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Case # 05-0270

An End-to-End Modeling and Simulation Testbed (EMAST) to Support Detailed Quantitative Evaluations of GIG Transport Services

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ABSTRACT

The future DoD transport vision is for the Global Information Grid (GIG) to provide an internet-like capability that meets the mobility, security, and reliability needs of a wide spectrum of DoD users. A variety of services must be provided to the users including management of resources to support QoS, a transition path from IPv4 to IPv6, and efficient networking across heterogeneous networks (i.e., wired/wireless, fixed/mobile, GND/Air/Space, etc.). Due to the complexity of the issues involved with the integrated GIG, it is only possible to quantify end-to-end GIG performance via modeling and simulation (M&S) techniques using component models having adequate fidelity. The purpose of this paper is to describe the End-to-End M&S Testbed (EMAST) that has been developed to address these issues.

INTRODUCTION

The future DoD transport vision is for the Global Information Grid (GIG) to provide an internet-like capability that meets the mobility, security, and reliability needs of a wide spectrum of DoD users. In order to achieve this vision, the transport design of each major DoD communications network must facilitate and direct the course toward an end-to-end, seamless, network-centric communications capability across all major DoD programs for which communications is a performance-determining factor. The move toward network-centric communications of the future must start with the fielded networks of today together with those that are in the process of being fielded or modernized. The final GIG design will include an integrated set of component networks comprised of both mobile and fixed assets at ground-based, air-based, and space-based locations. The communications traffic across the GIG will be comprised of a combination of voice, video, and data, across multiple security levels using an unclassified (black) transport layer. A variety of services must be provided to the users including management of resources to support QoS, a transition path from IPv4 to IPv6, and efficient networking across heterogeneous networks (i.e., wired/wireless, fixed/mobile, GND/Air/Space, etc.).

While the transport design of the component networks will be locally optimized, it is not clear that the end-to-end network communications performance of the integrated GIG will result in adequate performance simply because the component networks do. Due to the complexity of the issues involved with the integrated GIG, it is only possible to quantify end-to-end GIG performance via modeling and simulation (M&S) techniques using component models having adequate fidelity. The purpose of this paper is to describe the End-to-End M&S Testbed (EMAST) that has been developed to address these issues.

EXTENSION OF JTRS/FCS-C M&S ENVIRONMENT

The EMAST capability is an extension of the M&S Environment (MSE) developed over the past several years in support of the Joint Tactical Radio

System (JTRS) Joint Project Office (JPO) and the DARPA Future Combat Systems Communications program [1]. The MSE, as shown in Figure 1, is comprised of two COTS products: COMTEST [2] and OPNET Modeler [3][1], offered by SAIC and OPNET Technologies, respectively, augmented by a number of specially developed software (S/W) components depicted in gray in Figure 1 below.

COMTEST is used to develop the operational scenarios. It provides a graphical user interface (GUI) to facilitate the placement of nodes, define their mobility, and build the IER and thread-based traffic profile using a detailed set of linked property tables. The primary output of COMTEST is a set of files, which includes a scenario definition file (SDF), message definition files (MDF), and platform definition files (PDEF). These describe the scenario in terms of the nodes, their mobility as a function of time and the traffic profile information. COMTEST also generates a binary file containing the terrain profiles for each pair of nodes at every user-defined time increment. This information is used to generate the terrain-induced path attenuation data using TIREM [4].

OPNET is a discrete event network simulation package offered by OPNET Technologies that allows the user to develop, build, and evaluate models of any communication network, device, protocol, and application. OPNET is widely used in both commercial and DoD applications. The contractor-developed OPNET models for their respective technologies are integrated into the M&S Environment. Once the OPNET simulation is completed, performance data is generated that is IER and thread-based and includes a variety of performance parameters including completion rates, latencies, etc.

As shown in Figure 1, there are three sets of S/W components that were developed as part of the M&S Environment: (1) the SDF Parser, (2) the Pathloss S/W, and (3) the OPNET-Internal S/W components. The SDF Parser and the OPNET-Internal S/W components serve as the “glue” that support the COMTEST/OPNET interface while the Pathloss S/W provides the means by which terrain- and foliage-based attenuation can be quantified. Each of these S/W components is described in greater detail in [1].

PHASE I OF EMAST

Phase I of EMAST was completed in September ’04. As shown in Figure 2, EMAST builds upon the M&S Environment by utilizing the SDF Parser, the Pathloss S/W, and the OPNET-Internal S/W components as the “engine”. These components are augmented by a scenario repository that includes all of the scenarios generated using COMTEST within the framework of the M&S Environment and a model repository that includes “surrogate” versions of the wideband networking waveform (WNW), soldier radio waveform (SRW), and a Ka-band bent-pipe satellite terminal (Ka-SAT). These “surrogate” models were developed as an interim solution until the final contractor-developed models become available and include abstractions for some of the functionality supported by the respective waveforms for which limited documentation was available.

A key functional enhancement of EMAST relative to the MSE includes

[1] The ability of EMAST to support multiple radio device types (e.g., WNW, SRW, and KaSAT) simultaneously operating within multiple networks, and

[2] The ability of EMAST to support the evaluation of heterogeneous networks.

Both of these enhancements were needed to support the quantitative evaluation of communications networks on an end-to-end basis. The term “end-to-end” implies the need to consider heterogeneous networks which requires the capability to evaluate combinations of wired and wireless networks in fixed and mobile

[1] We will refer to OPNET Modeler as OPNET in the remainder of this paper

configurations, comprised of ground-based, air-based, and spaced-based assets.

PROOF-OF-CONCEPT ANALYSIS (METHODOLOGY)

A proof-of-concept (POC) analysis was performed to demonstrate the capabilities of EMAST Phase I. A notional representation of the scenario used for the EMAST Phase I POC analysis is shown in Figure 3. The "Boise Scenario", originally developed in support of the DARPA FCS-C program [5], was used as the basis in developing the EMAST Phase I POC scenario. The Boise Scenario represents a wireless 20-node scenario based in Boise, Idaho, comprised of fixed and mobile ground-based and air-based platforms. The traffic profile for the Boise Scenario, shown in Figure 4, includes unicast and multicast traffic, comprised of data, voice, video and multimedia components. The original Boise Scenario traffic was used as "background" traffic when generating performance data during the POC analysis.

The Boise Scenario was then modified to demonstrate EMAST's end-to-end capabilities by adding an additional fixed wired node (referred to as the CONUS Ground Entry Point or GEP) that was used as a source platform, and a wired IP cloud through which the CONUS GEP communicated with the wireless portion of the scenario in Boise. The wired IP cloud gained entrance into the wireless network through a SATCOM gateway node using the Ka-band bent-pipe SATCOM terminal (KaSAT) referred to earlier. The wireless portion of the EMAST Phase I Scenario used a combination of WNW and SRW radio devices.

A screen-shot of the COMTEST configuration for the final EMAST Phase I POC scenario is shown in Figure 5. The light blue lines represent mobile trajectories while the yellow and red lines represent traffic transmissions among the nodes. As shown previously in Figures 1 and 2, COMTEST is used to define the scenario. This is done in terms of initial node placement, node mobility via trajectory lines and the offer traffic profile in terms of Information Exchange Requirements (IERS) and threaded traffic. COMTEST then generates a set of files, referred to as scenario definition files (SDFs), Platform Definition Files (PDEFs) and Message Definition Files (MDFs), that unambiguously describe the scenario. The resulting SDF, PDEF, and MDF files are then parsed using the SDF Parser resulting in an OPNET network model that is used for the simulations. A screen shot of the resulting OPNET configuration for the EMAST Phase I POC scenario is shown in Figure 6. The green lines represent the mobile trajectories while the solid black lines represent fixed wired connectivity.

The thread generated for the EMAST Phase I POC analysis is shown in Figure 7. This thread is comprised of 10 IER sequence steps that include 3 SATCOM hops (IER sequence numbers 0, 7, and 8). It also includes a multicast transmission to SCV1, SCV2, and SCV3 during IER sequence 1.

PROOF-OF-CONCEPT ANALYSIS (RESULTS)

The object of the EMAST Phase I POC analysis was to generate end-to-end performance data for the EMAST Phase I POC thread in terms of thread completion rate and end-to-end delay as a function of offered traffic load, using two difference transport protocols – UDP and TCP. Data representing the throughput ratio of total offered traffic was also compiled. It should be noted that the performance data generated and presented in this paper are for the purpose of demonstrating MAST Phase I capabilities and are not meant to be used as design guidance for GIG architecture decisions.

The end-to-end completion rate and delay performance of the EMAST Phase I POC thread described in Figure 7 is shown in Figures 8 and 9 for offered traffic loads ranging from a little less than 20 Kbps through almost 400 Kbps.

Referring to Figure 8, we see that the completion rate decreases as the offered traffic load increases for both UDP and TCP. Initially, TCP performs worse than UDP because of the impact of 3 SATCOM hops which, because of the relatively poor bit error rate (BER) (on the order of 10^{-5}), re-transmissions results with subsequent time-outs and traffic loss. As the offered traffic load continues to increase above 200 Kbps, the TCP and UDP are similar and continue to decease due to congestion-induced traffic loss which is accentuated by the fact that the EMAST Phase I POC thread is comprised of 10 IER sequence steps, any one of which will cause a failure for the thread to complete.

Referring to Figure 9, we see that TCP incurs larger end-to-end delays over the full range of offered traffic loads investigated. This is attributed to the SATCOM-induced re-transmissions which incur a heavy delay penalty. We also notice that the end-to-end delays are relatively high for both UDP and TCP (on the order of 10s of seconds) – this is again attributed to the fact that the EMAST Phase I POC thread shown in Figure 7 must complete 10 IER sequence steps prior to completion.

Finally, the throughput ratio performance data is presented in Figure 10 as a function of offered traffic load. The throughput ratio is defined as the ratio of the total network traffic received divided by the expanded network traffic sent (which accounts for multicast traffic). As shown, the throughput decreases as the offered traffic load increases - this is attributed to congestion and its effect on IER transmissions with subsequent traffic loss.

STATUS AND FUTURE PLANS

The development of EMAST Phase I is complete and a proof-of-concept analysis was performed to demonstrate its capabilities. It was shown that EMAST can be used to generate detailed performance data for heterogeneous communications networks on an end-to-end basis. The scenario used to demonstrate the EMAST Phase I capabilities included a combination of wired and wireless components, in fixed and mobile configurations, comprised of ground-based, air-based, and spaced-based assets.

Future plans for EMAST include the development of a performance enhancement proxy (PEP) and the integration of a Space Communications Protocol Standard (SCPS) model to support comparative evaluations of competing transport protocols including UDP, TCP, and SCPS. Additionally, we plan to develop a QoS model to incorporate into our wireless radio device models that will reflect limited DiffServ functionality and weighted fair queueing. Finally, our plans include the development of a High-Assurance Internet Protocol Encryption (HAIPE) model to facilitate our investigations into the routing performance in black and hybrid (i.e., mix of red and black) networks.

REFERENCES

[1] *"Overview and Application of a Modeling and Simulation Environment to Support Protocol Performance Evaluations in Mobile Communications Networks", Comparetto, G., Lindy, E., Mirhakkak, M., and Schult, N., presented at the 2004 International Conference on Modeling, Simulation and Visualization Methods (MSV'04), Las Vegas, NV, Paper # CIC2471, 21-24 June 2004.*

[2] *"COMTEST Scenario Generator User's Manual And Technical Reference", created by SAIC, 1410 Springhill Road, Suite 400, McLean VA., 22102*

[3] http://www.opnet.com

[4] http://www.alionscience.com/products/index.cfm

[5] http://www.darpa.mil/ato/programs/fcs_comm.htm

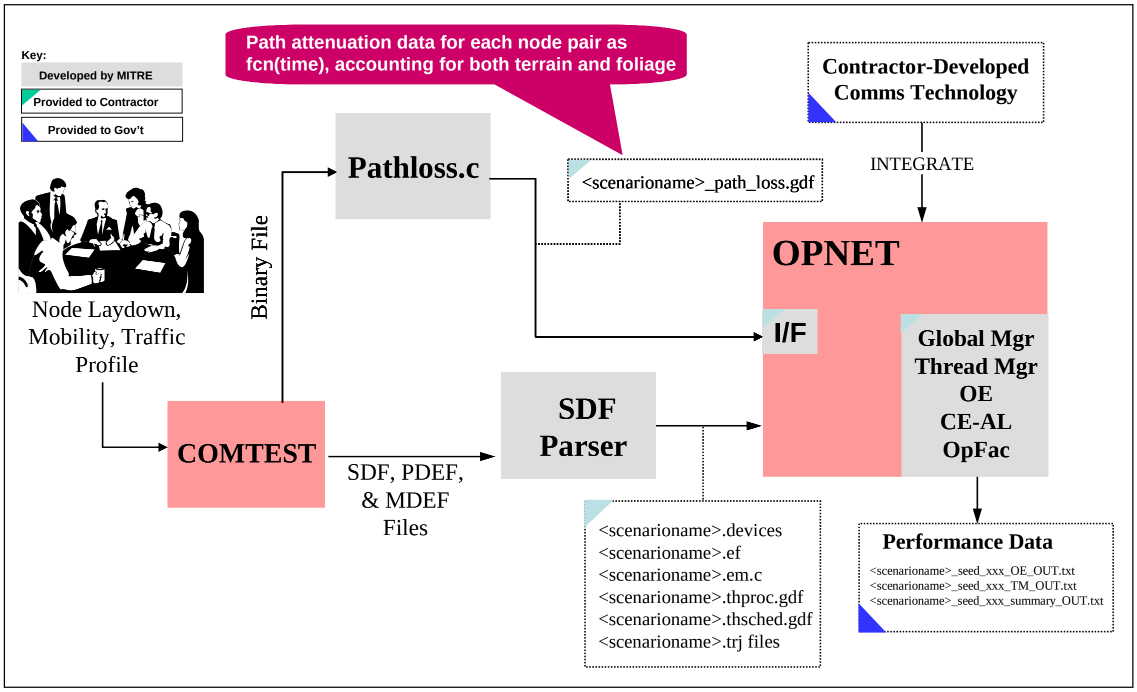

Figure 1: JTRS/FCS-C M&S Environment

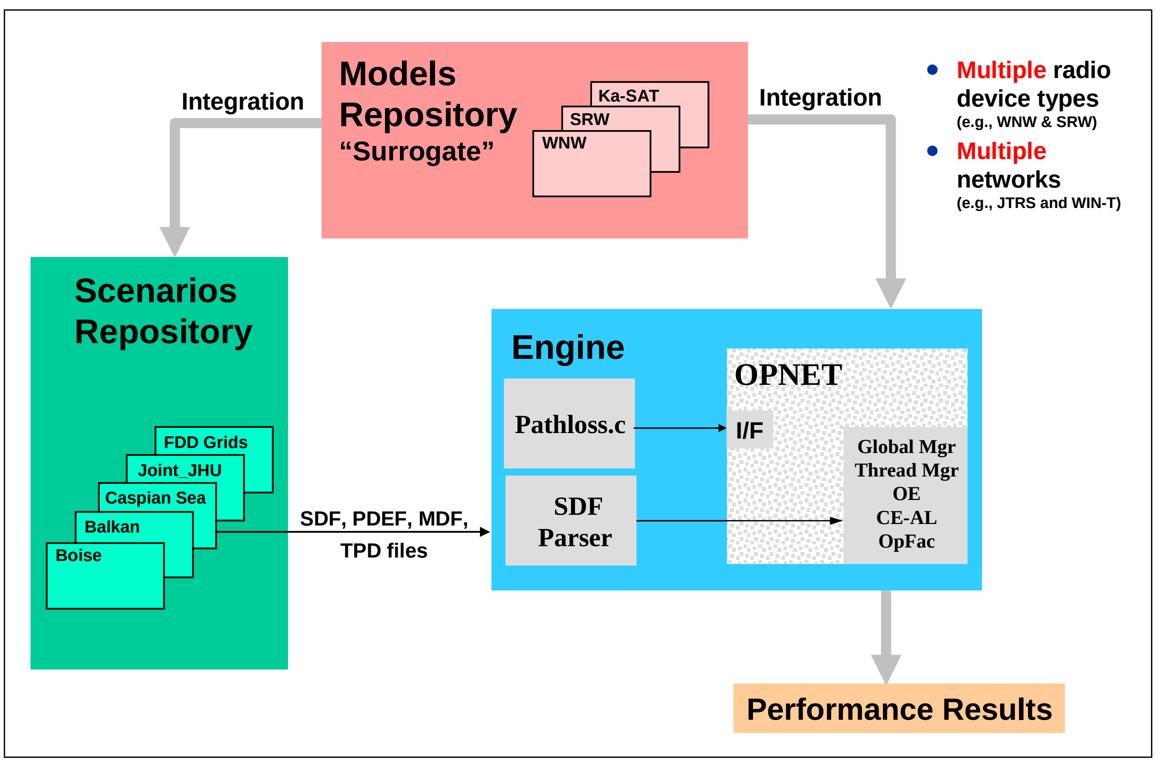

Figure 2: Phase I of End-to-End M&S Testbed (EMAST)

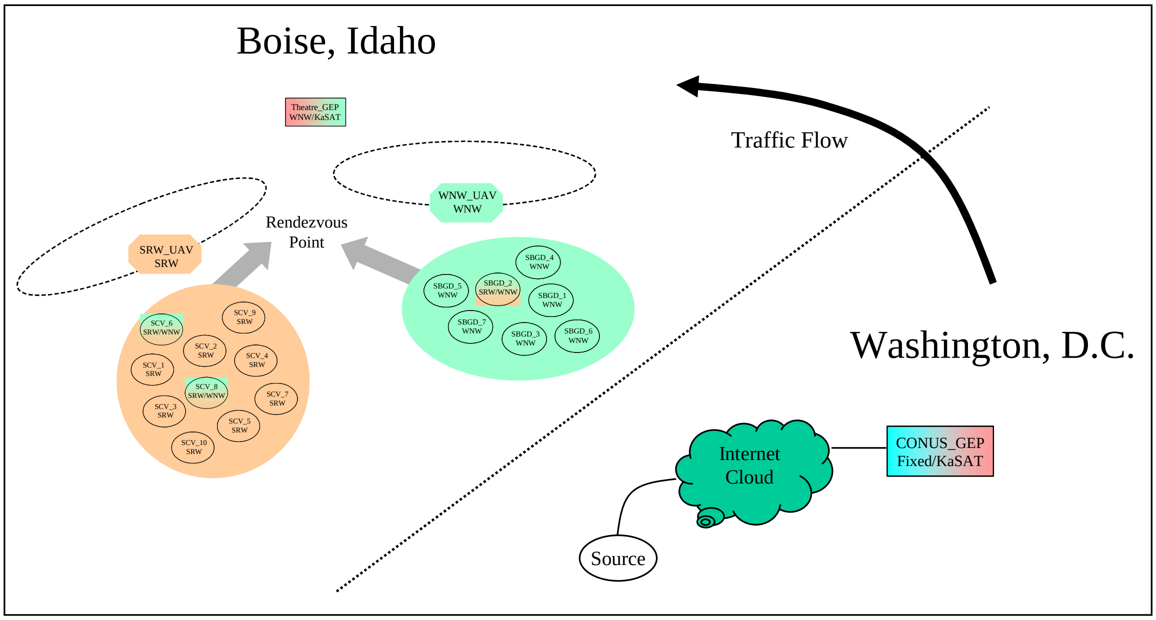

Figure 3: EMAST Phase I POC Scenario (Notional)

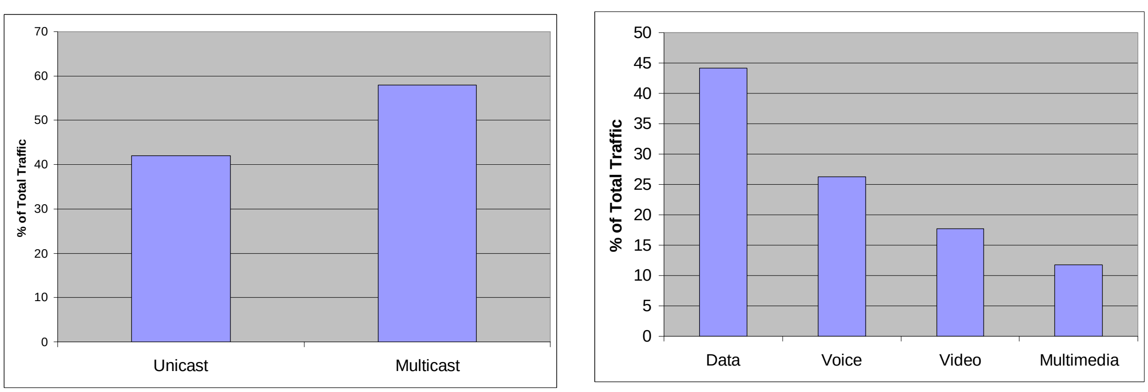

Figure 4: EMAST Phase I POC Scenario Traffic Profile

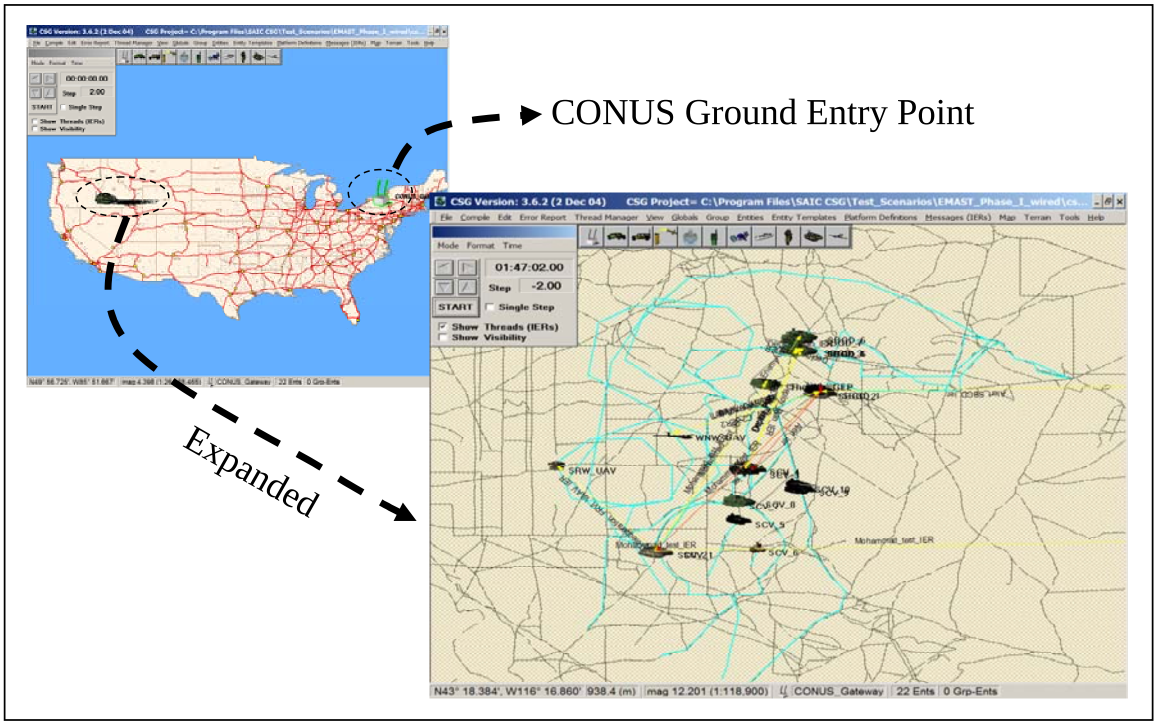

Figure 5: COMTEST Configuration of EMAST Phase I POC Scenario

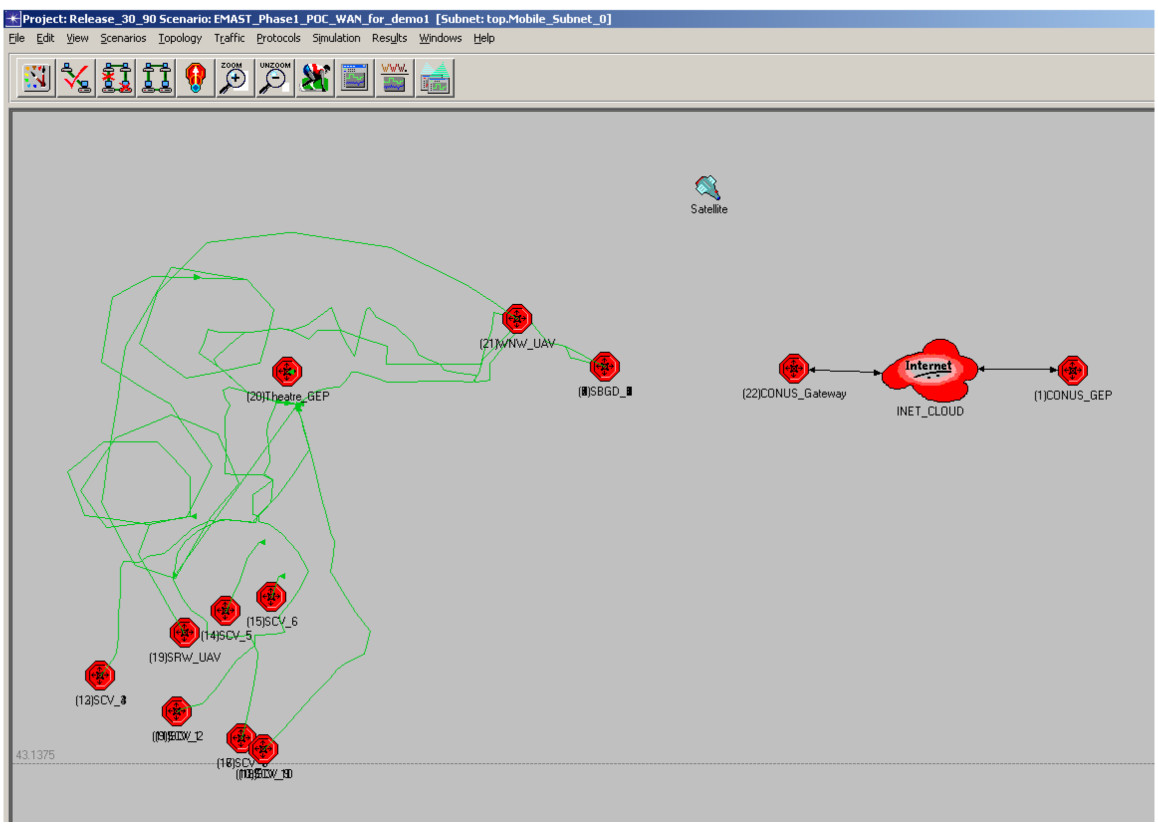

Figure 6: OPNET Configuration of EMAST Phase I POC Scenario

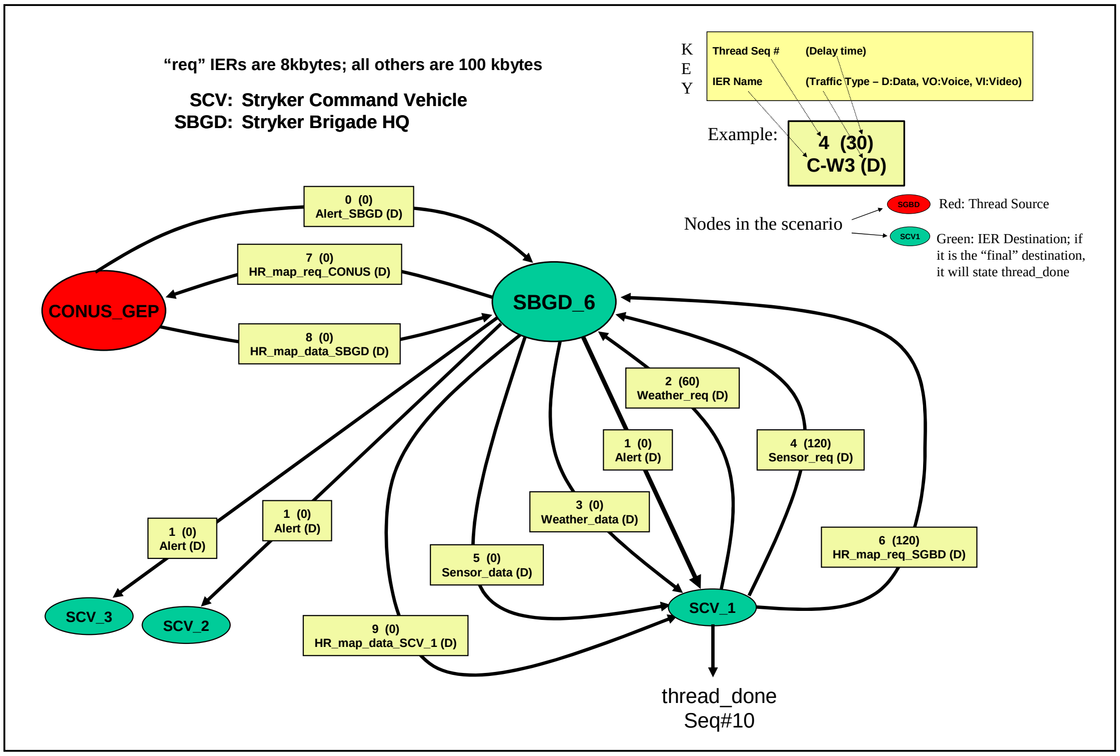

Figure 7: EMAST Phase I POC Thread

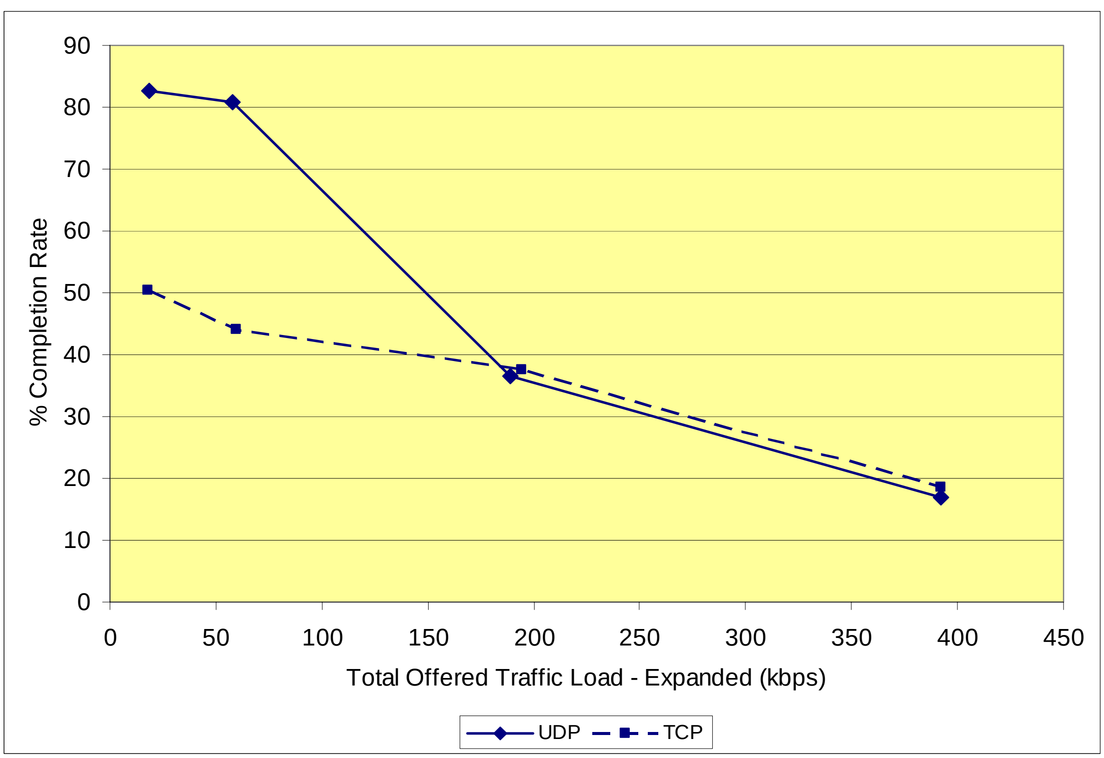

Figure 8: EMAST Phase I POC Thread Completion Rate

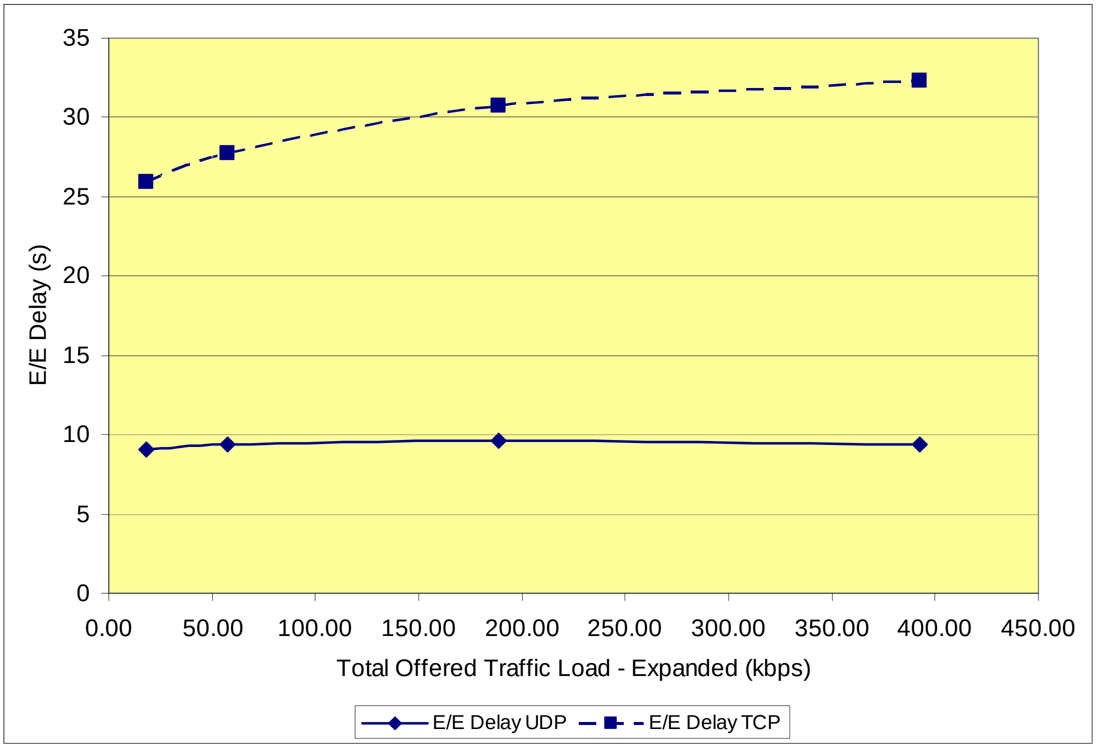

Figure 9: EMAST Phase I POC Thread End-to-End Delay

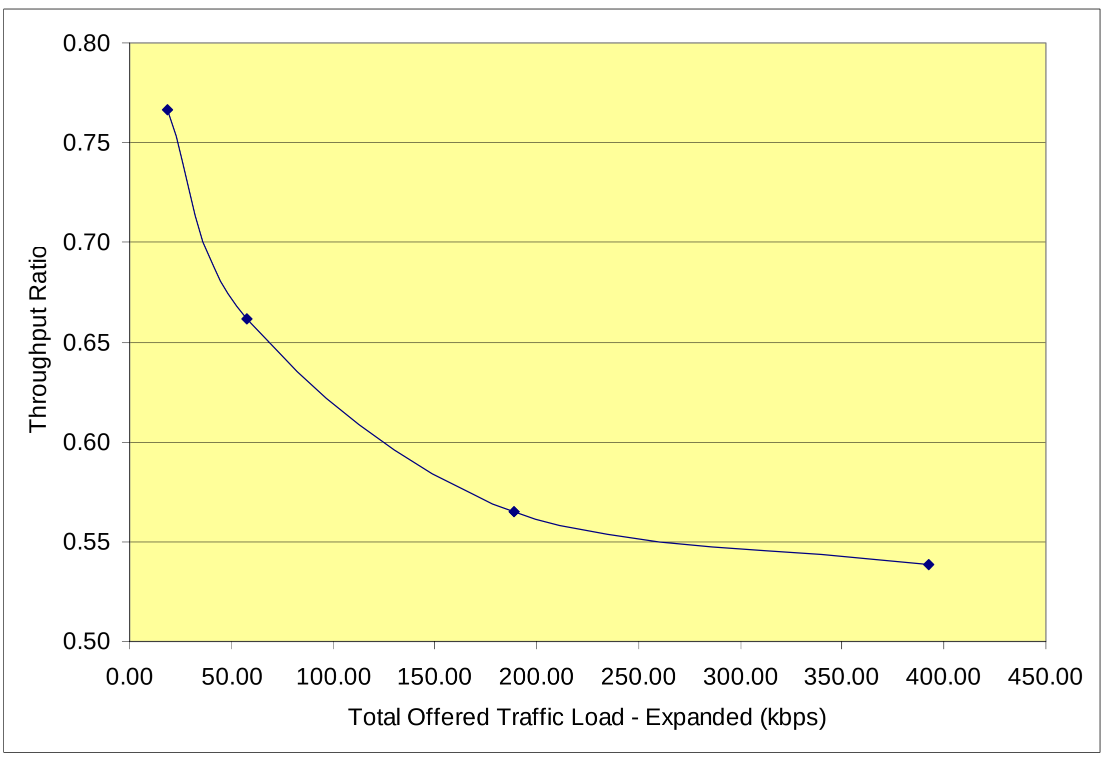

Figure 10: EMAST Phase I POC Analysis Throughput Ratio