

# TSAT NETWORK ARCHITECTURE

Jeff Pulliam, Yadunath Zambre, Ani Karmarkar  
TMOS Team, Lockheed Martin  
San Jose, CA

Vineet Mehta, Joe Touch, Josh Haines, and Matthew Everett  
TSAT Program Office, Space and Missile Command  
Los Angeles, CA

## ABSTRACT

*The Transformational Satellite Communications System (TSAT) is poised to become the DoD's next generation protected and processed satellite system. This paper describes the network architecture of the TSAT system. The presence of a high capacity IP router on the satellite payload is a key distinguishing feature of the TSAT system. The TSAT payload also provides RF and optical circuit switching capabilities. We describe the physical elements which comprise the TSAT network, and their interconnecting TSAT mechanisms that support fixed and mobile terminals, and the approach TSAT uses to support time-varying link conditions. We discuss key network protocols, communications standards and technologies employed within the TSAT system, with particular focus on routing, quality of service, network services, and network security. This paper also presents the TSAT approach towards supporting circuit services, as well as providing security at physical and link layer.*

## I. INTRODUCTION

Satellite communications continue to serve as a vital resource that provides connectivity and reachability for DoD/IC users, particularly in challenged environments and force conditions. In order to serve the needs of DoD/IC user, the US Government has a history of deploying protected satellite communications systems, beginning with MILSTAR I. Thus far, systems deployed and currently under development are circuit-based. The US Department of Defense is currently poised to develop the next generation satellite communications that will provide packet switched services along with circuit-based services, over a protected transmission platform, called the Transformational Satellite Communications System (TSAT). The TSAT system provides a number of enhancements over predecessor satellite communications systems:

- High capacity packet switched services in space
- A multi-gigabits per second rate space backbone
- High capacity circuit switching in space
- High rate circuits to airborne, spaceborne, and terrestrial terminals
- Widespread adoption of commercially established standards, technologies and Internet protocols
- Greater than 1 Mbps connectivity to mobile terminals

- Dynamic coding, modulation, and resource allocation for adapting to changing link conditions
- High degree of automation and ease in network planning, management and access

The increased capacity offered by TSAT is nearly an order of magnitude greater than its predecessor system, AEHF. This increase reflects the growth in capacity demand due to the number of hosts in the network, as well as the higher capacity demands of a diversity of applications.

The TSAT architecture employs a hybrid mix of switching technologies (RF circuit, optical circuit, and packet switching) to provide a high-capacity switching system while balancing size, weight, and power on the satellite payload. The capacity resources in the TSAT system is more efficiently utilized by mapping mission data flows to the appropriate switching technology, e.g., mapping high-rate ISR traffic to high-rate circuits rather than carrying that traffic over packet interfaces. TSAT's support of hybrid switching technologies and a variety of interfaces also serves to support a larger range of missions, compared to predecessor satellite communications systems.

The TSAT program as a whole has made deliberate efforts to employ commercially established standards and technologies in architecting the network. This approach is beneficial in bounding system development costs, lowering the risks to program schedule, and providing greater likelihood for interoperability with other systems employing commercial standards. The use of Internet technologies, particularly packet forwarding in space, allows for efficient use of system capacity. It also allows the system to support a diversity of applications and missions through its life.

The TSAT system will be unique in its ability to support mobile users (e.g., HMWVVs in-theater traveling in excess of 10 Mph) at link rates greater than 1 Mbps. With the added ability of TSAT links to adapt their modulation and coding to cope with changing channel conditions, TSAT will be able to provide its users highly reliable communications in challenging environments.

The variety of communication interfaces, switching capabilities, and system flexibility offered by TSAT would yield a system whose configuration and operation is too complex for human operators, without the assistance of automated planning and management tools. Therefore, the TSAT system employs a sophisticated planning and management system entitled TSAT Mission Operations System

(TMOS). This system provides capabilities for users/operators to request services from TSAT, as well as configure and operate the network in accordance with the service request.

In the remainder of this paper we describe the key requirements driving the acquisition of the TSAT system. We then discuss the network topology and the elements that comprise the network. Finally, we describe the functions and services performed by the TSAT network.

## II. KEY AND DRIVING REQUIREMENTS

The TSAT system will serve as a Tier 1 provider of data transport services with the overall Network-Centric architecture of the DoD. As a Tier 1 provider, the TSAT system will provide global coverage and connectivity for users. Compliance with the Network-Centric vision requires that TSAT natively support Internet protocols and packet forwarding capabilities. The TSAT network transports data as cipher text in accordance with the black core vision of the Global Information Grid (GIG) architecture. The TSAT system will be backwards compatible (i.e., interoperate

and connect to AEHF, the predecessor circuit-based MILSATCOM system). As a result, the TSAT system will provide AEHF compatible interfaces and the ability to plan and provision AEHF circuits. The TSAT system will also interconnect with the MUOS and WGS constellations. As illustrated in Figure 1, TSAT will provide data transport services for the following main mission categories: i) strategic, ii) tactical, and iii) airborne/spaceborne intelligence, surveillance and reconnaissance. The ability to support each mission category imposes particular requirements for the TSAT system.

Support for the strategic mission implies that TSAT links be anti-jam and low probability of intercept. Therefore, TSAT links must provide robust communications under natural or directed channel impairments. The system will be capable of transmitting with greater spectral efficiency under benign channel conditions.

In the case of tactical environment, the TSAT system will support a large number of terminals in multiple theaters of operation. The terminals typically vary in the transmission modes (coding, modulation, and burst rates)

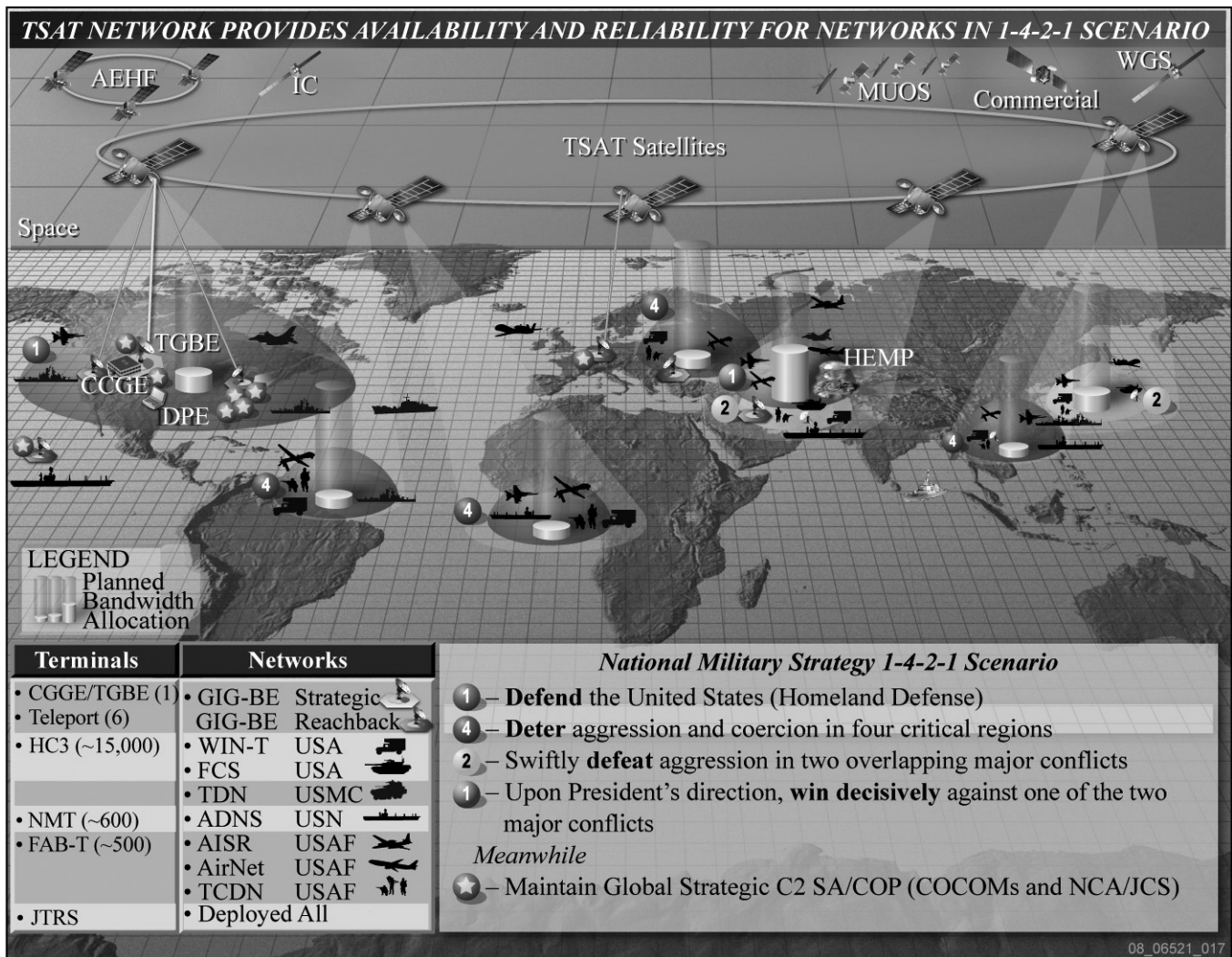


Figure 1. TSAT System

they support, the environment they operate in, their degree of mobility, their bandwidth demands, their participation in joint operations, their access to administrative/management support, the type of application traffic they transport and their susceptibility to threats. The airborne and space ISR missions demand high-rate data links between globally located sensing platforms to selected processing centers, primarily in the continental United States. The TSAT system architecture therefore must accommodate a range of heterogeneous users.

The sections that follow will discuss functional aspects of the TSAT network architecture that meet operational needs of the DoD/IC users and operators.

### III. TSAT NETWORK TOPOLOGY AND ELEMENTS

The TSAT network is administratively decomposed into three segments: i) the space segment, ii) the ground-based management and operations segment, and iii) the terminal segment. Terminals correspond to Internet Provider Edge (PE) routers, and the ground-based management corresponds to the management plane and its associated servers. The Space Segment comprises the core of the data and control plane.

An illustration of the TSAT network is given in Figure 2, where each segment is represented. We will first list the elements that comprise each segment, and then briefly de-

scribe the role of each element.

The Space Segment consists of a constellation of five geostationary satellites and CONUS *ground* gateway elements (CGGEs). The TSAT Mission Operations System (TMOS) consists of a TSAT Network and Operations Management (TNOM) element, TSAT Network Services Elements (TNSE), a TSAT GIG Border Element (TGBE), and Distributed Planning Elements (DPE). The Terminal Segment simply consists of ground, air, or space terminals and management entities that interface with the satellites (Space Segment) and the ground-based management system (TMOS). The terminal segment is not a single program, but represents a set of programs that have plans for developing terminals that will deploy TSAT waveforms. At present these include the WIN-T, ADNS/NMT, and FAB-T programs within the Army, Navy, and Air Force respectively. The teleports are specialized installations that host TSAT terminals along with terminals that connect to other satellite communications systems. These installations allow for interconnection between satellite systems. The TSAT system will interconnect with AEHF, MUOS, WGS and EPS systems at the teleports.

#### Space Segment

*Satellite Architecture:* The five geostationary satellites can be connected in various ways, including a ring or a line (string). Regardless of the physical topology, they form a

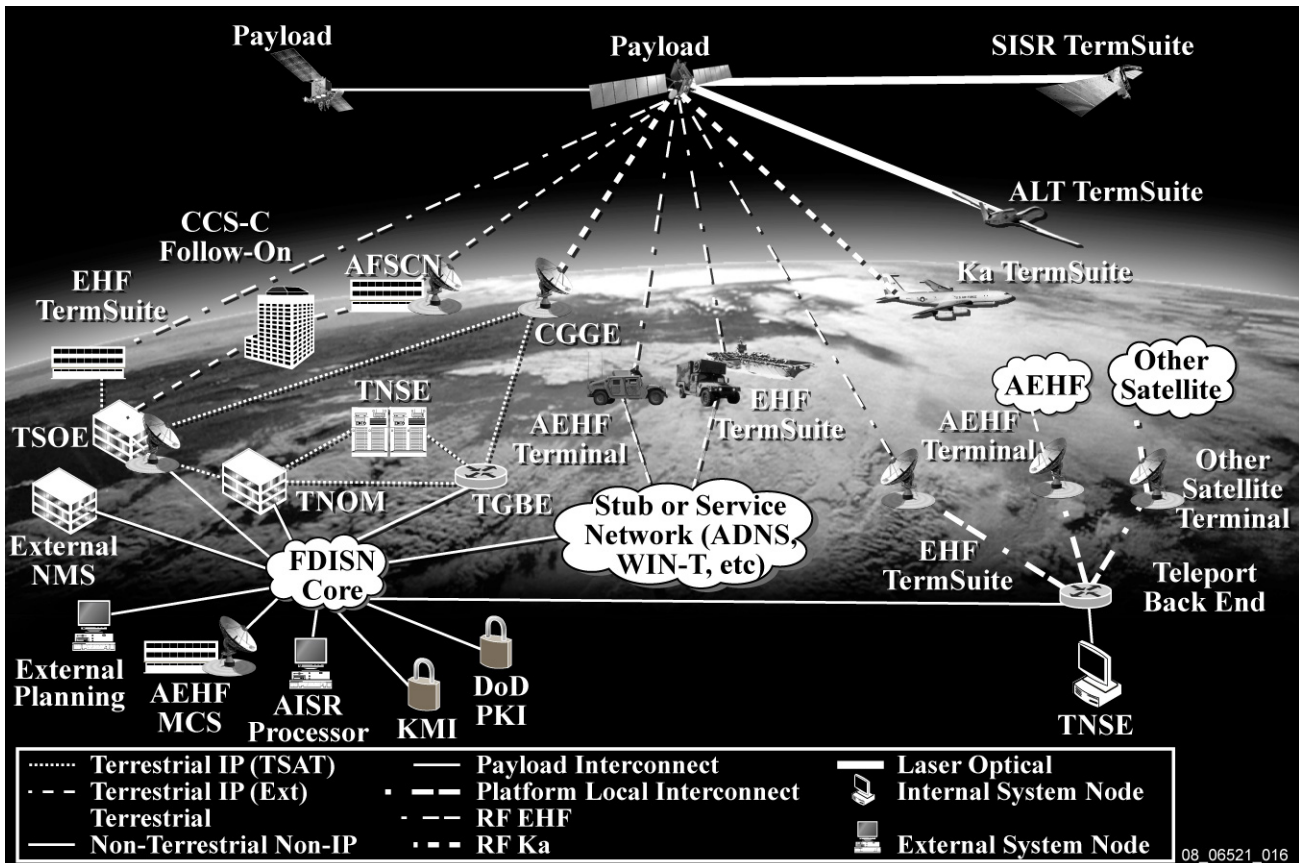


Figure 2. TSAT Network Architecture

full mesh logical topology. The use of a full mesh reduces the space forwarding load, and permits better traffic engineering management.

Satellite Element: The satellites host a payload that includes a set of major subsystems that affect the network architecture by presenting challenging link properties. Conventional Internet links are typically consistent and symmetric; our satellite links are quite different. A flexible antenna subsystem can vary beam patterns and waveforms on-the-fly, in response to weather conditions, traffic load, and coverage pattern requirements. Downlinks are broadcast, but uplinks are unicast. Downlink broadcast group membership and capacity will vary, over timescales that can include sub-roundtrip. The terminal links will be capable of operating at uplink data rates up to 45 Mbps and downlink data rates up to 128 Mbps using XDR+ RF waveforms, and the system also supports circuit rates of 311 Mbps, e.g., to airborne RF ISR. Link layer security is provided through the use of COMSEC/TRANSEC. The inter-satellite cross-links will be capable of transmission rates of 10 Gbps, while the optical ISR terminals will be capable of transmission at 2.5 Gbps, using OTN/SONET framing.

The satellite payload hosts subsystems that provide the ability to switch XDR, Ka and SONET circuits. The payload also hosts an Internet Protocol (IP) router. As mandated by DoD policy, the router speaks only IPv6.

CONUS Ground Gateway Element (CGGE): A distributed ground element exchanges high data rate satellite signals, performs signal conditioning, and transfers the signal in a transparent manner with the TGBE (which is part of the TMOS segment, described below). This element acts as a distributed, remote network interface to the satellite constellation.

### ***TMOS Segment***

TSAT Network and Operations Management (TNOM) Element: This is the primary entity for operating and managing the TSAT network, using a high degree of automation. This element handles all network management, planning, and configuration. It also manages policy and access control, performance monitoring, security mechanisms, and faults. The TNOM serves as the interface to external planning and management as well, e.g., to the GIG.

TSAT Network Services Element (TNSE): This element aids the TNOM in effectively executing management and operations functions, by acting as a local proxy for TNOM functions. In the TSAT satellite network, the connection between the TNOM and a Managed Network Element (MNE) can be unacceptably unreliable. The TNSE serves as an intermediary between the TNOM and the MNE. A TNSE is located geographically closer to the MNE, and is expected to be capable of independently performing a sub-

set of TNOM functions. In addition, a TNSE serves to off-load some of the processing burden from the TNOM.

Distributed Planning Element (DPE): This element assists mission planners in entering requests for services (also termed Mission Service Requests) or altering service allocations when situated remotely from the TNOM. It serves a similar proxy function as the TNSE, except focusing on support for mission planners. This capability is particularly important in the case of allocation or reallocation of XDR circuits, but less significant for packet services.

TSAT GIG Border Element (TGBE): This ground-based element serves as a high-capacity peering point to the Defense Information Systems Network (DISN). The TGBE hosts high-rate SONET circuit switching function, as well as a high-capacity router. The TGBE provides access for TSAT strategic, tactical, and ISR users to the terrestrial GIG through the DISN backbone. It also serves to extend the DISN backbone through high data rate circuit and packet interfaces with the TSAT space backbone.

### ***Terminal Segment***

The acquisition of terminals is programmatically and physically separate from the other parts of the TSAT system. However, the design of terminals and their subtending networks must be considered jointly with other parts of the TSAT system. The TSAT system allows for the use of both circuit and packet interfaces for terminals in each of the supported link types (circuit, packet, and for airborne, optical). The link layer framing employed is unique to each link type. For lower-speed RF links, the TSAT system employs XDR framing technology, which has been matured by the AEHF program. The high-speed RF and optical channels employ SONET framing technology, which has been matured by commercial manufacturers of optical transport equipment for well over a decade. For lower-speed RF links, the TSAT system does add a novel feature at the link layer – Dynamic Bandwidth and Resource Allocation (DBRA). The feature allows TSAT links to adapt their modulation and coding, as well as the uplink capacity that is shared among a group of terminals. The successful implementation of the DBRA function requires terminals to support agent functions at the terminal that can be manipulated by a DBRA controller on the Payload, coordinating link access to manage the dynamic capacity resource. Packet terminals are expected to host a PE router that is controllable by TNOM or TNSE, notably to support maintaining network performance in accordance with Service Level Agreements (SLAs). It is also critical for creating a policeable network security perimeter.

## **IV. TSAT NETWORKING FUNCTIONS AND SERVICES**

The TSAT system offers a number services and functions to facilitate effective use of the network by MNE. The

functions and services provided can be categorized broadly as: Network Services, Routing, QoS, Network Management, and Network Security. The TSAT network services are based on an IPv6 platform, consistent with the DoD mandate for DoD Network to transition to use IPv6 only. This decision does pose challenges for the DoD network operations and acquisition community because IPv6 protocols and technologies are at their initial stages of deployment within the Internet.

*Network Services:* The TSAT system will provide typical Internet services to MNEs. These include assigning globally-unique addresses (e.g., via DHCP) and name resolution (e.g., via the DNS). Additional TMOS services include configuration of management entity locations (primary and backup), and interfaces for changing service levels, reporting events and statistics, and policy management.

Although the types of services TSAT will provide to MNEs have been established, the details related to how some of these services will be provided present some challenges and are the subject of ongoing investigations within the TSAT program. The manner in which TSAT distributes addresses within its domain and/or to user networks is dependent on the development of consistent GIG-wide address plan by DISA. In addition to this, TSAT expects to accommodate users and edge networks that follow their own addressing structure.

The location of management entities is predicated on the reliability with which MNE must access the network and operations management systems. The types of statistics, their volume, and their frequency of transmission should be proportionate with the bandwidth and processing constraints of the TSAT system, as well as that of the terminal elements.

The use of policies within the TSAT network, including the edge terminals, is the topic of ongoing debate between TSAT program, the GIG system engineering groups, and terminal programs. Most parties involved in developing components of the GIG architecture agree on the value in applying a Policy Based Network Management (PBNM) approach. However, the GIG architecture community continues to struggle with the appropriate elements of the network to which policy should be applied, the sophistication of policy-based systems in making operational decisions within a network domain, and the manner in which policy-based systems in peer network domains are expected to interoperate. The outcome of discussions within the GIG-wide community weigh heavily on the types of policy interfaces supported within the TSAT administrative domain.

*Routing:* The TSAT system provides unicast, multicast, and Virtual Private Network (VPN) services for user terminals authorized to access the TSAT network. In the

TSAT architecture, the terminals serve to define the administrative boundary of the TSAT network. In particular, the terminals host a Provider Edge (PE) and a Customer Edge (CE) router. The PE router has an interface that faces the payload router and an interface that faces the CE router. The CE router serves as the edge node for connecting into a user network. Therefore, the link between the PE and CE routers defines the boundary between the TSAT administrative domain and that of a user network. The peering arrangement and exchange of routing information between the TSAT domain and the user domain is accomplished through an exterior gateway protocol (EGP). The TSAT network employs the Border Gateway Protocol (BGP) as its EGP because of its maturity and prevalent use within the Internet. The TSAT domain itself is divided into multiple autonomous systems (ASs). The core AS consists of nodes in the space backbone network and a select set of fixed ground nodes (such as teleports). The membership and connectivity of nodes within the core AS is expected to remain stationary. The routing architecture employs iBGP for router peering within the core AS. Connectivity of the space backbone to other terminals is expected to vary dynamically based on mission and mobility. Therefore, each terminal is placed in its own AS. The routing architecture employs eBGP for peering between terminal PE and the payload router.

Support for multicast will be provided through the use of Protocol Independent Multicast Sparse Mode (PIM-SM) to generate the multicast forwarding trees based on routing tables built by BGP. The use of multicast is tuned to the peculiarities of the satellite interfaces, notably the asymmetries of the beams (broadcast groups down, unicast up).

The TSAT network will also support Provider Provisioned Virtual Private Networks (PP-VPNs) primarily to assist maintaining connectivity within a user AS that may split due to a loss of line-of-sight links. The selection of PP-VPN base routes over line-of-sight routers will be based on OSPFv3 metrics.

Mobility poses challenges to the TSAT network. Mobility events include: terminals moving between beams of a satellite, terminals moving between satellites, link outages and degradation due to weather and obstructions (e.g., COTM), and movement of nodes within user networks behind the TSAT PEs. Although it is not possible to provide a detailed treatment of the effects of these types of events (such as loss of reachability, route flapping, route convergence) within this paper, the ability of the TSAT system to provide reliable and adequate level of service to the users depends on the successful network operation through mobility events. The design, development and implementation of mechanisms at the physical, link, and network layers to accommodate mobility events continues to be a key area of work within the TSAT program.



Quality of Service (QoS): TSAT network approach to QoS consistent with the Differentiated Services (DiffServ) architecture. In accordance with DiffServ, TSAT network elements are capable of performing per packet classification, conditioning, policing, and differential queuing/scheduling. The conditioning and policing of traffic is expected to be performed primarily at boundary nodes (typically user terminals or teleports, the latter being essentially a large user terminal). Differential treatment of packets that transit the TSAT domain is based on the Differentiated Service Code Point (DSCP) placed in the Traffic Class field of the IPv6 header. The forwarding plane treatment related to each service class with the TSAT network is consistent with that of the GIG aggregate service classes. The GIG Technical Foundations (GTF) documents (formerly NCIDs) current propose four aggregate service classes. The intent is to maintain packets' DSCP markings as they transit the TSAT domain. Within the offered DiffServ classes, the TSAT network expects to provide a limited amount of low-delay, low-jitter, and low-loss service, termed Unsignaled Critical Service (UCS). The TSAT network will also provide guaranteed services over the DiffServ framework using ARSVP. The TSAT QoS architecture supports MLPP (Multi-Level Precedence and Preemption) through the UCS and ARSVP mechanisms. Since TSAT links are dynamic and shared, Service Level Agreements (SLAs) with the users govern how bandwidth resources are distributed amongst the terminals in order to maintain the requisite level of service for higher priority terminals and traffic. The SLAs are established through a TMOS planning process based on Mission Service Requests (MSRs) submitted by operators on the behalf of users. The TSAT QoS architecture employs a Bandwidth Broker concept as a means for delivering a level of service in accordance with the SLA. The Bandwidth Broker approach is implemented as a set of distributed agents located at TNOM/TNSE, payload and terminals. The agents located at TNOM/TNSE set the guiding policies for agents located at payload and terminals. The Bandwidth Broker agents located at the payload and terminals use the policies to influence configurations that govern the distribution of resources amongst terminals under a payload, as well as configurations for conditioning and policing/filtering.

Although the basic architecture of QoS within the TSAT domain is well established, its efficacy in delivering the desired level of performance for critical missions poses challenges. In order for premier traffic classes to achieve the desired level of service, the TSAT QoS system must cope with time varying link conditions and rates (due to actions of DBRA algorithms). The QoS system must also monitor the state of the network (including the character of traffic entering the network) to appropriately apply controls within the core and at the edge through the coordination of the Bandwidth Broker. Accomplishing this level of

coordination continues to be an area of intense work within the program.

Network Management: The network management approach employed by TSAT is described here briefly. A more detailed treatment is provided in a separate paper. The TSAT network management approach is modeled after the FCAPS model deployed by telecommunications carriers. The abbreviation FCAPS expands to Fault, Configuration, Accounting, Performance, and Security. Although the billing function related to Accounting in the traditional FCAPS model is not particularly relevant to TSAT, the related capability of usage and event logging are still needed. The TSAT network employs the FCAPS model within a hierarchical architecture for network management. In this approach, the network management functions are distributed across three layers of hierarchy. The hierarchical model is chosen to ensure that authority for supplying configurations, policies, and decisions/actions is traceable to a single actor. The TNOM element serves as the top authority, and is positioned at the root of the hierarchy. The TNOM passes management directives to the selected TNSEs, and accepts service requests, statistics, event/fault data, and configuration updates. The TNSE resides at the second level of hierarchy, and filters all communications from the TNOM to the MNE agents. It is located geographically in proximity to the MNE in order to enhance availability to network management services. It can also process and reduce the information collected from the MNEs for the purpose of reducing traffic load on the network and processing load on the TNOM for network management tasks. The MNE agent resides at the bottom layer of the hierarchy. This agent performs configuration and monitoring function upon the MNE, as directed by TNSE and TNOM.

The difficult link environments in which TSAT will deliver services to terminals pose a challenge for the design of the network management system as well. The large number of network elements the system must configure and manage also pose a significant challenge. Although the basic construct for the network management is reasonably well understood, there is still much work to be done to understand how network management functions are distributed to provide adequate: access, reliability, responsiveness, a load balanced system, capabilities to monitor/manage changes in network state, and a low complexity interface for the operator/user.

Network Security: The TSAT network is poised to be a critical resource for the DoD/IC enterprise. It must therefore provide high availability, be accessible only to authorized users, and be resilient to attacks. In order to accomplish these objectives, the TSAT network provides security mechanisms at physical, link, and network layers. At physical layer, the TSAT antenna systems are design to

have anti-jamming properties. The RF subsystems of the terminal and payload modems also employ frequency hopping for low probability of intercept. At the link layer the encryption is employed to maintain confidentiality of the transmitted data stream. Additional confidentiality is provided by encryption of messages at the network layer. TSAT assumes a black core architecture, which implies that user data entering the TSAT network is encrypted by the user using IPsec. Therefore, the user is responsible for the confidentiality and integrity of that data. Unencrypted user data is discarded as it enters the TSAT network. Control and management traffic generated within the TSAT domain is also secured using IPsec. In order to mitigate unauthorized access to the TSAT network a stateful login process employed that requires terminal have valid credentials in order to obtain any service. Delivery of credentials to TSAT network elements expected to follow approved DoD key management and distribution mechanisms.

Delivering highly available secure services for the user, while maintaining system security is a significant challenge for the TSAT network, as well as peer GIG networks. Many of the functions involved in providing security at the network layer are areas of vigorous debate and study within the GIG network architecture community. Some of the problems that pose significant challenges are: i) implementing security architectures that maintain system

availability and inter-network communications, ii) an effective and robust keying infrastructure, and iii) effective technologies that support a black core architecture (e.g., HAIPE bypass and HAIPE Server Peer Discovery).

## V. SUMMARY

In this paper we have described the current architecture for the Transformational Satellite Communications System (TSAT) network. Although this system is expected to be deployed several years from now, it will serve as an extraordinary and valuable asset for military users and operators. The TSAT system will also mark a new era in military satellite communications due to the integration of communications systems that support multiple types of missions that were previously the domain of individual satellite systems.

The TSAT program has made significant progress in developing a network architecture. This paper has identified a set of challenge areas where the TSAT program is working hard to develop effective solutions to serve the users and warfighters.

## ACKNOWLEDGEMENTS

We thank our colleagues at the TSAT program for their support, valuable input, insightful comments, and guidance.