TacSat-4 Mission and the Implementation of Bus Standards

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ABSTRACT

This paper provides an overview of the TacSat-4 mission with a focus on the COMMx payload. It discusses the lessons-learned to date and the challenges of building a payload to fly on the prototype spacecraft Bus built to the ORS Phase III Bus standards. Each TacSat experiment tests key elements of an operational system by taking frequent tangible steps to spiral capability and receive operational feedback, while moving toward Operationally Responsive Space (ORS) acquisitions. The TacSat-4 experiment's mission was selected by a Joint panel. Tacsat-4 has several ORS system level objective including using a prototype bus to mature spacecraft bus standards for acquisition and to fly in a "low" highly elliptical orbit, enabling a new set of ORS missions that require dwell, such as communications. TacSat-4 provides a Communications-on-the-Move and Data-Exfiltration payload. Building a TacSat that operates in a high radiation, highly elliptical orbit is quite challenging for the low cost class and short schedules that TacSats must support. The COMMx payload is currently undergoing system level environmental testing. The ORS Bus Standards flight prototype is complete and ready for integration with the payload. Space vehicle integration and test will be performed from August to October 2008 with launch scheduled for September 2009.

TACSAT-4 MISSION

The TacSat-4 experiment was selected by the joint community. This second iteration refined the process created during TacSat-3 selection, and the process was formally documented. The payload capability selected in October 2005 includes Comms-on-the-Move (COTM), Blue Force Tracking (BFT), and Data-X. The COTM capability provides UHF legacy radio support and a Mobile User Objective System (MUOS)-like channel. The BFT capability collects existing UHF devices with tasking priority expected for underserved areas. The Data-X capability focuses on data collection from Navy buoys, which are typically remotely located on the seas and in littorals. The TacSat-4 payload operates in a bent pipe fashion, working directly with legacy radios and/or sensors and ground terminals. Mission highlights and CONOPS are shown in Figure 1.

TacSat-4 will be placed in a long dwell, 4-hour highly elliptical orbit, allowing 1 to 2 hour dwells per pass. Ultimately this orbit will enable persistent theater coverage with minimum satellites and launches (typically 4) supporting this low cost class of mission. TacSat-4 is using the bus resulting from the ORS Phase 3 Bus Standards effort, which allowed the bus standards to be refined throughout the design and testing process. Mission objectives and further details are discussed in the next section. Launch is planned in September 2009 with the ORS Office and SMC's Space Development and Test Wing (SDTW) providing a Minotaur-IV launch with mission assurance and range support. The Navy is leading the TacSat-4 experiment, ONR is funding the payload and flight operations, and NRL is the program manager.

Communications on the Move: TacSat-4 will provide ten UHF channels to support a combination of COTM, Data-X, and BFT simultaneously. Legacy radios will be supported in their native modes (2.4 to 16 kbps) without any antenna pointing requirements. An in-theater ground terminal will allow advanced capabilities such as voice and data from legacy radios to be Internet Protocol (IP) wrapped and networked. One channel will support the MUOS-like, wideband mode.

Blue Force Tracking: There are many national needs and requirements for BFT and more general Blue Force Situational Awareness (BFSA). The value of a TacSat experiment and future operational augmentation is in the ability to collect data from existing devices in underserved areas. The orbit type chosen lends itself well to collecting from most areas of the world (see Figure 4).

Data-X: Many types of Data-X needs exist. The primary Data-X need surfacing during the TacSat-4 selection process was for buoy data collection. Buoys are remotely deployable on the seas and often require organic air assets to support them. TacSat-4 will provide additional coverage and expects to test various Navy Concepts of Operation (CONOPS) for buoy data collection. The payload Data-X capability collects data

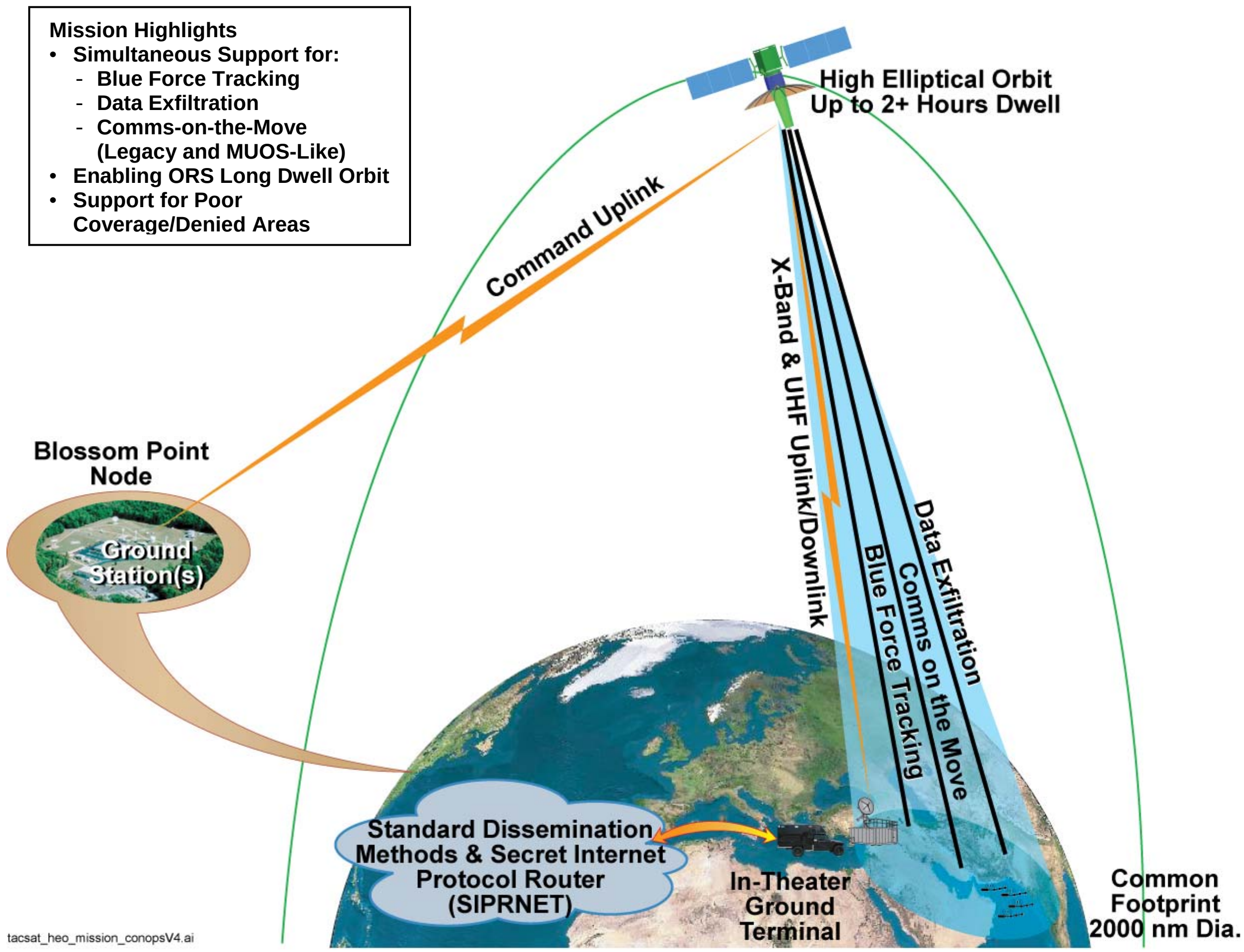

Figure 1: TacSat-4 mission highlights and CONOPS

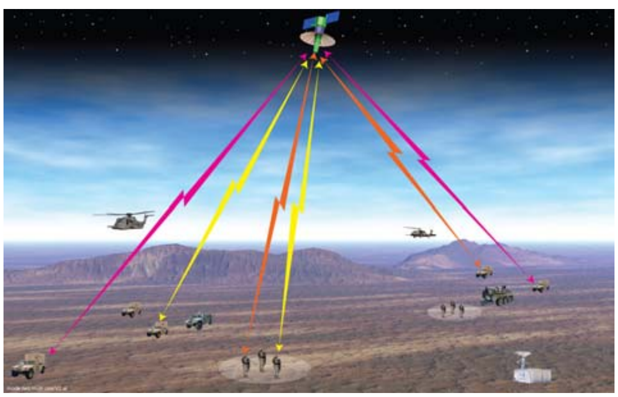

Figure 2: Communications on the Move

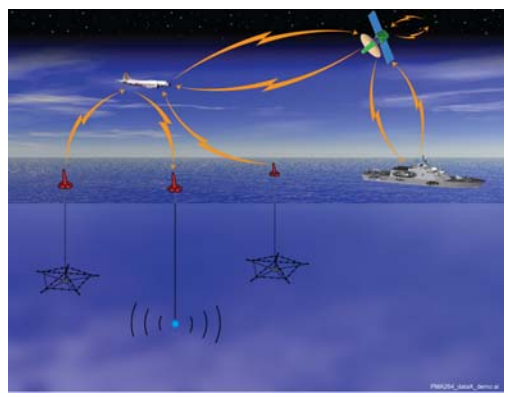

Figure 3: Buoy Data-X

from moderate-to-high power sensors, such as most buoys.

Support Phase 3 Bus Standards Development: TacSat-4 is using the prototype bus developed under the Phase 3 Bus Standards work. TacSat-4 provides a real payload and mission used to test and mature bus standards in preparation for acquisition. Reference the "TacSat-4 Prototype Bus and ORS Phase III Bus Standards Update" paper, also in this same conference (22nd Annual AIAA/USU Conference on Small Satellites).

Long Dwell Highly Elliptical Orbit (HEO): Several missions, such as communications, require long dwells or constant coverage of a theater to be of value. These

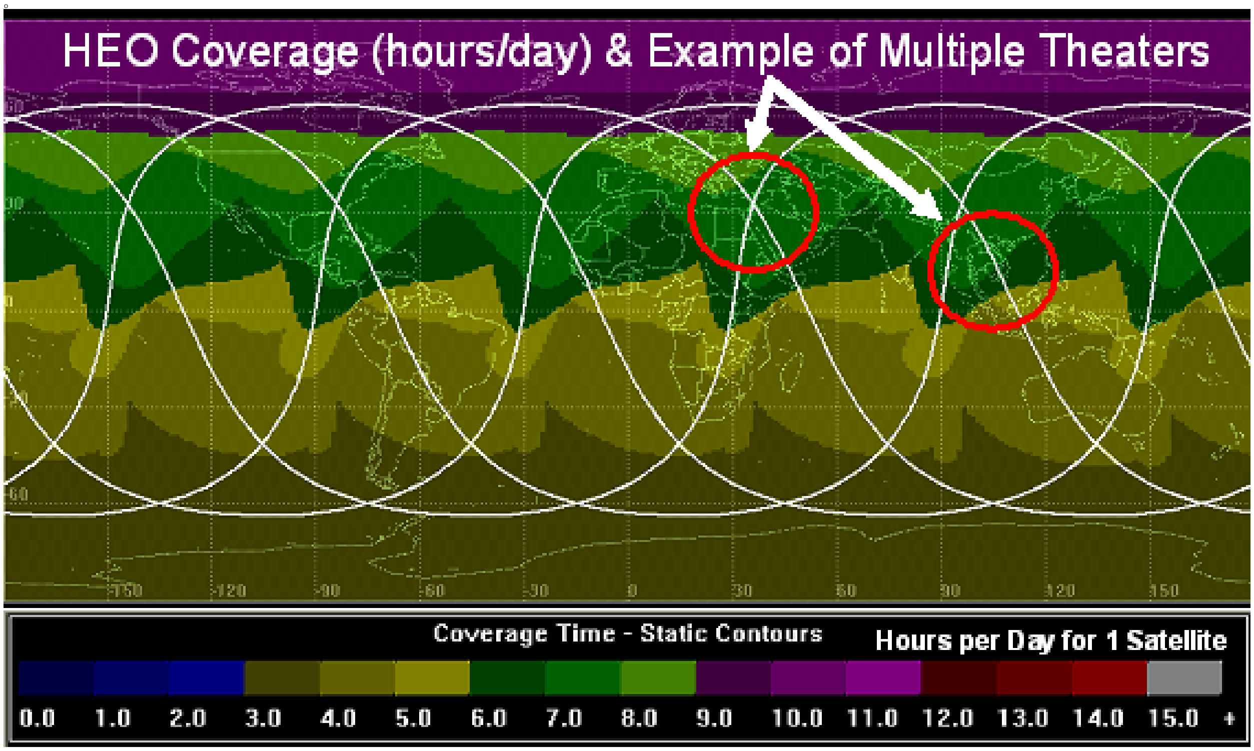

Figure 4: Example Highly Elliptical Orbit Coverage

missions cannot practically be performed with Low Earth Orbiting (LEO) satellites because of the number of satellites and launches required. Geosynchronous Earth Orbit (GEO) satellites are the mainstay of national and commercial systems for long dwell missions, but are generally beyond the reach of ORS because of the launch cost and the aperture and power needed at this distance (36,000 km). For ORS, highly elliptical orbits with 3 and 4 hour periods may provide a favorable set of characteristics by providing 24-7 coverage of multiple theaters with a small number (such as 4) of satellites and launches. These orbits have significant radiation, so the TacSat challenge is to provide a low cost satellite capable of surviving in this environment. These orbits also provide excellent coverage at high and low theater inclinations which GEO satellites do not cover well. In some cases, highly elliptical orbits give better coverage in mountainous or obstructed areas. These orbits provide excellent flexibility for payload tasking over various theaters world-wide, supporting augmentation of underserved areas and primary theaters. Figure 4 shows the coverage time of one satellite in a 4-hour highly elliptical orbit with example primary and secondary theaters.

The orbit shown is biased toward the northern hemisphere; mirrored coverage times can be achieved with a southern orbit bias (via changing the argument of perigee). TacSat-4 will use a Minotaur-IV to achieve this orbit; this will be a new orbit for Minotaur-IV. A TacSat-4 success in this orbit will be a significant milestone for ORS system advancement.

COMMX PAYLOAD DEVELOPMENT

The COMMx Payload was selected for the TacSat-4 mission. It is the first payload developed for use with the ORS Phase 3 Standard Bus. The requirements for the Bus and Payload were both written as part of the ORS Phase 3 Standard Bus effort by the Integrated System Engineering Team (ISET). The requirements for the Bus and Payload were NOT written to suit the payload or the mission as would be typical on most spacecraft. Rather, the requirements were written for a single bus and multiple payloads that would support a variety of TacSat missions. This fact complicated the development of COMMx and in some cases increased the cost and schedule of the COMMx development.

The COMMx payload consists of an approximately 3 foot cube primary structure with a 12 foot reflector dish mounted on top with a 6 foot tall support cone for the UHF feed. All of the subsystem components for COMMx have been delivered and except for the Loop Heat Pipe system, they are all integrated. The COMMx payload is currently undergoing system level environmental testing as shown in Figure 5.

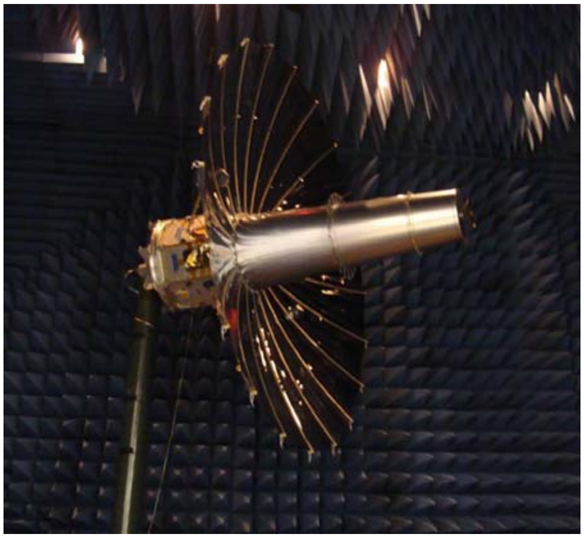

Figure 5: COMMx in Anechoic Chamber for Self Compatibility and Alignment Tests

There were a number of significant technical achievements made in the development of the payload. Some of the achievements are as follows:

Dish Reflector Development: The 12' Dish Reflector is a completely new technology design which takes advantage of the loose mechanical tolerances allowed when operating at UHF frequencies. These relatively loose tolerances allow an ORS class cost reflector to be achieved.

Passive Intermod (PIM) Test Set: In order to test the COMMx payload for PIM, a test set was developed which is capable of testing for PIM across a broad portion of the UHF spectrum. This PIM Test Set is likely the only one in the country capable of testing for PIM across such a broad portion of the UHF spectrum with sufficient sensitivity.

Multipactor Test Set: A Multipactor test set was developed which is capable of testing all the COMMx high-power UHF hardware (UHF Feed, Quadripole, Circulator, cables, loads and filters) for Multipactor.

Primary Structure: Designed, analyzed and integrated lightweight primary structure that meets 50 Hz stiffness requirement for a 180 kg payload.

CHALLENGES OF PAYLOAD DEVELOPMENT WITH THIS STANDARD BUS

Being the first payload for the ORS Phase 3 Standard Bus presented some unusual challenges for the development of the COMMx payload. The two main reasons for the additional challenges are that the Standard Bus requirements were being developed while COMMx was being designed, and that the bus requirements were NOT based on the COMMx payload or the TacSat-4 mission. The three requirements which had the greatest impact on the COMMx payload are the following: limit of 200W orbit average power provided by the bus for payload operations, payload stiffness requirement of 50 Hz or greater, and the requirement for the payload to be thermally isolated from the bus.

Maximum of 200W orbit average power provided by bus for payload operations. The ORS Phase 3 Bus Standards requirements limits the payload to 200W orbit average power. The 200W orbit average power was not enough to satisfy the COMMx requirement to operate for 2 hours with the baseline design. This caused the RF electronics to be customized for significantly improved efficiency rather than using off the shelf components as planned.

Payload stiffness requirement of >50 Hz. The ORS Phase 3 Bus Standards Payload Developer's Guide requires that the payload stiffness be greater than or equal to 50 Hz. This stiffness requirement is extremely challenging to meet for 150+ kg payloads. This requirement significantly increased the design, analysis and integration costs of the COMMx primary structure.

Payload thermally isolated from the bus. The OFT Phase 3 Bus Standards Payload Developer's Guide requirement originally stated, "*The bus shall provide thermal contact resistance of 10degC/W across the mounting interface.*" This requirement affectively thermally isolates the payload from the bus. Since communications payloads tend to be on for long periods of time and then off for long periods of time, this led to the need for a complex thermal system. On COMMx, the payload runs at 600W while the payload is on and 30W while the payload is off. These two requirements led to the need for a state-of-the-art Loop Heat Pipe thermal control system on COMMx.

COMMX LESSONS LEARNED TO DATE

The COMMx team has overcome numerous challenges to get where we are today. We have learned some lessons along the way which may be applicable to other projects/missions. Here are some of our lessons learned to date:

Development of all portions of the mission should be developed on the same timeline. Failure to develop all portions of the mission simultaneously can lead to technical problems and cost increases down the line. The mission portions that are late developing can lead to design changes on other subsystems which will be more expensive to accommodate due to their higher level of maturity. The Payload Developers Guide lagging the COMMx Payload development was the primary example here.

Thoroughly understand test fixtures and test equipment required when developing program cost and schedule. Understanding the cost and complexity of these systems is just as important as understanding the cost and complexity of the flight hardware but can be overlooked as people focus on the flight hardware. For example, the PIM test setup and testing required significant resources not fully understood at the beginning of the program.

Be careful to avoid developing budgets based on schedule targets. Given schedule targets, it is very easy to develop budgets that are artificially low if the schedule targets are not achievable.

TACSAT-4 OVERVIEW

TacSat-4 has accomplished many milestones and overcome numerous technical challenges. The ORS Phase 3 Bus Standards prototype is complete, and the COMMx Payload is in system environmental testing. Once COMMx has completed payload level environmental testing, it will be integrated and tested with the ORS Phase 3 Bus to become the space vehicle. The space vehicle is scheduled to be completed in October 2008, and the launch of TacSat-4 is planned for September 2009.

TacSat-4 has already been utilized to test and mature the ORS Bus Standards. Once TacSat-4 is launched, it will provide Comms-on-the-move, Blue Force Tracking and Data-X support to a variety of user groups. TacSat-4 will also demonstrate the utility of the Highly Elliptical Orbit for TacSat missions.