EARTH OBSERVING SYSTEM (EOS) COMMUNICATION (Ecom) MODELING, ANALYSIS, AND TESTBED (EMAT) ACTIVITY

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ABSTRACT

This paper describes the Earth Observing System (EOS) Communication (Ecom) Modeling, Analysis, and Testbed (EMAT) activity performed by Code 540 in support of the Ecom project. Ecom is the ground-to-ground data transport system for operational EOS traffic. The National Aeronautic and Space Administration (NASA) Communications (Nascom) Division, Code 540, is responsible for implementing Ecom.

Ecom interfaces with various systems to transport EOS forward link commands, return link telemetry, and science payload data. To understand the complexities surrounding the design and implementation of Ecom, it is necessary that sufficient testbedding, modeling, and analysis be conducted prior to the design phase. These activities, when grouped, are referred to as the EMAT activity. This paper describes work accomplished to date in each of the three major EMAT activities: modeling, analysis, and testbedding.

1.0 OVERVIEW

NASA has begun the implementation of the EOS as part of the Mission to Planet Earth (MTPE) initiative. The MTPE initiative is NASA's main contribution to the interagency Global Change Research Program. EOS supports this initiative by providing a capability to observe and study Earth from multiple, low-earth orbiting spacecraft. In addition, EOS also provides the capability to collect, process, and distribute the observed data to the world wide scientific community.

EOS consists of three main components: EOS Space Measurement System (EOSSMS), EOS ground system, and the EOS Scientific Research Program. The EOSSMS is composed of a series of spacecraft that provide remote sensing capabilities to collect scientific data relating to the Earth's atmosphere, oceans, and land surface. This scientific data is then processed and distributed among the various members of the user community by the EOS ground system. The EOS ground system also provides the data acquisition, command generation, and delivery capabilities. The EOS ground system includes the EOS Data and Information System (EOSDIS) and GSFC-managed NASA institutional support elements, as well as elements from several other non-NASA sources, including U.S. Government agencies, user support facilities, and international partners.

EOSDIS, a key element of the EOS ground system, is a geographically distributed data information system that supports the operation and management of in-orbit EOS spacecraft. EOSDIS consists of EOS Data and Operations System (EDOS), Ecom, EOSDIS Core System (ECS), Science Computing Facilities (SCFs), and NASA Science Internet (NSI). Figure 1, shown on the next page, presents the overall EOS data systems architecture from Ecom's perspective.

The primary objective of Ecom is to provide connectivity between EDOS sites, and to support data transfers between EDOS sites and Distributed Active Archive Centers (DAACs). Ecom also interfaces with the ECS segments and the Mission Operations and Data Systems Directorate (MO&DSD) institutional systems to support Space Network (SN) scheduling and spacecraft orbit and altitude determination. In addition, Ecom interfaces with the Ground Network (GN), Deep

Space Network (DSN), and Wallops Orbital Tracking Station (WOTS) to support EOS contingency requirements.

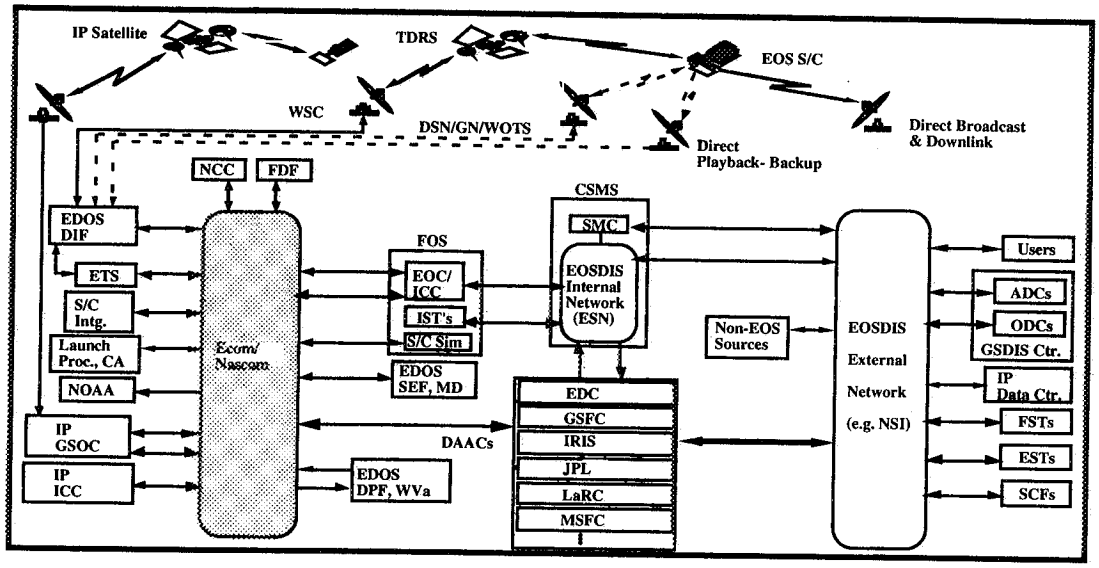

Figure 1 - EOS Data Flow

To understand the complex nature of the Ecom system and its interfaces, it was necessary to conduct sufficient investigation early in the project life cycle to resolve key implementation and technology issues. To assist in this investigation process, Nascom developed an in-house laboratory environment to perform the necessary modeling, analysis, and testbedding. This environment is referred to as the EMAT activity.

2.0 HISTORICAL PERSPECTIVE

In support of the Government Open Systems Interconnection (OSI) Profile (GOSIP) mandate, a Code 540 Research, Technology, and Operations Plan (RTOP) project, known as the Nascom OSI protocol (NOSIP) testbed, was formed in 1989. The purpose of the NOSIP testbed was to test the functionality and performance of the first four layers of the OSI protocol stack. Additionally, the testbed was to evaluate commercial off-the-shelf (COTS) equipment (e.g., hubs, routers) that implemented these protocols. From 1989 to 1993, exhaustive NOSIP tests were conducted in various local and wide area network configurations using different vendors' communications equipment. Results documenting the capabilities and limitations of these protocols and associated equipment were published in the semi-annual RTOP presentations and reports.

In 1992, a high level EDOS/Ecom requirements were formulated and provided to Nascom. Subsequent documents outlining Ecom requirements also became available in the following months. Accordingly, the need to address Ecom related issues became more pressing. After carefully weighing the available resources, Nascom decided to withdraw from the RTOP program in 1993 to support the Ecom project. However, due to the RTOP's direct applicability to several Ecom issues, the work, equipment, and staff were absorbed by the newly created EMAT activity.

The EMAT activities formally began at the beginning of fiscal year (FY) 1993, and will continue until Ecom's Critical Design Review (CDR), scheduled for May 1995. After CDR, EMAT work

will be incorporated under the Ecom testing activity, which will emphasize Ecom system testing and integration. The modeling, analysis, and testbedding work performed after the Ecom testing and integration phases will be performed via the Ecom Sustaining Engineering Facility (SEF).

3.0 OBJECTIVE

The objective of EMAT is to perform the necessary modeling, analysis, and testbedding to support the Ecom project design, test, and integration phases. To meet this objective, EMAT will:

- perform testing to verify if COTS equipment can meet Ecom requirements
- recommend candidate hardware and software elements for Ecom
- identify requirements beyond COTS' capabilities
- perform availability, error, and trade-off analyses
- use modeling tools to obtain the candidate wide area network (WAN) topologies
- conduct periodic market surveys and assessments.

4.0 ORGANIZATION AND RESPONSIBILITIES

The EMAT activities are performed by Nascom personnel and their System Engineering, Analysis, and Support (SEAS) contractor. EMAT personnel also perform joint testing with AT&T to help define Federal Telecommunications System (FTS) 2000 services that Ecom/Nascom can use in the future. Pertinent results obtained from this joint testing activity are incorporated with the EMAT results. The Ecom Project Manager, in conjunction with the Ecom Project System Engineer, determine the EMAT work priorities and scheduling.

5.0 REPORTING MECHANISM

The EMAT team periodically presents its results in the *EMAT Reports*. These reports have been issued prior to each major Ecom project review. To date, three separate *EMAT Reports* have been delivered to the Ecom project.

The *EMAT Reports* primarily consist of four major sections. The first three sections detail the work accomplished in the three major areas, namely, modeling, analysis, and testbedding. The last section of the *EMAT Reports* presents results, conclusions, and recommendations organized by issues (e.g., delay, throughput, error sensitivity). This section allows the authors to integrate all related results and arrive at an overall conclusion for each major issue.

6.0 MODELING

The purpose of the EMAT modeling effort is to address and resolve those areas of Ecom that are not feasible for testbedding. There are two such areas that have been identified by the EMAT team. They include WAN topology modeling and reliability, maintainability, and availability (RMA) modeling.

The WAN topology modeling effort is accomplished in two phases. In the first phase, Ecom and EDOS periodically update a jointly developed EDOS and Ecom traffic model (EETM). This model contains assumptions and equations that allow both projects to interpret and process information stated in the *EDOS and Ecom Requirements* document. The output of this model is a database containing traffic volumes and types between individual source-destination pairs. The second phase uses this information to develop candidate Ecom WAN topologies.

A COTS modeling tool is used to develop the WAN topologies. This tool uses the EETM results, along with Ecom design rules and assumptions as an input. The resultant output contains candidate Ecom topologies optimized by performance and cost. The optimization is primarily accomplished by the tool's algorithms and tariff database. Minimal manual intervention is required to complete the optimization process. The resultant, candidate topologies, along with the design rules and assumptions, are presented in the *Ecom System Design Specification.*

The EMAT WAN modeling effort has provided important insight into designing WANs using common carrier circuits. Additionally, it has provided EMAT with the necessary platform to model "what if" scenarios in support of the Ecom and EOS costing exercises. The output of these "what if" exercises have already resulted in modifying, and in some instances eliminating, the cost sensitive EOS requirements.

The second type of modeling performed in this phase is RMA modeling. An in-house developed modeling tool called Automated Reliability, Availability, and Maintainability (ARAM) is used to produce these models. These models allow EMAT personnel to analyze the RMA characteristics of various network configurations. The ARAM modeling tool requires as input, network configurations with accompanying RMA numbers for each element within that configuration. Operations concepts regarding manpower availability and staffing are also required as an input into the ARAM tool. The output of this modeling activity provides, at a minimum, the mean time to restore service (MTTRS) and availability numbers for the modeled network configuration.

Every candidate Ecom design undergoes RMA modeling to ensure that the MTTRS and availability requirements are met. The modeling duration is sufficient to simulate failures throughout the life of the Ecom system. The Ecom design identified in the *Ecom System Design Specification* has successfully undergone RMA modeling verification.

7.0 ANALYSIS

There are two kinds of analysis activities supported in the EMAT environment: mathematical analysis and tradeoff analysis. The mathematical analysis addresses the verification of theoretical performance via computational means. The tradeoff analysis focuses on conducting market surveys to perform technology versus cost studies and performance versus cost studies. No special tools are required to perform either of the above activities. However, to facilitate the research process associated with each, EMAT has established a reference library containing vendor brochures, equipment catalogues, textbooks, reference manuals, and conference papers.

The mathematical analysis conducted so far within the EMAT activity has focused on obtaining the communications protocol overhead and determining the Ecom error performance. The communications protocol overhead analysis was performed to determine the additional bandwidth required to transmit the individual user data streams. The obtained communications protocol overhead numbers were used to develop the equations appearing in the EETM.

The Ecom error performance analysis was conducted to characterize Ecom's real-time and science services. This analysis was performed on several end-to-end configurations. Past test results, current common carrier performance numbers, and theoretical calculations were used to obtain the pertinent results. These results, expressed as error free seconds and packet loss ratios, are included in the *Ecom Design Specification.*

In addition to conducting mathematical analysis, EMAT personnel periodically perform market surveys to keep abreast of new COTS products and technologies. These surveys are primarily accomplished by mapping vendor literature and presentations to Ecom requirements. The latest survey performed in EMAT focused on Asynchronous Transfer Mode (ATM) switches. This

survey was performed to initiate the procurement process to acquire three ATM switches. Over the past year, EMAT has also conducted market surveys to evaluate Network Management System (NMS) packages, T3 multiplexers, routers, and local area network (LAN) analyzers. These surveys usually culminate in informal product recommendation lists. Products appearing on these lists are then evaluated in the EMAT laboratory.

8.0 TESTBED

The purpose of the testbed portion of the EMAT activity is to create and maintain an operational laboratory, procure and/or borrow communications equipment, develop test scripts and scenarios, and evaluate the functional and performance characteristics of COTS communication equipment in candidate Ecom configurations. This purpose is accomplished in two phases.

The first phase addresses the development of an operational laboratory, as well as completion of low (0-10Mbps) and high (10-100 Mbps) speed tests using Transmission Control Protocol (TCP)/Internet Protocol (IP) and Transport Protocol (TP) 4/Connectionless Network Protocol (CLNP) protocols over Fiber Distributed Data Interface (FDDI) and Ethernet LANs. The necessary test equipment, workstations, and other required tools are procured in this phase.

The second part focuses on ATM and Synchronous Optical Network (SONET) testing. The objective in this phase is to evaluate COTS ATM switches and interfaces in multiple LAN-WAN configurations. The design, configuration, and integration of the Simple Network Management Protocol (SNMP) based COTS network management (NM) package is also addressed in this phase.

8.1 PHASE I TESTING

In the first phase of testing, the TCP/IP, TP4/CLNP, Ethernet, and FDDI protocols are used to characterize and evaluate the functionality and performance of COTS hubs, routers, and multiplexers. The COTS equipment is configured and tested in selected LAN-WAN-LAN configurations. Key functional and performance parameters collected and analyzed from these tests are described below:

i)	No Loss Point:	Determines the maximum single steam data rate that the hub, router, or multiplexer can sustain without losing data.
ii)	Loss:	Describes the pattern and amount of data loss at rates above the No Loss Point.
iii)	Service Restoral:	Finds the time and effect of restoring connectivity due to either a hub, router, multiplexer, or link failure.
iv)	Delay:	Provides delay incurred by a packet due to either transport delay or equipment latency.
v)	Filters:	Characterizes the effect on No Loss Point due to packet filtering.

To obtain the above parameters, exhaustive testing is performed using different packet sizes, test durations, and vendor equipment. As a standard operating procedure, short term (1- 5 min.) tests are performed initially to prove the test functionality and to obtain a preliminary No Loss Point. Long duration (1-36 hr.) tests are then performed to obtain accurate results. To simulate a "real world" Ecom environment, the SNMP polling feature is enabled, the router's packet filtering option is selected, and the WAN simulators are programmed to simulate circuit delay and errors.

A typical Phase I test configuration is shown below in Figure 2. In this configuration, the LAN analyzer provides generation and capture capability of IP or OSI packets. The FDDI concentrators provide the connectivity between the analyzer and the two FDDI LANs. The routers reside on these LANs and are connected to each other via WAN simulators. Depending on the individual test scenario, variations to this configuration are made to include additional LAN analyzers, multiplexers, end systems, and Ethernet hubs.

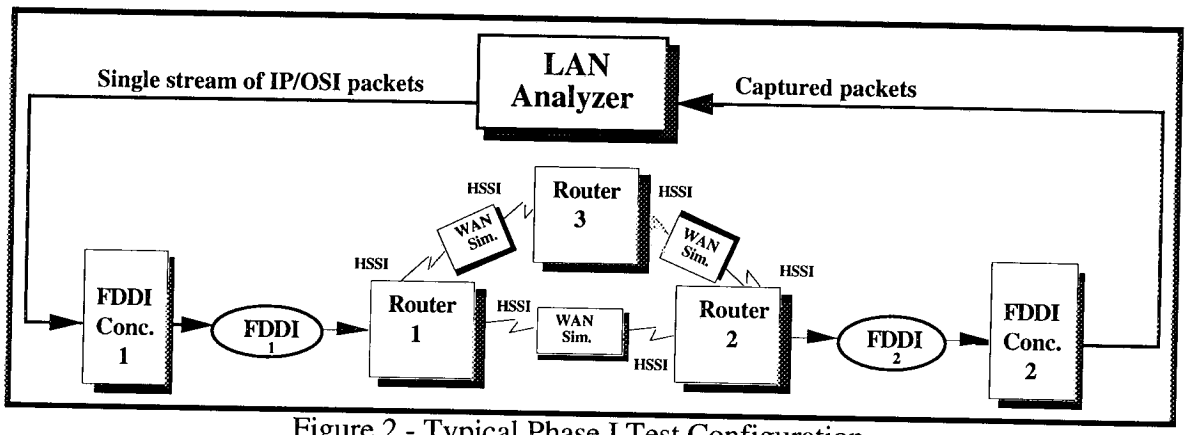

Figure 2 - Typical Phase I Test Configuration

The test results obtained to date in this phase have verified the capability of COTS equipment to process standard protocols at high data rates (1-25 Mbps) in Ecom specific configurations. The Ecom delay and service restoral requirements have also been validated. Additional testing still needs to be performed as newer equipment becomes available in the marketplace. Due to vendor agreements, the actual results are classified as sensitive material and, accordingly, are not included in this paper. Interested readers should contact the Ecom Project Manager to request these results.

8.2 PHASE II TESTING

In Phase II, the objective is to evaluate ATM switches to determine if they can be used for Ecom. Additionally, this phase addresses the integration and development of an SNMP NMS with a COTS Structured Query Language (SQL) database and trouble ticketing system. To meet these objectives, COTS ATM switches and NMS packages are purchased/borrowed, tested, and evaluated in the EMAT laboratory.

8.2.1 ATM TESTING

The ATM switch evaluation began in April 1994 with the acceptance of three, COTS ATM switches. After resolving initial switch power-on configuration issues, actual testing work began. Specific issues investigated included switch failover, circuit failover, bandwidth management, cell loss, switch management, and router/switch integration.

The switch failover tests addressed the redundancy features of the switches and the capability to automatically transfer to a back-up switch. The circuit failover tests explored the re-establishment of Permanent Virtual Circuits (PVCs) in the event of a failed common carrier circuit. The bandwidth administration management tests focused on call admission control, bandwidth allocation, traffic shaping, traffic policing, congestion control, and virtual circuit prioritizing mechanisms. The cell loss tests characterized cell loss occurring in the switches under various traffic loads. The switch management tests determined the vendor-specific management capabilities, as well as the ability to manage the switches via a third-party, multi-vendor SNMP based NMS. The router/switch integration effort interfaced the routers and workstations with

ATM switches to support end-to-end testing. The preliminary results obtained from these tests are documented in the ATM test reports.

The generic ATM testing configuration used to resolve ATM issues is shown in Figure 3. In this configuration, three ATM switches are connected to each other on the WAN side via DS-3 channel simulators. On the user side, these switches are connected to workstations, routers, and ATM analyzers. This configuration is modified depending on the specific issue that is being investigated.

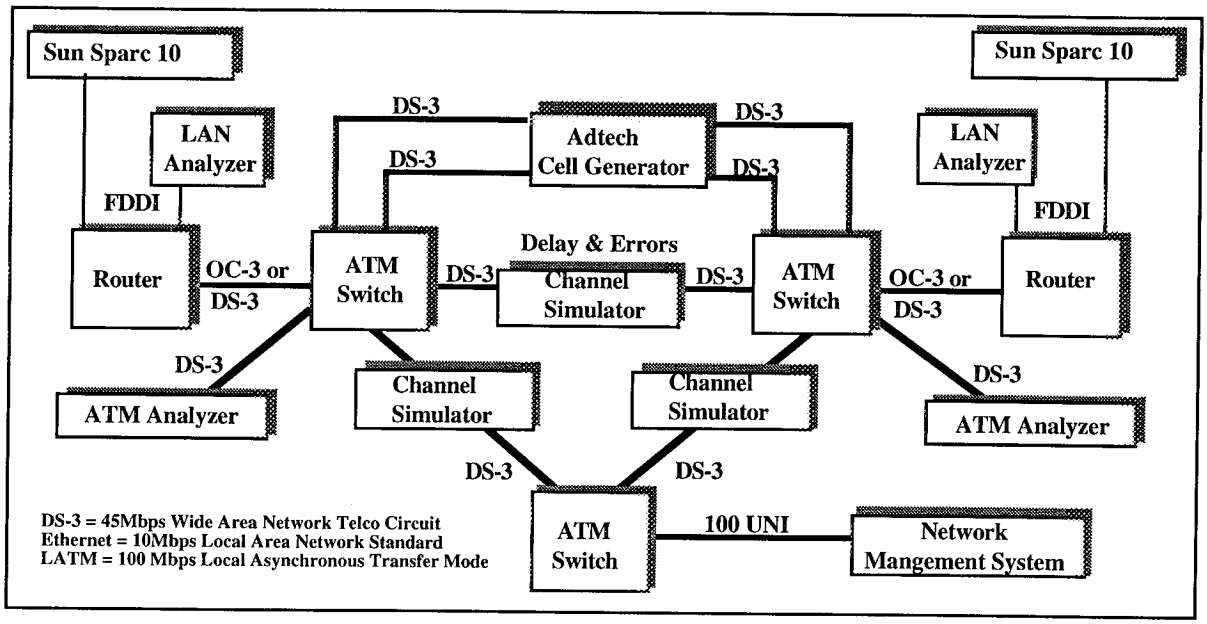

Figure 3 - ATM Test Configuration

The testing and evaluation of the EMAT procured switches is nearly complete. Work has already begun to evaluate other vendors' switches. As ATM technology and associated products mature and become readily available in the marketplace, they will be brought in and evaluated in the EMAT laboratory to ensure compliance with Ecom requirements. The test results obtained from these evaluations will be documented in future ATM test reports.

8.2.2 NMS TESTING

EMAT is currently prototyping a state-of-the-art, integrated NMS. The objective of this effort is to obtain an integrated NMS that extracts network health/status information, processes this information for alarm conditions, stores and reports this information, tracks fault conditions, and sends selected data to the EDOS NMS.

To accomplish this objective, COTS products are evaluated and development work is initiated. The COTS products evaluated include network management applications (NMApps), SQL databases, and trouble ticket systems (TTS). The NMApps packages configure and monitor the network. In addition, they collect the network's health/status data. The SQL database programs allow design and development of databases that facilitate data storage and retrieval mechanisms. The TTS provides an automated trouble ticket generation, processing, and tracking capability.

The NMApps, SQL database, and TTS are integrated in EMAT to obtain a complete NMS. This integration requires some in-house development work. This work focuses primarily on developing the interface between the NMApps software and the SQL database, and between the NMApps

software and the EDOS management system. Minimal development work may also be required to integrate the ATM management system with the NMApps. Major portions of this integration work is either under way or completed. The results and evaluations obtained to date are presented in the *EMAT Reports*.

9.0 CONCLUSION

Over past few years, EMAT has provided an excellent environment in which to conduct modeling, analysis, and testbedding activities. The results of the EMAT activity have helped verify that Ecom requirements can be met via COTS equipment, allowed Ecom to identify unrealistic requirements, and enabled Ecom to characterize the performance associated with the design. This effort has not only helped Ecom and Nascom, but also other projects within the MO&DSD directorate. As communications technology evolves and newer and better products become available in the marketplace, EMAT will continue to provide the government with the capability to test and evaluate products, and thereby minimize risk, prior to the design and implementation of communication networks.

10.0 ACKNOWLEDGMENTS

The information appearing in this paper represents a body of work performed over the past several years by Ecom project personnel. Civil servants, in conjunction with SEAS contractors, have worked diligently to create and operate the EMAT environment. The author appreciates the assistance provided by these personnel. In addition, the author would like to specifically thank Steven Smith, Bradford Torain, John Steedman, and Felicia Grice of the Ecom project for providing their reviews and comments on this paper.