MULTI-BAND INTEGRATED SATELLITE TERMINAL (MIST) - A KEY TO FUTURE SOTM FOR THE ARMY -

Gary Comparetto
Principal Engineer
The MITRE Corporation
(703) 983-6571
garycomp@mitre.org

Bill Hall
Senior System Engineer
PM MILSATCOM
(732) 532-7316
bill.hall@c3smail.monmouth.army.mil

ABSTRACT

The Army's communications capability must keep pace with the evolution of a globally deployable Joint Task Force (JTF) and force projection Army, while supporting forced entry and contingency operations. The warfighter must have the freedom and flexibility to move quickly on the battlefield using a communications terminal that is tactically responsive, mobile, interoperable, and provides SATCOM-on-the-move (SOTM) and SATCOM-on-the-pause (SOTP) capability.

PM MILSATCOM is helping to define this next-generation ARMY SATCOM terminal that is referred to as the Multi-Band Integrated Satellite Terminal (MIST) and is currently scheduled to be fielded in several phased out to 2014. In so doing, PM MILSATCOM initiated several studies to better define the MIST program, help formulate the acquisition strategy, validate the MIST funding schedule, and to initiate Government cost estimates for the MIST program. The purpose of this paper is to summarize the key findings of the study performed by the MITRE Corporation in support of PM MILSATCOM. Our focus here is to summarize the notional terminal architecture design options postulated in that study, and to identify the key technology areas that need to be advanced in order to ensure successful operation of the MIST terminal.

INTRODUCTION

A technology-driven approach was applied in this study, using 2006 as the cut-off date. However, we also took into account anticipated operations of the MIST terminals when formulating our terminal design alternatives based on the ARMY's desire to move to a network centric communications infrastructure.

Six primary design drivers were applied in this study including ; (1) weight/size *(we assumed the MIST terminal must not exceed weight/size requirements of a HMWWV)* , (2) risk *(measured with respect to technology and cost)*, (3) frequency band of operation *(the full set considered includes C, X, Ku, Ka, and EHF)*, (4) SOTM capability *(assumed in all design alternatives)*, (5) achievable data rate - ADR *(a different "required" ADR was applied for SOTM and SOTP operations)*, and (6) cost *(clearly, MIST terminal design concept alternatives must be affordable)*.

NOTIONAL MIST TERMINAL DESIGN CONCEPT ALTERNATIVES

We determined that the MIST terminal should be developed with a "family of terminals" concept in mind. That is, we wanted to identify a minimal set of equipment "building blocks" that could be combined in a variety of ways to meet several categories of high-level operational requirements. The building bocks can then be used to help analyze the trade-offs between a requirements-driven approach and a technology-driven approach and can also be used to support a Cost as an Independent Variable (CAIV) study.

Three terminal categories were identified in this study. The Category A terminal design concept alternatives were formulated with the goal in mind of supporting upper echelon WINT-T Node/TOC range extension, although other operational scenarios would also be supportable. For this category, the terminal design concept alternatives support both SOTM and SOTP operations, non-simultaneously, using two separate antennas providing connectivity into two separate networks. Category A terminals are the largest of the three categories identified. It was assumed that Category A terminals would be HMMWV-mounted, with the full vehicle space and power available to support MIST terminal operations. The target achievable data rates used in developing the Category A design alternatives were 10 Mbps (minimum) for SOTP operations and 128 kbps (minimum) for SOTM operations.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE
Multi-band Integrated Satellite Terminal (MIST) - A Key to Future SOTM for the Army-

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
MITRE Corporation,7515 Colshire Drive,McLean,VA,22102-7539

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Note that these are "target" (or "threshold") ADRs; in most cases the design concept alternatives support ADRs much higher than the minimum target values identified.

The Category B terminal design concept alternatives were formulated with the goal in mind of supporting maneuver range extension for Bde and Bn level TOCs, although other operational scenarios would also be supportable. For this category, the terminal design concept alternatives support both SOTM and SOTP operations, non-simultaneously, using a *single* antenna providing connectivity to a *single* network. It was assumed that Category B terminals would be vehicle-mounted, with only part of the vehicle's space and power available to support the MIST terminal. The target achievable data rates used in developing the Category B design alternatives were 2.5 Mbps (minimum) for SOTP operations and 128 kbps (minimum) for SOTM operations.

Finally, the Category C terminal design concept alternatives were formulated with the goal in mind of supporting lower Tactical-Internet (TI) range extension, although, as with the Category A and B terminals, other operational scenarios would also be supportable. For this category, the terminal design concept alternatives support both SOTM and SOTP operations, non-simultaneously, using a single antenna providing connectivity to a single network. It was assumed that Category C terminals would be vehicle-mounted, with only part of the vehicle space and power available to support the MIST terminal. The target achievable data rate used in developing the Category C design alternatives was 128 kbps (minimum) for both SOTP and SOTM operations.

We developed a baseline terminal design concept for each of the three terminal categories defined previously. We then formulated a number of design iterations for each terminal category by varying one or, at most, two easily definable design parameters. The design parameters were chosen carefully based upon our understanding of the key trade-offs that might be made in formulating the final MIST terminal design.

The *Terminal Design Concept A: Baseline* is shown in Figure 1 and supports full-mesh, two-way communications using FDMA for both SOTP and SOTM operations, non-simultaneously, supporting up to 8 simultaneous accesses (or channels). Separate networks are assumed for both SOTP and SOTM operations. The 2.4 meter dish supports an achievable data rate (ADR) of 34 Mbps per terminal while the .3 meter dish supports a an ADR of 8.5 Mbps per terminal. For this configuration, the ADR scales as (8/n)*ADR for operational scenarios in which "n" simultaneous accesses (or channels) are desired (where "n" is greater than 8). Each access can be further divided using TDMA techniques with the Network Control Function required to control the access allocations.

The antenna segment for the *Terminal Design Concept A: Baseline* includes a 2.4 meter, off-set feed, parabolic dish antenna to support SOTP operations using an Inertial Navigation System (INS) for pointing. Additionally, a .3 meter, off-set feed, parabolic dish antenna is used to support SOTM operations using a closed-loop pointing system. The closed-loop pointing system to support SOTM operations in rugged terrain is identified as a technology challenge.

The RF segment for the *Terminal Design Concept A: Baseline* includes the full range of frequency bands being considered - C, X, Ku, Ka, and EHF. Notice that there is a separate equipment chain for each frequency band that includes the antenna feed, a diplexer, a low noise amplifier (LNA), a high power amplifier (HPA), and an up/down converter. Furthermore, there is a separate Ka-band equipment chain shown to support SOTM operations using the .3 meter dish antenna.

In the baseband segment, a single FDMA modem is used to support all frequency bands, except EHF, in support of SOTP operations. The FDMA modem would include one modulator and "n-1" demodulators where "n" is the number of *simultaneous accesses* supported. A Network Interface unit is shown that would serve as the "brains" of MIST terminal communications. This unit would have the capability of routing data to/from the local host LAN resident on the MIST terminal, remote fixed or mobile assets via SATCOM, remote fixed assets locally situated via an external LAN cable, and remote mobile assets via a separate RF communications system.

Eight design iterations were also investigated for the Category A terminals - A1 through A3 were applicable to the SOTP portion of the MIST terminal design, while A4 through A8 were applicable to the SOTM portion of the design. In each case, the iteration is a "delta" to the baseline terminal design concept A.

- *A1*: C-band operations is eliminated from the design
- *A2*: Both C-band AND EHF operations are eliminated from the design
- *A3*: Support X-band and Ka-band operations, simultaneously, for SOTP
- *A4*: Use a single TDMA access instead of 8 simultaneous FDMA accesses for SOTM
- *A5*: Employ a hub-spoke configuration instead of a full-mesh design for SOTM
- *A6*: Use spread spectrum versus FDMA for SOTM

- *A7*: Support receive-only SOTM operations
- *A8*: Use phased array antenna versus a parabolic dish for SOTM

The *Terminal Design Concept B: Baseline* is shown in Figure 2 and supports full-mesh, two-way communications using FDMA for either SOTP or SOTM operations, supporting up to 8 simultaneous accesses (or channels). The baseline design can support an achievable data rate (ADR) of 8.5 Mbps per terminal with a .3 meter dish antenna. For this configuration, the ADR scales as (8/n)*ADR for operational scenarios in which "n" simultaneous accesses (or channels) are desired (where "n" is greater than 8). Each access can be further divided using TDMA techniques with the Network Control Function required to control the access allocations.

The antenna segment for the *Terminal Design Concept B: Baseline* includes a .3 meter, off-set feed, parabolic dish tracking antenna. The closed-loop pointing system to support SOTM operations in rugged terrain was identified earlier as a technology challenge. The RF segment for the *Terminal Design Concept B: Baseline* includes a self-contained Ka-band equipment chain comprising the antenna feed, a diplexer, a low noise amplifier (LNA), a high power amplifier (HPA), and an up/down converter.

The baseband segment includes an FDMA modem having one modulator and "n-1" demodulators where "n" is the number of *simultaneous accesses* supported. A Network Interface unit is also shown in the baseband segment, similar to the one described for the *Terminal Design Concept A: Baseline*.

The *Terminal Design Concept C: Baseline* is shown in Figure 3 and supports full-mesh, two-way communications using spread spectrum CDMA techniques to support non-simultaneous, SOTP and SOTM operations, supporting up to 8 simultaneous accesses (or channels). The baseline design can support an achievable data rate (ADR) of 128 kbps per terminal with a small conformal phased array antenna. *Note that the key differences between the "C" and "B" baseline terminals include the type of antenna (phased array versus parabolic dish), the type of channel access scheme (DSSS versus FDMA), and the level of external connectivity.* For "C" terminal configuration, the ADR scales as (8/n)*ADR for operational scenarios in which "n" simultaneous accesses (or channels) are desired (where "n" is greater than 8).

The antenna segment for the *Terminal Design Concept C: Baseline* includes a conformal phased array antenna. The transmit portion includes 630 elements packaged in an 8 inch diameter circular footprint, providing 25 dB gain. The receive portion includes 85 elements packaged in a 4.5 diameter footprint, providing 16.5 dB gain. The angular coverage, based upon scan angle limitations, is 120° to 140°. Note that this design concept would not be feasible if a greater angular coverage is required. This is due to the fact that a pedestal and tracking system would be needed which would go against the original intent of this category - *simplicity and a small antenna footprint*.

The RF segment for the *Terminal Design Concept C: Baseline* includes a self-contained Ka-band equipment chain comprising the antenna feed, a diplexer, a low noise amplifier (LNA), a high power amplifier (HPA), and an up/down converter. The transmit power required to support 128 kbps is 380 W. Ku-band operations could readily be added to this terminal design category.

The baseband segment includes a direct sequence spread spectrum (DSSS) modem having one modulator and "n-1" demodulators where "n" is the number of *simultaneous accesses* supported. Spread spectrum techniques are applied here to circumvent potential ITU Earth terminal transmission limits. A Network Interface unit is also shown in the baseband segment that would route data to/from the local host LAN resident on the MIST terminal. This unit is much less complex than the unit identified in the Category A and B terminal design options since there is no MIST-external connectivity other than SATCOM for the Category C terminal design option.

KEY TECHNOLOGY AREAS

The SOTM requirements are drivers for much of the design, however there are many different facets that are important. We will examine the key areas and discuss them.

The antenna technology of the future appears to be phased array since it can electronically track the signal without mechanical motion and can transmit multiple independent beams. However, besides cost, there are several drawbacks to phased array. Scanning is limited to +/- 60 to 70 degrees with sidelobes that increase with scan angle. Plus the bandwidth is limited to 5-10% with full scan due to grating lobes resulting from elements spaced too far apart for the scan angle.

For power amplifiers in non-phased array solutions, there are two separate issues. For SOTM, a gimbaled dish will require the power amplifier and up/down conversion to be mounted on the moving dish. For small dish sizes, this will result in smaller amplifier sizes. The overall problem is that the small terminal will require considerable satellite resources. For the non-SOTM applications, a TWT versus SSPA trade must be made. The power out tends to favor the TWT, while packaging (size and weight) and graceful degradation are pluses for SSPA. Reliability is an important factor that needs to be researched closely to determine which will perform better in this timeframe.

Network protocols will be important in any new terminal. The design must be flexible so it can be changed since networking protocols continue to evolve. Studies currently in progress for the SCAMP block II indicate that Enhanced TCP, TCP for Transactions, SACKS and Large windows are favored for the transport layer for Unicast while RMTP-II and PGM are favored for Multicast. At the network level, Distance Vector and DSR are recommended for Unicast while FGMP and PIM-DM are most suitable for Multicast. At the media access level, DAMA, DPRMA, USAP, and DAMAN were selected. For the transport level, the protocol must have a unique congestion control mechanism and a large re-transmission timeout.

Waveform issues are complicated by the fact that we don’t know if we will be processed or transponded, how large networks will need to be, and what kind of connectivity will be needed. FDMA with a DAMA TDMA is a trend while CDMA is also popular. Modulation type will be determined by the available spectrum and military AJ requirements. Higher order modulations are the trend as higher power is available on the satellite and bandwidth is limited. Turbo codes can be used to improve BER at low S/N and help overcome ITU transmit power density limitations by spreading the transmitting signal. The drawback is that it extends the already high delays associated with satellite communications.

Size and weight are major factors in MIST design. Category A terminals will need to fit on a HMMWV-like vehicle with the five bands required (assumes commercial and military Ka are different bands). Category C terminals will need to be lightweight and mounted on various vehicles.

CONCLUSIONS

There are still many unknowns associated with the MIST terminal and more definition and study are required. The results of this study give us a glimpse of the complex issues associated with MIST, but solidifies the basic concept and resolves some issues. Satellite communications on-the-move is a definite requirement for the near future and the first step is contained in this study.

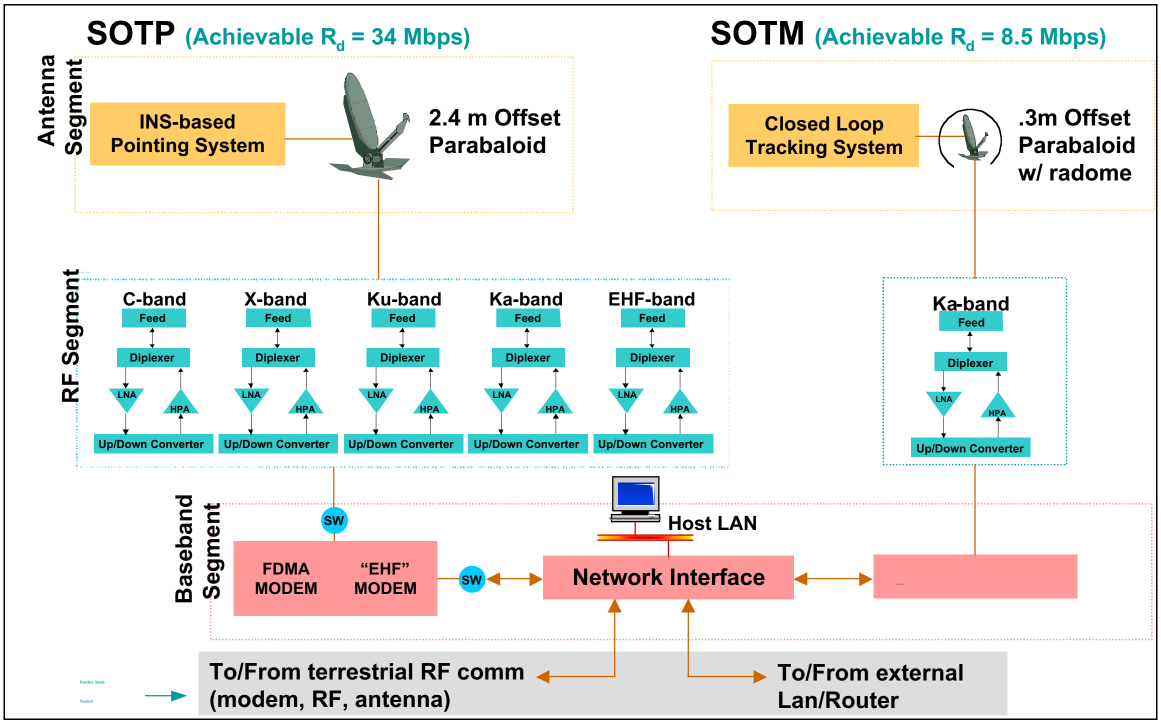
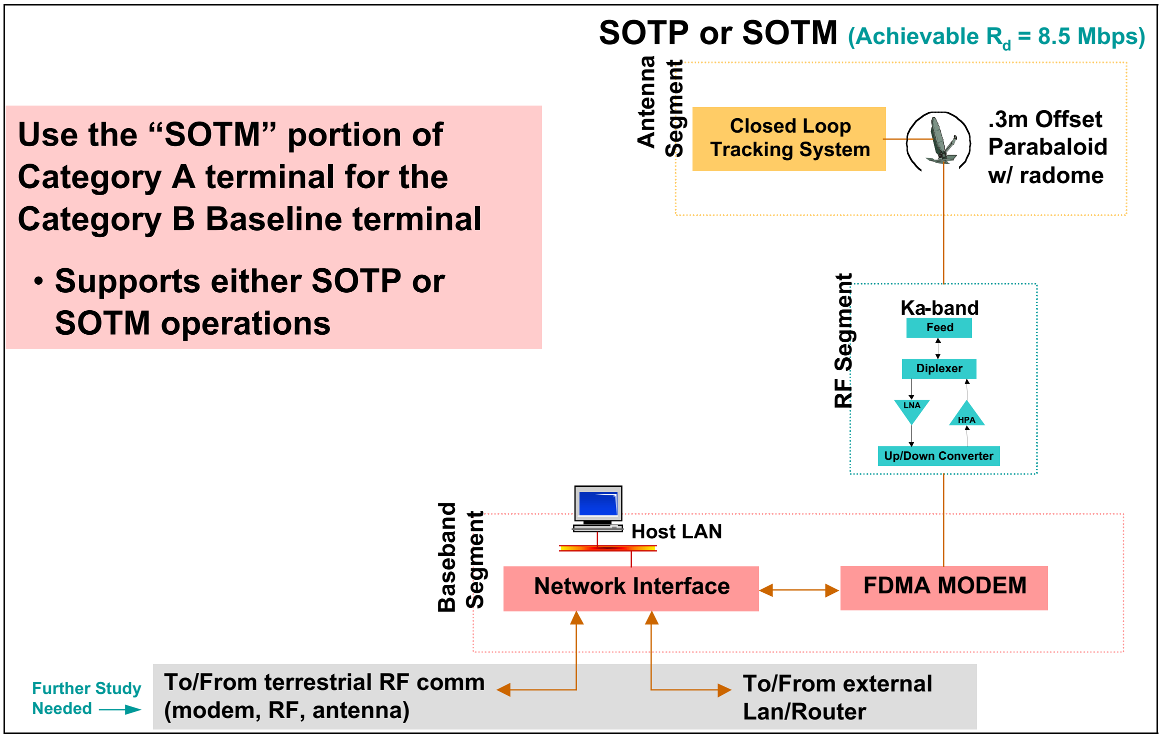


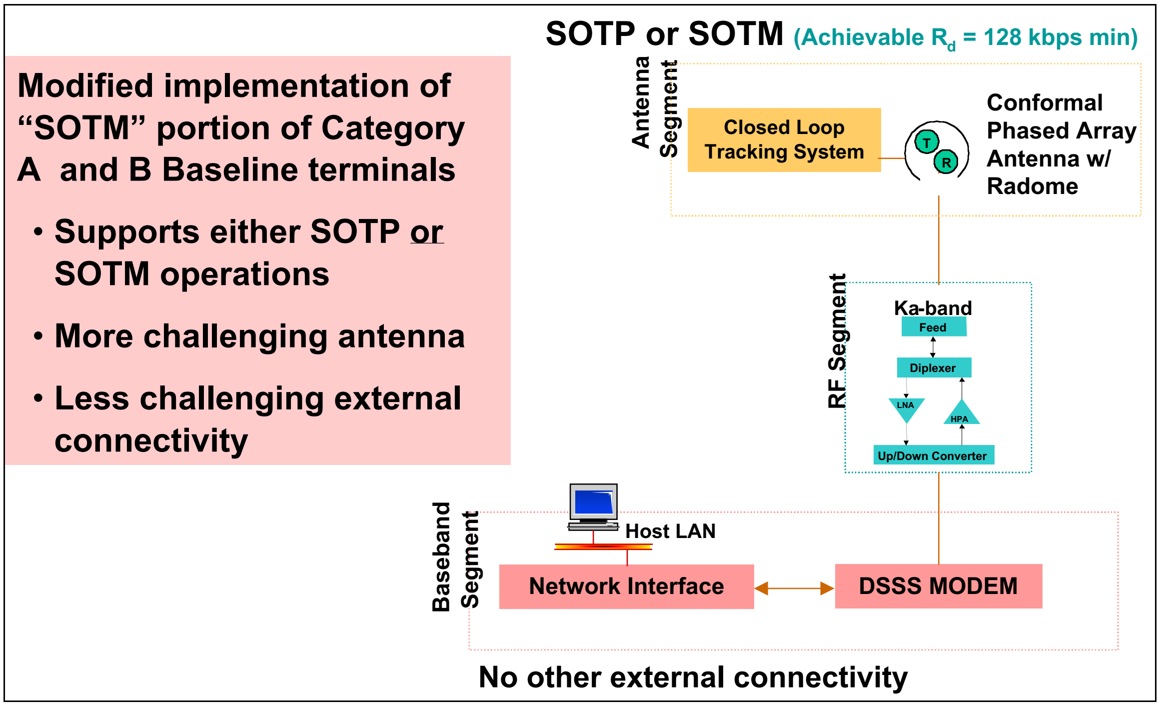
Figure 1: Functional Block Diagram of *Terminal Design Concept A: Baseline*



Use the "SOTM" portion of Category A terminal for the Category B Baseline terminal

- Supports either SOTP or SOTM operations

Figure 2: Functional Block Diagram of *Terminal Design Concept B: Baseline*



Modified implementation of "SOTM" portion of Category A and B Baseline terminals

- Supports either SOTP or SOTM operations
- More challenging antenna
- Less challenging external connectivity

Figure 3: Functional Block Diagram of *Terminal Design Concept C: Baseline*