 - 2 kbps data rate for a user EIRP of ~7 dBW. The current baseline, for operations with the new Second TDRSS Ground Terminal (STGT), is simultaneous support of 10 users. To be noted, however, is that this can be greatly expanded via utilization of additional ground-beamformers. As such, the MA RTN capability **is not a scarce resource**, and considerable operational flexibility is achievable.

As part of the Code 531 study activity, two primary candidate MARDA concepts have been examined to date. The first of these concepts is illustrated in Figure 6a. To accommodate random access return link user transmissions, each user is continuously covered by a dedicated, dynamically steered TDRSS MA RTN antenna beam. A key requirement in this approach is that enough beamformers and demodulators are available at WSC. Since WSC equipment chains are dedicated to each TDRSS node, the possibility of an uneven distribution of users among the TDRSS nodes means that the total number of needed beamformers/demodulators exceeds the number of MARDA users. Simulations to date have indicated that 10 to 11 beamformer/demodulator combinations per each of three TDRSS nodes are

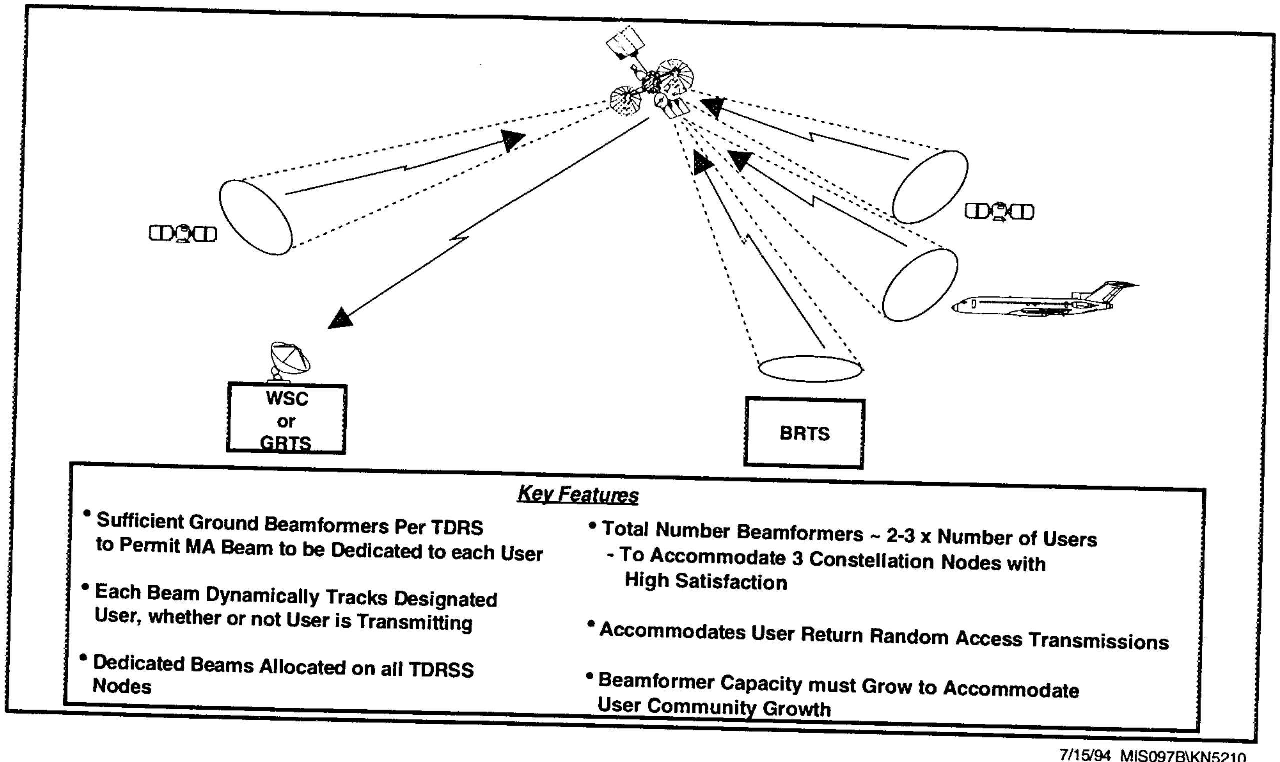

Figure 6a: Candidate MARDA Approach 1 - Dedicated MA RTN Beams

required to assure continuous coverage of all MARDA users for the stressed mission model previously described (7 nominal users plus 10 new small-sats). This quantity of MA beamformers/demodulators approximately reflects the baseline STGT/WSGT capacity, but MA augmentation would be required for the site supporting the 85°E node. Clearly, however, additional MA augmentation would be required for larger user populations and/or users that are more "stationary" in nature than spacecraft. However, with limited user data rates and the rapidly advancing state-of-the-art in communications technology, the cost of such beamformer/demodulator combinations may be kept within acceptable bounds.

By keeping an MA RTN antenna beam centered on each user, the users are assured the full MA RTN G/T during MARDA operations. The corresponding operational complexity is the need for dynamic MA antenna steering and dynamic receiver configuration at WSC to account for both user dynamics and handovers between the TDRSS nodes. Associated operational assessments are in progress.

The second approach to MARDA implementation is illustrated in Figure 6b. The approach uses a set of stationary MA RTN beams at WSC to cover the field-of-view of each TDRSS node. A set of low-rate demodulators is provided for each beam, with each demodulator matched to a user-unique PN code. Each such demodulator is always available to acquire and demodulate a user's transmissions as it passes from beam to beam. As in the first approach, full random access transmissions by TDRSS users are supported. However, unlike the earlier architecture, no prior knowledge of user position or dynamic MA antenna steering are required. But note that a user does not achieve the full TDRSS MA RTN boresite antenna G/T if it is near the edge of one of the fixed beams.

Analyses to date have indicated that a pattern of 19 beams per each of three TDRSS nodes can be used to provide near full-time coverage of TDRSS users as illustrated in Figure 7. The beamwidth used in this Exhibit is 4.34° -- achieved using defocusing of the TDRSS MA RTN array which has a normal beamwidth of ~3.2°. The number of beams per TDRS is approximately doubled if the 3.2° beamwidth is desired. Array defocusing is at the cost of some loss in TDRSS MA RTN G/T performance; the cost and performance trades between the number of needed MA RTN beams and the potential for TDRSS array defocusing, is continuing to be addressed.

Figure 8 illustrates a candidate implementation of this second MARDA approach -- showing the bank of low-rate demodulators associated with each of the

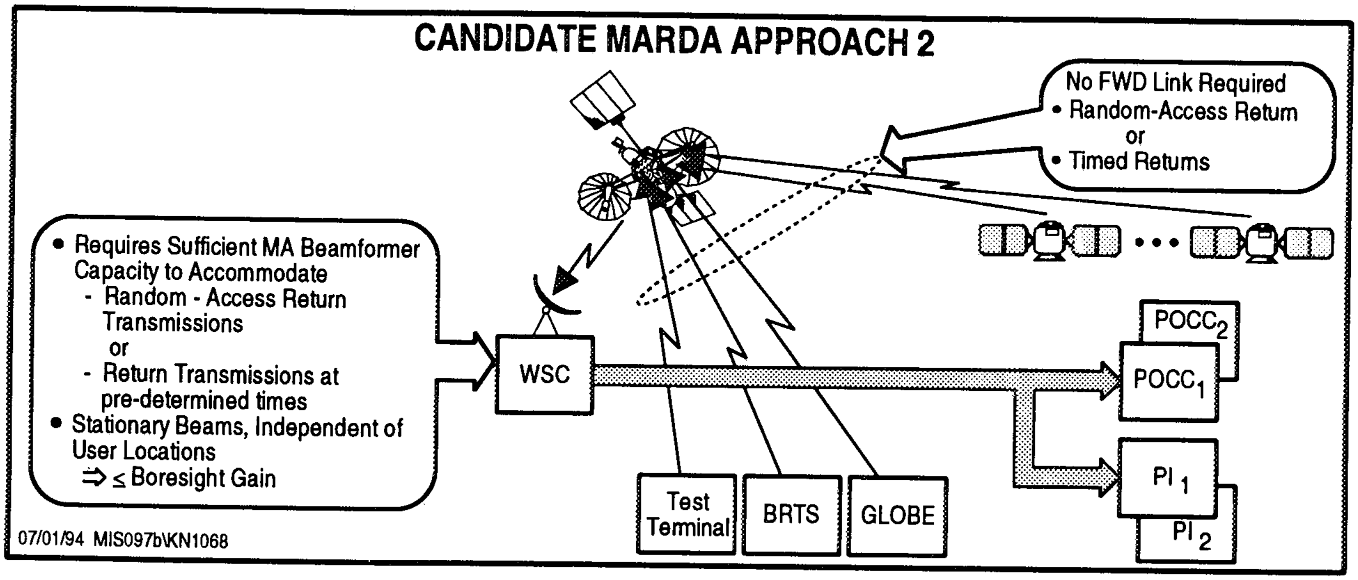

Figure 6b: One-Way MA Return

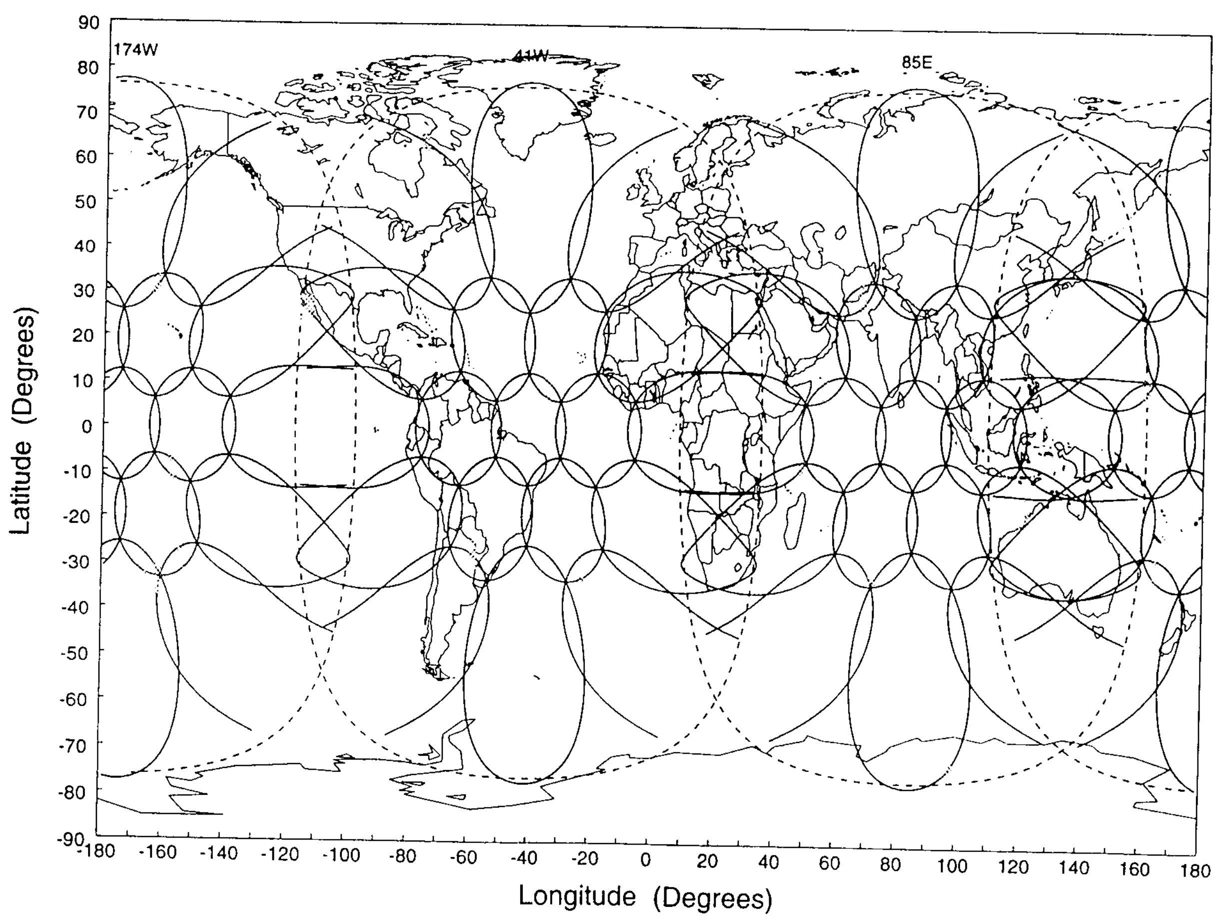

Figure 7: TDRS MA Return Beams on the Surface of the Earth; Earth Coverage Pattern TDRS Elevation Mask: 5 Degrees, Inclination: 0 Degrees, Beamwidth: 4.34 Degrees

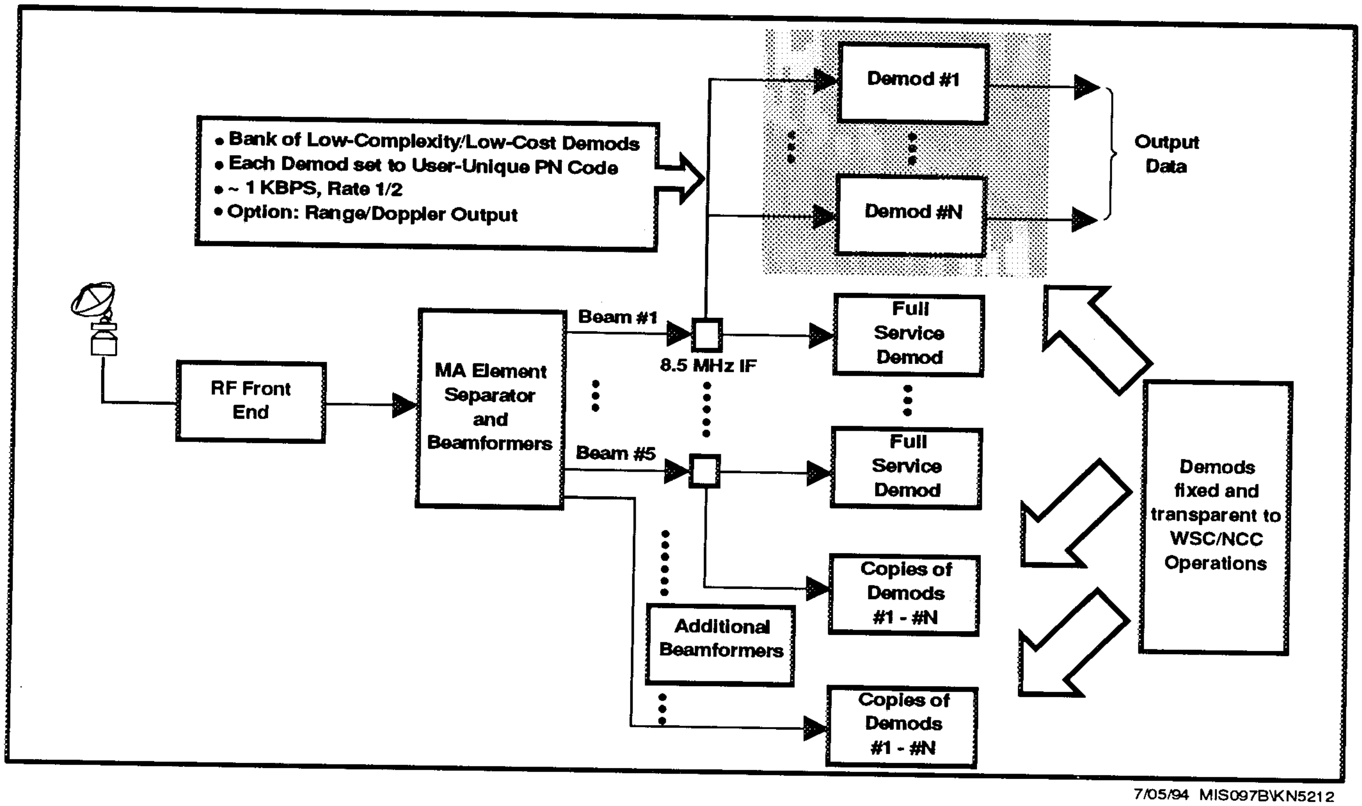

Figure 8: Candidate WSC/GRTS MARDA Augmentation

fixed MA RTN beams. Because the number of beamformers is fixed and independent of the number of TDRSS users, the architecture has the potential to provide service to a very large number of TDRSS MA users with only the addition of demodulators needed to add new users. As long as user data rates are kept low (i.e., on the order of a few kbps), self-interference among the CDMA users can be kept negligible. Based on advancing technology, beamformer and demodulator size and cost can be kept low, and this represents an active area for examination.

While this second MARDA approach is oriented towards support to a larger DA user community, it also offers the opportunity to provide DA TDRSS services to new user types not previously considered. For example, the use of fixed MA RTN beams which cover Earth means that an appropriate user on the surface of the Earth could obtain TDRSS return service on demand regardless of location. Such service could greatly benefit geographically dispersed sets of low data rate users. One such example is the GLOBE Program -- a U.S. Government initiative to establish an international partnership for environmental monitoring by students on a worldwide basis. In its initial phases, the GLOBE Program will use a limited set of fixed TDRSS MA RTN beams to demonstrate transfer of science data between remotely located students and science processing centers. Such a set of users is entirely consistent with this implementation of the MARDA architecture.

5.0 SUMMARY AND OBSERVATIONS

In Section 2.0, the concept of "ideal" user demand access service was defined as service initiation whenever desired, with no NCC scheduling, and little or no contention for service with other users. As described above, innovative application of the TDRSS MA forward and return service capability appears well suited to providing near ideal demand access services to low-rate TDRSS users. The approaches for implementing forward and return DA service have the key advantage of not requiring changes in the user transponder implementation or in the existing constellation of TDRSS satellites.

On-going GSFC Code 531 activity is oriented towards detailed examination of the relative merits of each of the available service options described above. In particular, the operational and implementation impacts associated with each approach are currently being addressed. It is expected that the current effort will lead to definition of a candidate demand access capability that provides both enhanced service to the TDRSS user community while at the same time simplifying Space Network operations.