Distributed SATCOM On-The-Move (SOTM) Terminal Open Standard Architecture

Tat Fung, Jeff Hoppe, Syed Akbar, Tom Rittenbach, and Jenelle Vickberg

***Abstract*—The U.S. Army Communications-Electronics Research, Development and Engineering Center (CERDEC) is developing technology for a Distributed Satellite Communications (SATCOM) On-The-Move (SOTM) Terminal (DST). Army tactical vehicles are increasingly crowded with many combat and communications systems. The concept of distributed terminals has been developed to address vehicle integration problems, with the premise that SOTM systems consisting of several smaller components will present fewer integration issues. These system components are distributed around the vehicle as space and function dictate. The development of open standard architecture (OSA) for DSTs will enable flexible engineering design and integration of diverse technologies to realize these systems. Furthermore, OSA will enable competitive acquisition of system components to reduce acquisition and life-cycle costs, and will enable faster fielding of incremental and innovative solutions.**

***Index Terms*—antenna, distributed, modular, open architecture, SATCOM, standards, terminal.**

I. Operational Concept

The current U.S. Army Satellite Communications (SATCOM) On-The-Move (SOTM) terminal consists of a mechanical gimbaled dish antenna and an integrated control unit mounted on top of the vehicle (Fig. 1). This results in a large visual signature due to the large antenna profile, which increases the vulnerability of the platform as a battlefield target. Additionally, most turreted combat platforms cannot accommodate large profile terminals due to the movement of the turret. The traditional antenna also poses inherent challenges in performance, as it is blocked by collocated obstructions such as the turret, and risks to personnel safety when the antenna radiates toward the on-vehicle crew who operate protruding from the vehicle hatches.

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Fig. 1. Current SOTM vehicle integration concept.

The Distributed SOTM Terminal (DST) is designed to distribute the antenna into several apertures around the vehicle to mitigate vehicle integration issues. The distributed aperture terminal is envisioned to consist of a flat-panel electronic antenna with a lower visual signature. Both the distribution and profile of the components will reduce interference with turret and gun operation. Antennas will be mounted on multiple sides of the vehicle and will radiate away from the vehicle to mitigate personnel safety risks and to eliminate satellite blockage from obstructions on the vehicle. Some of the key benefits of the distributed aperture terminal are as follows:

- Lower profile antenna designs;
- No satellite view blockage from gun turret, vehicle heading, or cargo on top of vehicle;
- Smaller components with flexible integration;
- Reduced radiation hazards to on-vehicle personnel.

The DST operational concept is depicted in Fig. 2.

The DST terminal will typically use low form factor antennas such as flat-panel phased arrays. The intended advantage of this is to increase the available mounting locations of the antennas. Fig. 2 (*left*) shows one transmit antenna and one receive antenna on each side of the vehicle. Separate antennas for transmitting and receiving are typically necessary for phased array antennas. The DST will receive the satellite signal by combining signals from any antennas that receive the signal. Fig. 2 (*right*) depicts a case in which two antennas receive the signal, and the system combines the signals prior to the modem. The coherent signal will be ~3 dB higher than the signal obtained from any singular antenna in

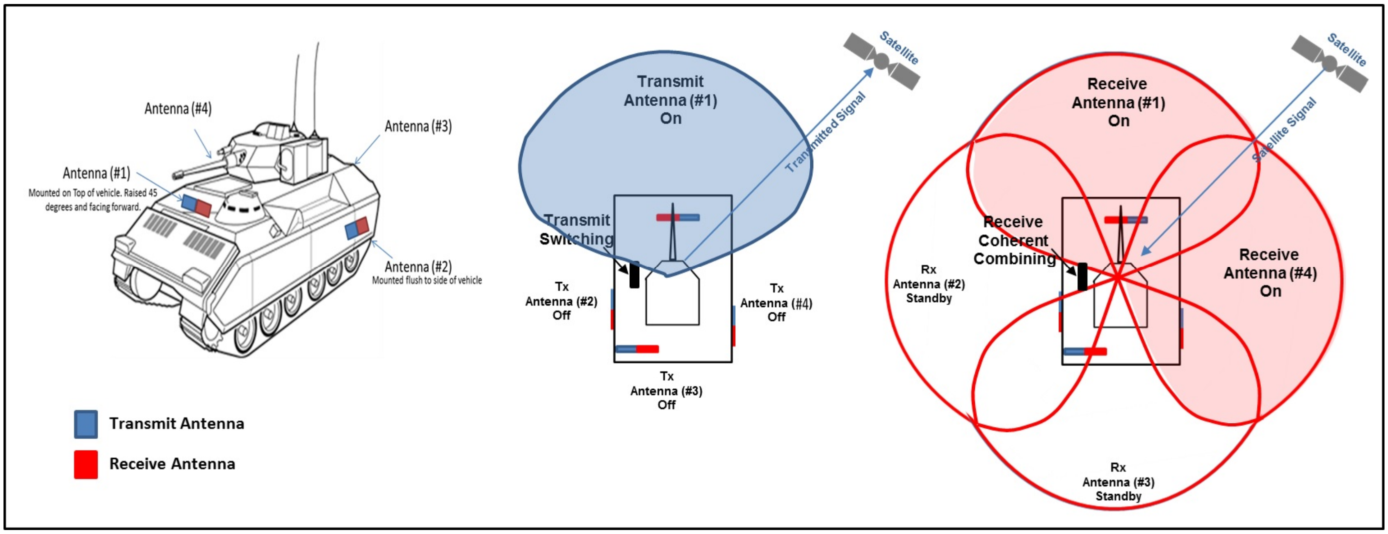

Fig. 2. DST operational concept.

the transition regions and will aid in providing a consistent receive performance at all angles around the vehicle.

The DST will transmit to the satellite by using a switch (Fig. 2, *center*). While it would be advantageous to use multiple antennas to transmit, similar to the receive concept, off-axis grating lobes are a major issue during transmission because they can cause adjacent satellite interference. To switch antennas, the proper transmit antenna is first selected by the system, and then the switch is conducted in the most efficient manner possible.

II. DST OSA Consortium

The DST Open Standard Architecture (OSA) Consortium was established under a U.S. Army Communications-Electronics Research, Development and Engineering Center (CERDEC) research and development program called Distributed/Embedded Standard SOTM Terminal Architecture (DESSTA). DST OSA Consortium members include a CERDEC government team, as well as individuals from U.S. government agencies, industry, professional associations, and academia, as appropriate. Currently there are 10 industry members working under Collaborative Research and Development Agreements (CRADAs) with CERDEC. Consortium member companies are listed in Table I.

The mission of the DST OSA Consortium is to develop an open system/standard architecture for distributed SOTM terminals. The aim is to increase competition among SATCOM developers by allowing for the development of competitive products delineated by open interfaces defined in the architecture. Each system component will ideally be compatible, interoperable, and interchangeable, allowing for uniform test and evaluation, speedy integration into systems of systems, and rapid fielding of incremental system improvements. This interoperability will objectively reduce the engineering and development cost for a family of tactical SOTM systems, speed acquisition and fielding, and enable more acquisition competition at the system component level. It is expected that this will also reduce system life-cycle cost for

TABLE I
DST OSA Consortium Members

Member Company	Point of Contact
Alico Systems, Inc.	Syed Akbar
Ball Aerospace & Technologies Corp.	Wes Pickens
FIRST RF Corp.	Tim Meenach
General Dynamics	Stuart Williams
Harris Corp.	Tom Saam
L-3 Linkabit	Dave Leung
Mercury Systems	Brian Kimball
Northrop Grumman Corp.	John Featherston
ThinKom Solutions, Inc.	Bill Milroy
Toyon Research Corp.	Ryan Strader

the military and allow companies with the best solutions to increase market share. The DST OSA will use modular open systems architecture (MOSA) techniques to achieve a modular framework that allows for realization of platform agnostic, flexible, and robust DST systems. The DST OSA will be a U.S. government open-source product wholly owned, and initially managed, by the government.

DST OSA objectives are as follows:

- Establish a functional decomposition standard pattern for terminals, defining common integration layers.
- Develop a common system-level architecture that decouples hardware and software module dependencies to enable reuse.
- Decouple hardware and software dependencies, enabling efficient and innovative design and engineering of systems.
- Maximize opportunities for competition and cost reductions across all life-cycle phases.
- Foster collaborative development between government and industry.

- Protect industry's intellectual property rights.
- Enable integration of new capabilities through tech refresh or new program increment without significant terminal redesign.
- Support plug-and-play system integration of commercial off-the-shelf (COTS) and third-party module development efforts.

III. DST OSA

Fig. 3 illustrates a top-level overview of the modular architecture selected for all DST systems. The DST OSA comprises six components:

- System control unit (SCU);
- Signal processing unit (SPU);
- Antenna system;
- Installation kit;
- Vehicle external interface;
- Satellite air interface.

The interconnection interfaces between the six components will be defined in the DST OSA Architecture Definition Document (ADD). These interfaces will be specified via formal Interface Control Documents (ICDs), which will be nonproprietary and open to both the U.S. government and U.S. Department of Defense contractor communities.

Taking this architecture to the next level of abstraction will show the connectivity between these components and interfaces. Fig. 4 shows the top-level block diagram architecture of an OSA-compliant DST. Defined external interfaces reside on the left side of the diagram, and the satellite air interface is on the right. The core terminal is the central control unit of the DST; it provides connections to the external interfaces and controls the four (or more) antennas that are distributed on the vehicle. The boxes in the right-hand column are the distributed antennas. These antennas connect to the core terminal SCU via a digital signal over the control plane interface, and to the core terminal SPU via an analog signal over the signal plane interface.

IV. Architecture Component & Subcomponent Definition

The notional decomposition of the functional entities within each of the six components within a DST system is shown in Fig. 5.

The core terminal comprises both the SCU and SPU components. A key function of the SCU component is transmit antenna selection. This is accomplished without input from the modem so that the DST is modem agnostic. Instead, the SCU compiles the transmit antenna patterns at the system level and aggregates Global Positioning System (GPS) data, Attitude and Heading Reference System (AHRS) data, satellite ephemeris data, and antenna tracking data in real time to select the transmit antenna. Additionally, the SCU provides interface management, monitoring, and control functions for the DST at the system level. An Ethernet switch is incorporated in the

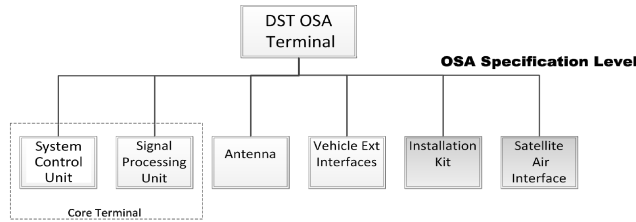

Fig. 3. DST top-level architecture.

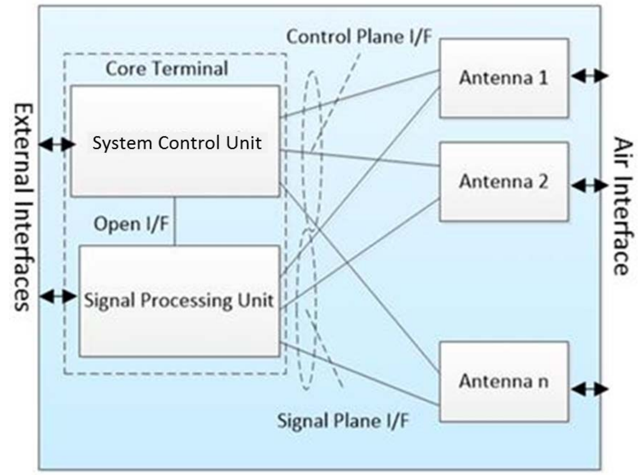

Fig. 4. DST OSA top-level block diagram architecture (I/F = interface).

core terminal to provide access to these interfaces. Other functions include the built-in test (BIT), timing and frequency, console server, and mechanical and power interfaces.

One of the signal processor's prime responsibilities is combining receive signals from multiple antennas that will have varying levels of performance at various look angles to the satellite. The combining function will smooth out the performance variation of the distributed antennas. Ideally, combining will provide seamless hemispheric performance of the antenna subsystem.

Each DST component consists of a number of subcomponents, which perform the various functions required of a SATCOM system. For example, the antenna receive adapter subcomponent provides a mechanism for adaptive power control so the dynamic range can be optimized for the terminal, while the receive signal conversion and digitization subcomponent digitizes the L-band signal so signal combining can be implemented.

The antenna component comprises the following: the receive and transmit radiating elements; up and down frequency converters to convert to and from radio frequency (RF), as well as to and from L-band intermediate frequency (IF); antenna control; a beam stabilization unit to compensate for antenna-specific vibration or movement; BIT; and mechanical and power interfaces.

The installation kit component provides the vehicle-specific cables, mechanical mounting adapters, and connectors needed to install the DST OSA terminal on a vehicle.

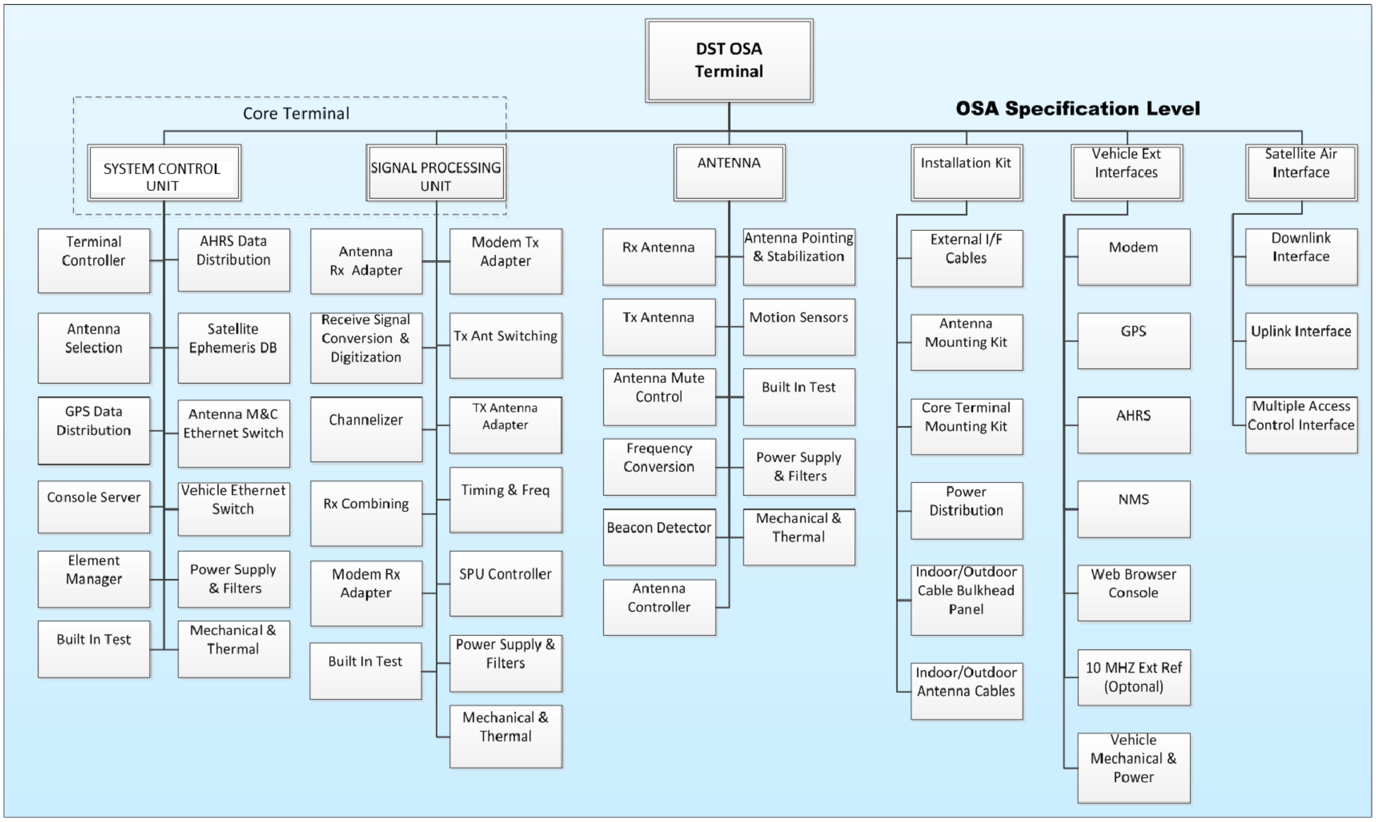

Fig. 5. DST OSA top-level functional block diagram architecture (DB = database; M&C = management and control; NMS = network management system; Rx = receive; Tx = transmit).

The vehicle external interface component includes all external vehicle devices that need to interface with the DST OSA terminal, including the modem, GPS, AHRS, network management system, console, and vehicle mechanical and power.

Lastly, the satellite air interface specifies the operation of the DST OSA terminal over the specified satellite.

V. System Views

To illustrate the required system interactions of the modular architecture and guide but not constrain the DST OSA component developer, a series of highly detailed system views have been included in the DST OSA ADD. A view is defined as a compilation of subcomponents with functions or processes that interact with a specific, integrated purpose. A view describes, defines, and derives the requirements and functionality of the system, components, and logical interface inputs and outputs; views also provide a reference architecture solution for the integrated purpose. Views illustrate the reference design and included rules and recommendations for implementation. Rules are requirements, whereas recommendations are suggestions for the component developer. The following list provides a brief description of the primary DST OSA views.

DST OSA Built-In Test (BIT) View: The purpose of the BIT within the DST OSA terminal is to monitor and report on the overall health and status of all terminal components.

DST OSA Monitor Power Usage View: The power monitor usage (PMU) function is responsible for monitoring the terminal's power usage and powering down or idling DST OSA antennas, as necessary, to minimize the DST OSA terminal's overall power usage.

DST OSA Pointing and Tracking (P&T) View: The P&T view describes the means by which each of the distributed DST antennas performs its P&T functions.

DST OSA States and Modes View: The states and modes view describes the operations of the DST OSA terminal and its various states and modes.

DST OSA Distribute Time and Positional Data View: The distribute time and positional data view describes the means by which the DST core terminal distributes and utilizes platform time and positional data information.

DST OSA Terminal Operation View: The terminal operation view explains the operations of the DST OSA terminal and its progression as it transitions through its various states and modes, from powering on, through SOTM operations, and finally through terminal shutdown.

DST OSA Tx, Rx Antenna Selection View: The transmit antenna selection (TAS) process provides information to the terminal's SPU, directing which of the four distributed transmit antennas should be selected for satellite transmissions. The receive antenna selection (RAS) process allows the receive combining process to select which of the distributed receive antennas are to be utilized for receive combining.

VI. Component Emulators

To facilitate rapid validation of the interface definitions defined in the DST OSA specifications, a family of open-source emulators is being developed that emulates the SCU, SPU, and antenna component control interfaces. These DST OSA emulators exercise the primary control interfaces by passing a series of DST OSA-compliant packets between the SCU, SPU, and antenna emulators via the Internet Protocol (IP) Ethernet interface. Packets can be captured via Wireshark to validate that the interface is in compliance with the DST OSA ADD ICDs. These open-source emulators will accelerate and simplify the process of developing and validating DST OSA-compliant components by providing a “gold standard” for interface validation that can be used independently at the component developer’s worksite.

VII. MOSA

Future SATCOM terminals are going to be developed embodying the MOSA approach. The MOSA approach requires that the system design be modular and have well-defined interfaces, preferably with commonly used industry standards. This is a viable business strategy for the development of today’s SATCOM terminal, as it results in quick and affordable development. The development needs to leverage commercial products from multiple sources and commercial sector investment in new technology and products. DST OSA provides MOSA architecture for a particular class of SATCOM terminals that use distributed communications and on-the-move antennas with coherent combining. The development approach needs to design an open system that results in an adaptable and affordable system. The effectiveness of a MOSA implementation is guided by the major principles of MOSA:

- Establish and enable business and engineering practices that ensure successful development and implementation of an open architecture for the system.
- Employ modular design tenets that partition functionality into discrete, cohesive, and self-contained units with well-defined interfaces.
- Designate common key interfaces between system modules that provide access to critical information or services.
- Leverage open standards by conducting ongoing market research and selection for those standards that are common and developed by consensus-based standards bodies.
- Verify certification of conformance to the selected standards to ensure that the modules interface and function together properly.

Following these MOSA principles, the DST OSA will be based on an open standards modular interface technology. The components were selected and the interfaces are defined such that all use cases, inter-component messages, and inter-component activity diagrams are captured as part of the DST OSA specification.

VIII. Technology Transition

The DST OSA is intended to be agnostic to specific program performance requirements to the largest degree possible. This will allow the broadest use of the OSA by allowing performance requirements to vary for each system procurement without impacting the OSA definition. Additionally, validation of component OSA compliance can also be separate from system performance validation.

For these reasons, the OSA focuses on capturing interface details, such as software activity diagrams, that are orthogonal to specific program performance requirements, of which effective isotropic radiated power (EIRP), ratio of antenna gain to system noise temperature (G/T), channel bandwidth and system throughput, and size, weight, and power – cost (SWaP-C) requirements are a subset. However, the architectural design decisions and modular interface definitions have been heavily influenced by SWaP-C considerations. These considerations are documented in the OSA.

For a program to procure an OSA-compliant DST, it is envisioned that several documents will be needed: the Performance Work Statement (PWS), which details quantitative system performance requirements; the DST OSA ADD, which defines the architecture and logical interfaces; and the OSA ICDs, which detail the physical attributes of the interfaces.

The DST OSA Consortium is currently defining OSA validation procedures. One probable path discussed would be to validate vendor products using open-source component software emulators. The emulators would be U.S. government owned and maintained and would be hosted in a virtually networked software environment.

In combination, these OSA documents and software products will allow DST OSA compliance to be readily validated across a variety of DST OSA component vendor products. The DST OSA will be maintained as technology evolves, while a library of component emulators will allow rapid and parallel development of compatible component products. Products can then be assembled, tested, and certified in a conventional SATCOM manner at the system level. Ultimately, it is envisioned that the DST OSA will become a component standard in the family of Army open standards (i.e., Vehicle Integration for Command, Control, Communication, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR)/Electronic Warfare (EW) Interoperability (VICTORY), Modular Open RF Architecture (MORA), etc.) that are continuing to evolve for each technology area relevant to Army C4ISR developments. This will accelerate and simplify development and integration of these increasingly complex systems.

IX. Conclusions, Challenges & Future Work

Current Army SOTM terminals are mechanically gimbaled dish antennas, which cause large visual signatures and increased vehicle vulnerability. Turreted platforms cannot easily integrate these antennas without obstructing turret movement or satellite views. The DST, however, is a distributed aperture system that lowers the profile of mounted SATCOM antennas, avoids obstructing turret movement and satellite view, utilizes smaller components for flexible integration, and reduces radiation hazards to on-vehicle personnel.

To best develop and procure DST systems, an OSA has been created. An accepted DST OSA enables flexible design and integration, increased SATCOM competition, and rapid fielding of incremental system improvements. The standard architecture allows for each system component to be compatible, interoperable, and interchangeable, leading to uniformity in testing, evaluation, and integration into systems of systems. This collaborative development effort between government and industry not only protects industry's intellectual property rights and enables new capability integration without significant terminal redesign, it also maximizes opportunities for competition and cost reduction across all life-cycle phases and allows for fast and affordable deployment.

Developing an OSA is only one challenge in the DST paradigm. As these systems are developed, their costs and benefits will need to become more thoroughly understood to address the larger Army challenge: integrating DST systems across a family of turreted platforms.

One area of future work that the DST facilitates is integration of antennas onto/into the vehicle armor. Research and development into armor-embedded antennas will likely grow as DST technology advances and cross-discipline coordination evolves. The DST OSA will remain a vital piece of this effort to ensure robust competition and validated performance of DST integrated systems.

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