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

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 2005**	2. REPORT TYPE	3. DATES COVERED **00-00-2005 to 00-00-2005**

4. TITLE AND SUBTITLE **An End-to-End Modeling and Simulation Testbed (EMAST) to Support Detailed Quantitative Evaluations of GIG Transport Services**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **The MITRE Corp,7515 Colshire Drive,McLean,VA,22102-7539**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**27**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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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].

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

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 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

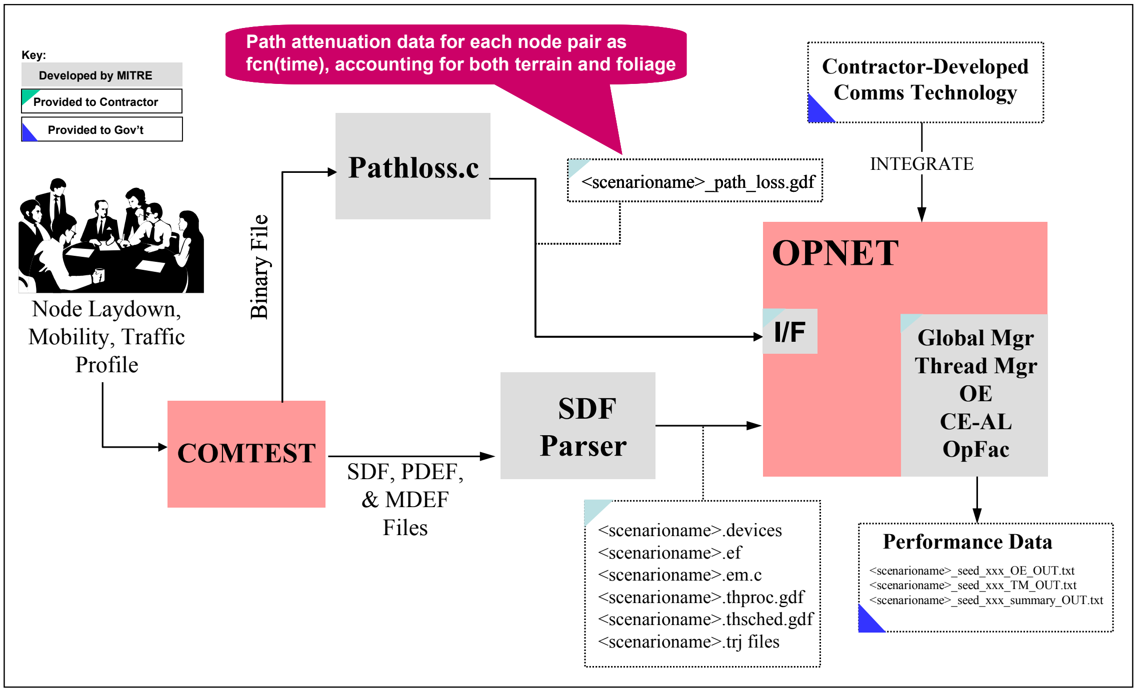

Figure 1: JTRS/FCS-C M&S Environment

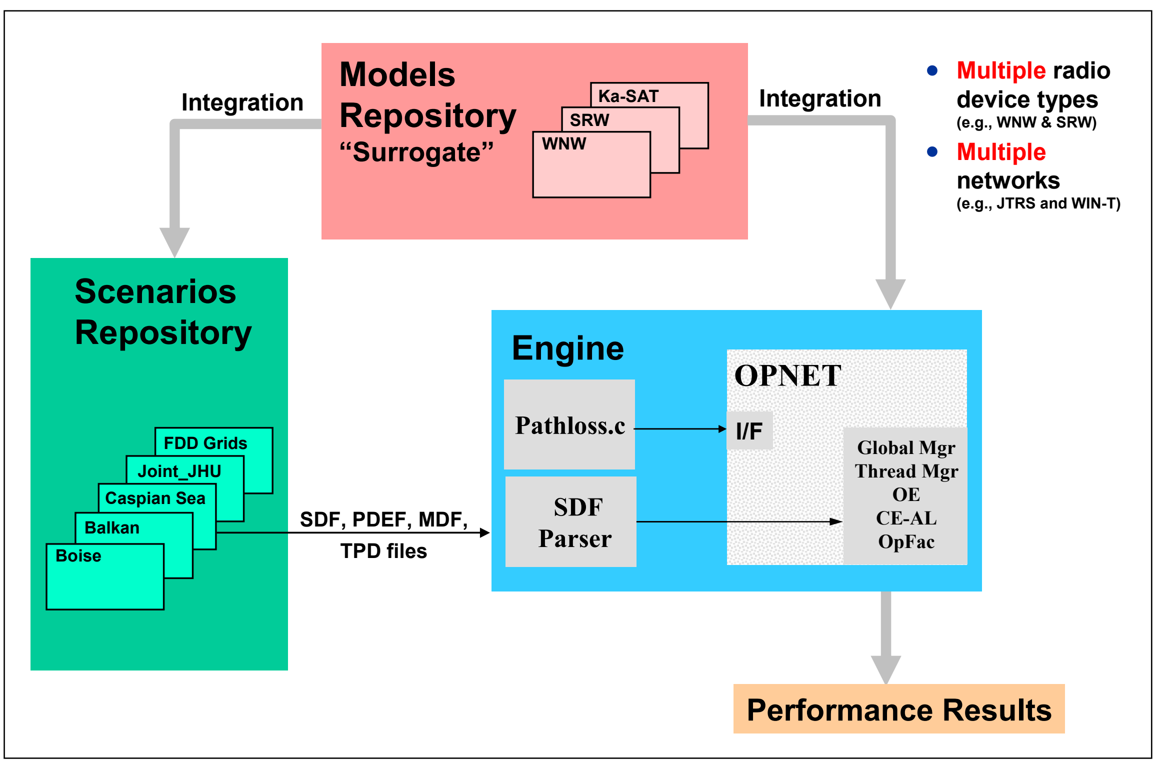

Figure 2: Phase I of End-to-End M&S Testbed (EMAST)

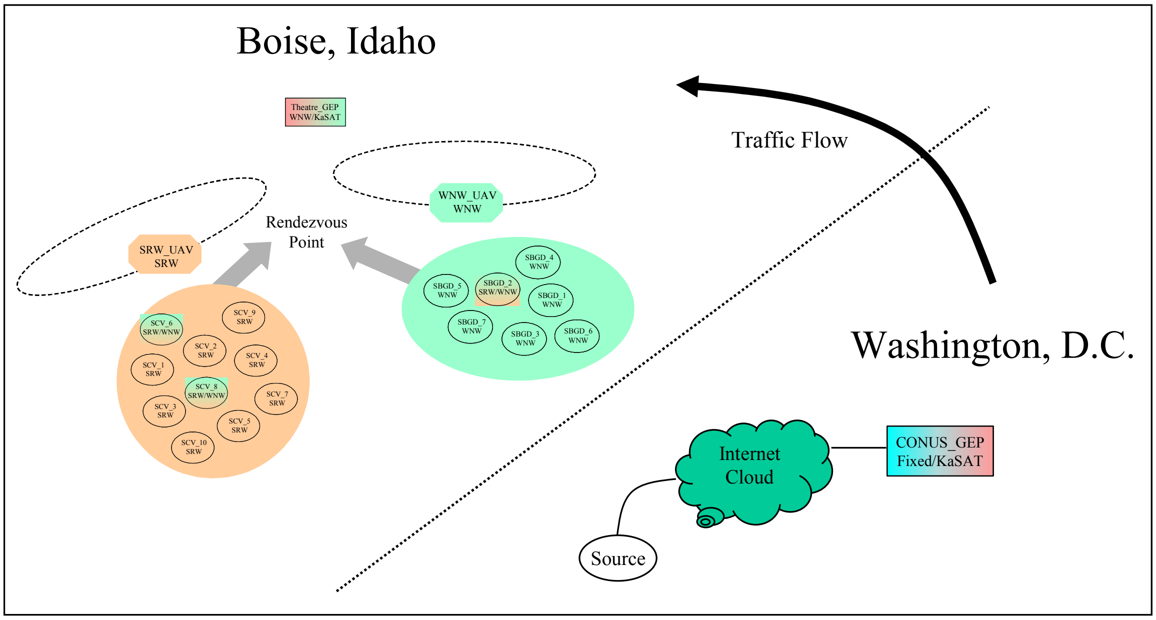

Figure 3: EMAST Phase I POC Scenario (Notional)

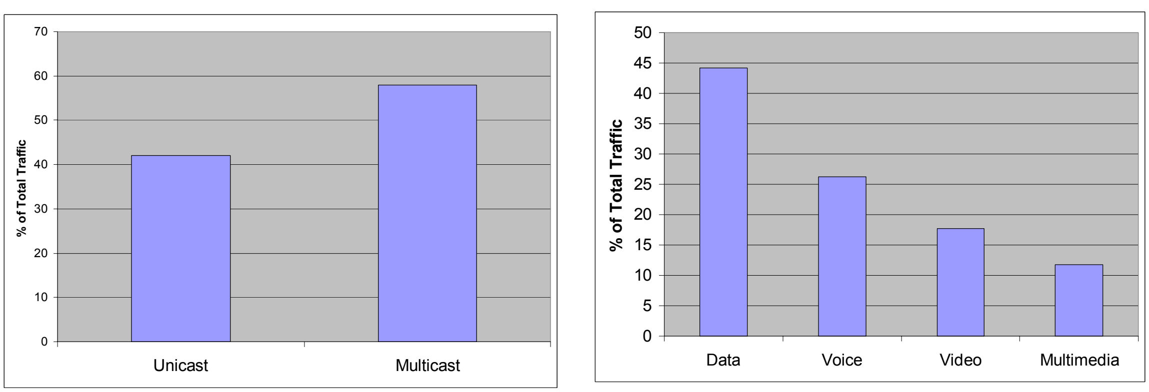

Figure 4: EMAST Phase I POC Scenario Traffic Profile

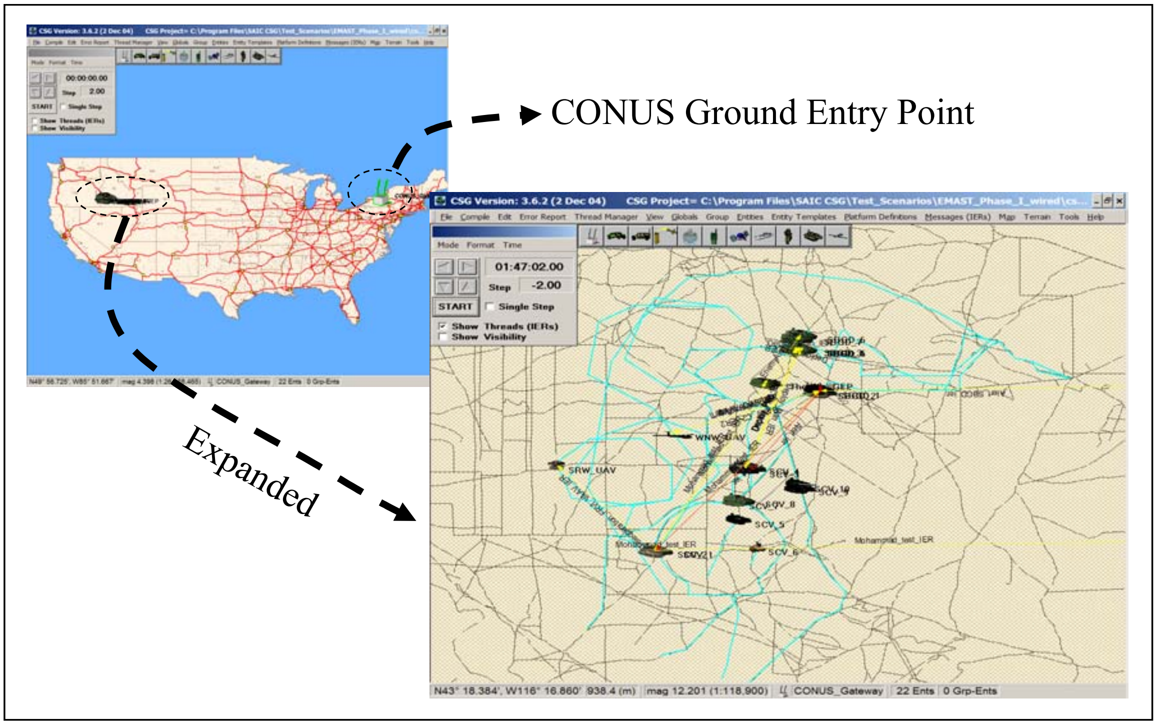

Figure 5: COMTEST Configuration of EMAST Phase I POC Scenario

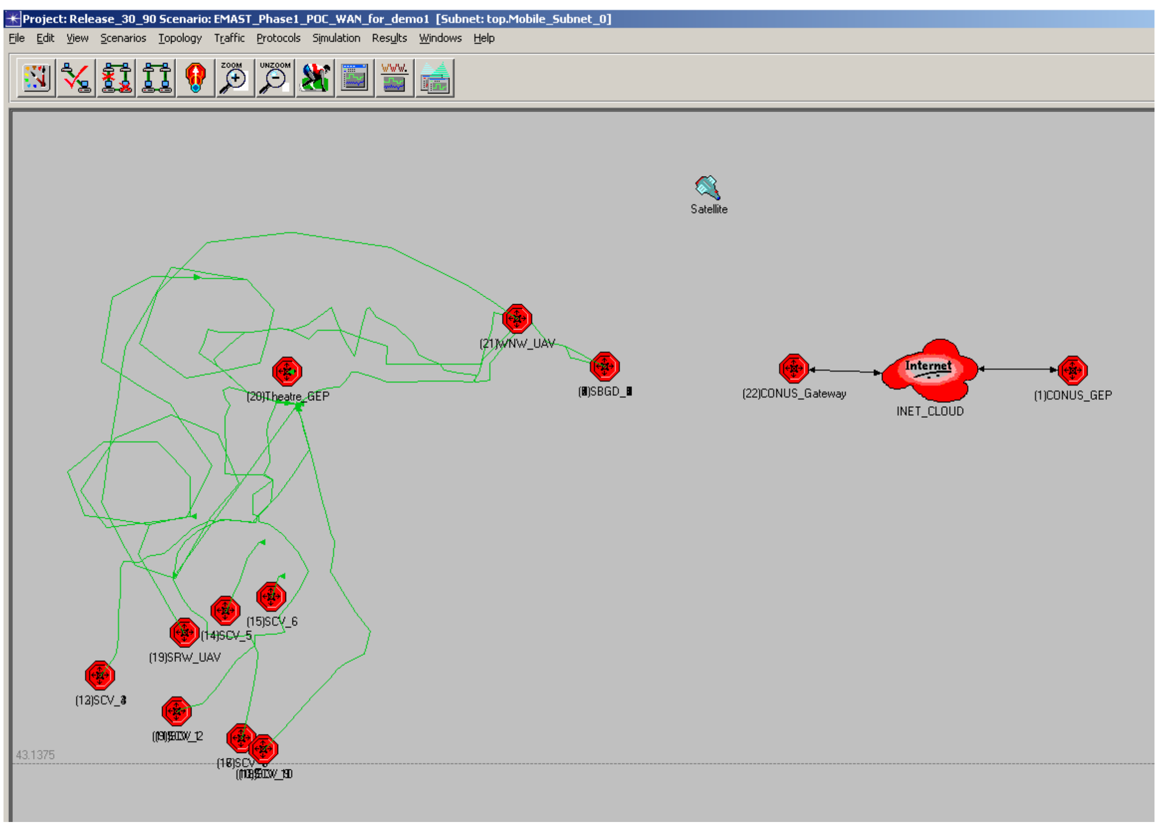

Figure 6: OPNET Configuration of EMAST Phase I POC Scenario

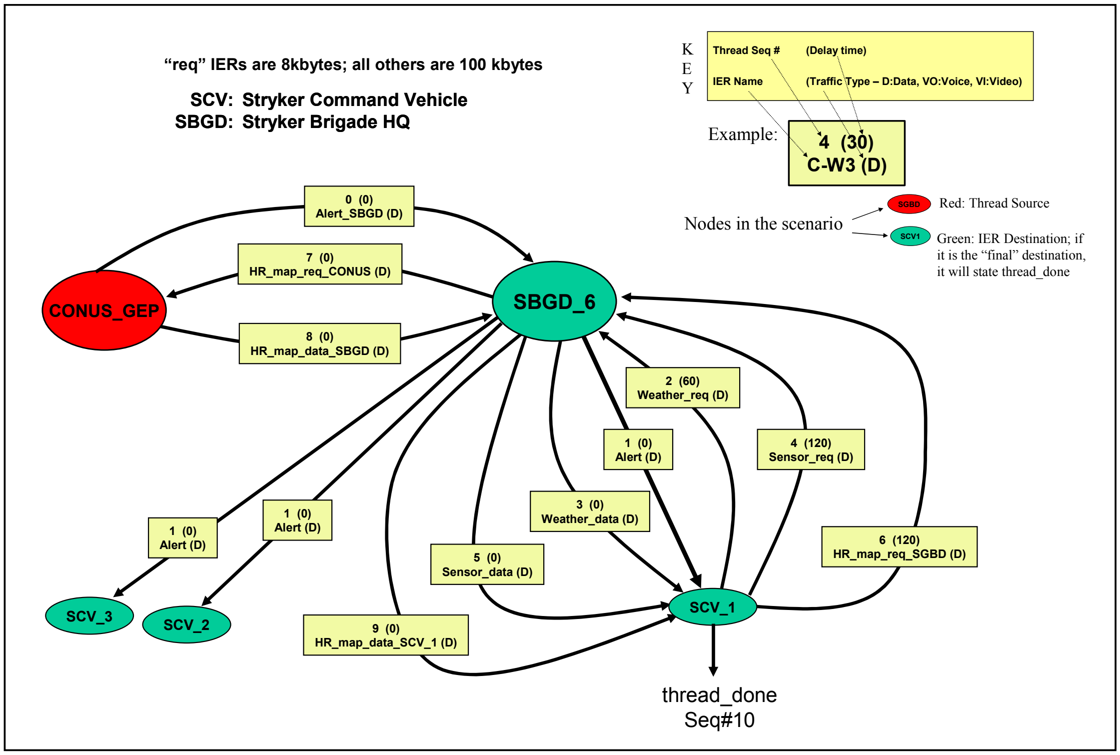

Figure 7: EMAST Phase I POC Thread

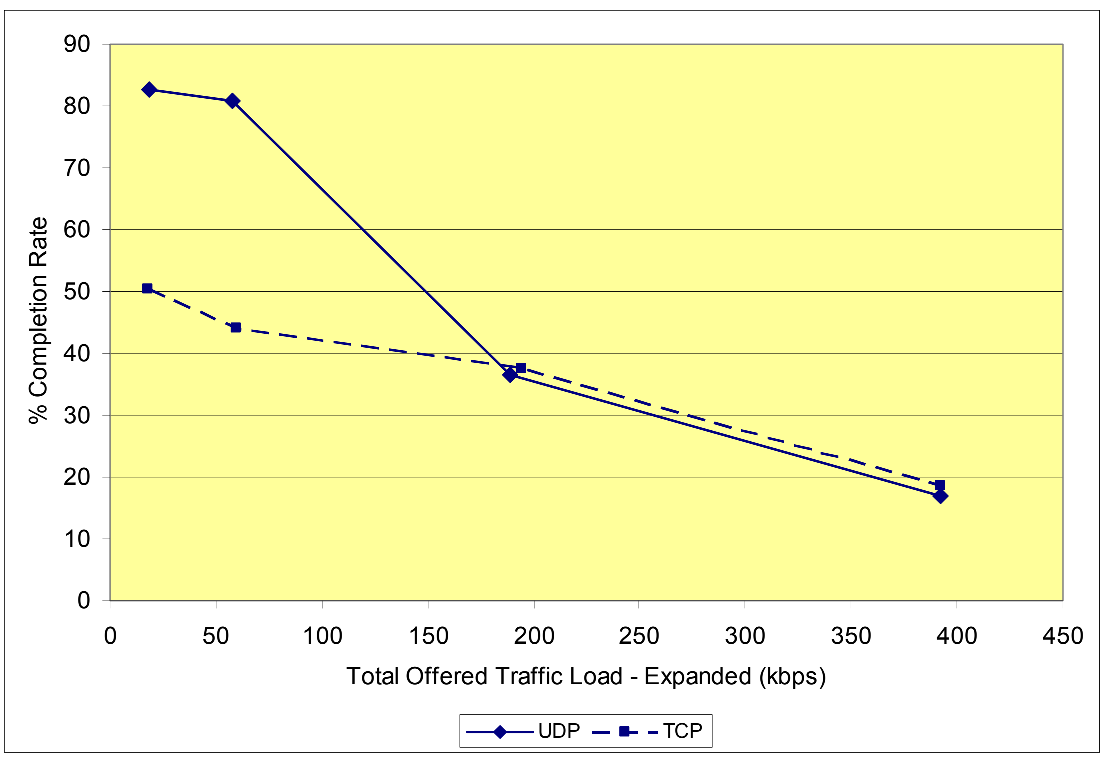

Figure 8: EMAST Phase I POC Thread Completion Rate

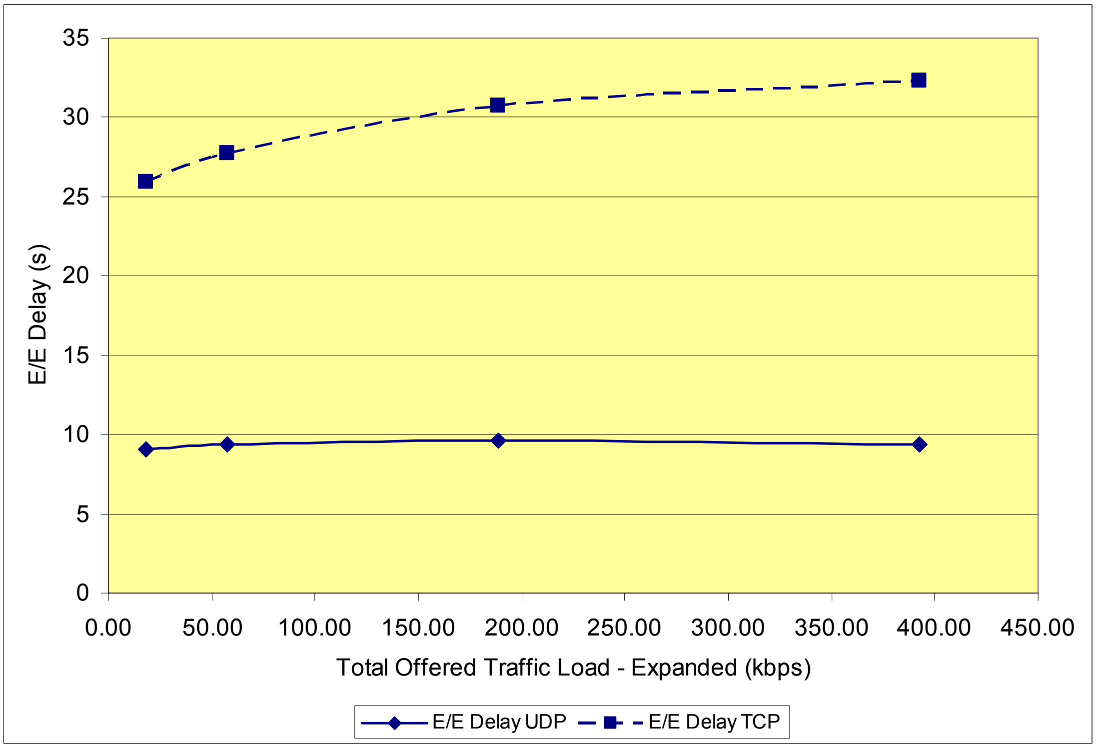

Figure 9: EMAST Phase I POC Thread End-to-End Delay

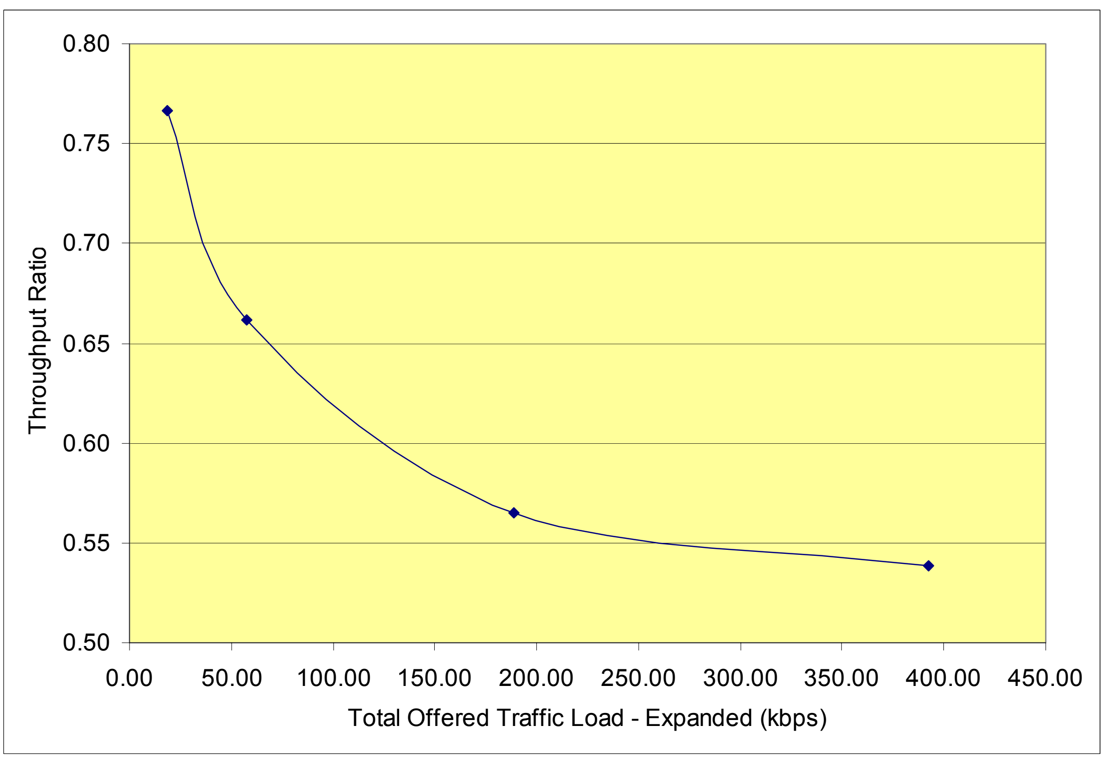

Figure 10: EMAST Phase I POC Analysis Throughput Ratio

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

14 June 2005

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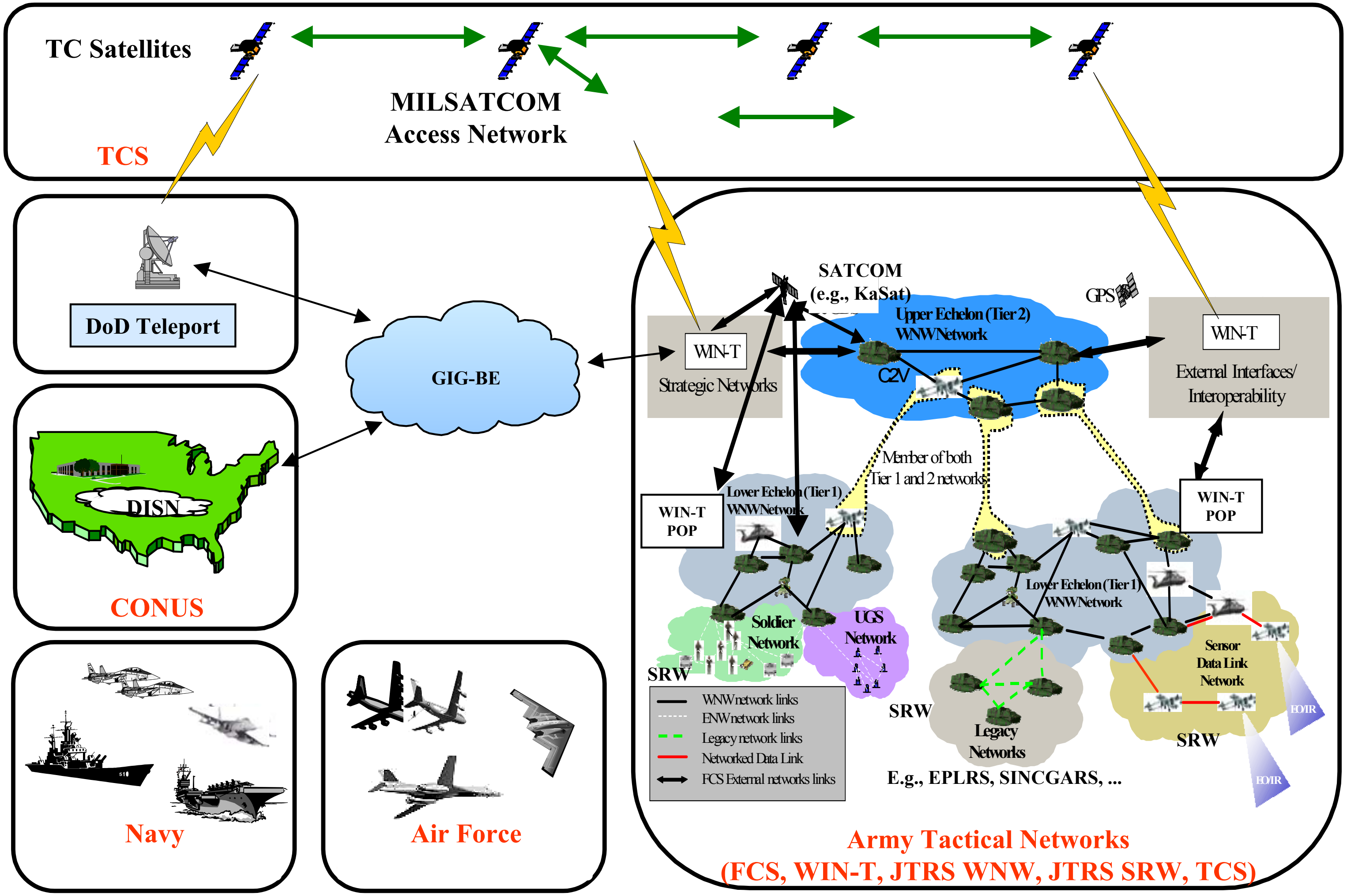
Objective: Evaluate Various Aspects of End-to-End Communications via M&S



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M&S: Modeling and Simulation

Technical Approach

- Extend the Modeling and Simulation Environment (MSE) developed by MITRE over the past several years in support of the JTRS and DARPA FCS-C programs
  - Single radio device type in a MANET wireless environment
  - Representative operational scenarios
  - Accounts for terrain-induced path attenuation
  - Supports reproducibility and re-use of models and scenarios
- Develop an End-to-End M&S Testbed (EMAST) having the same capabilities as the MSE plus ability to support:
  - Multiple radio device types (e.g., WNW & SRW)
  - Multiple networks (e.g., JTRS & WIN-T)
  - Heterogeneous networks (i.e., wired and wireless)

What Is An M&S Environment?

- For our purposes …..

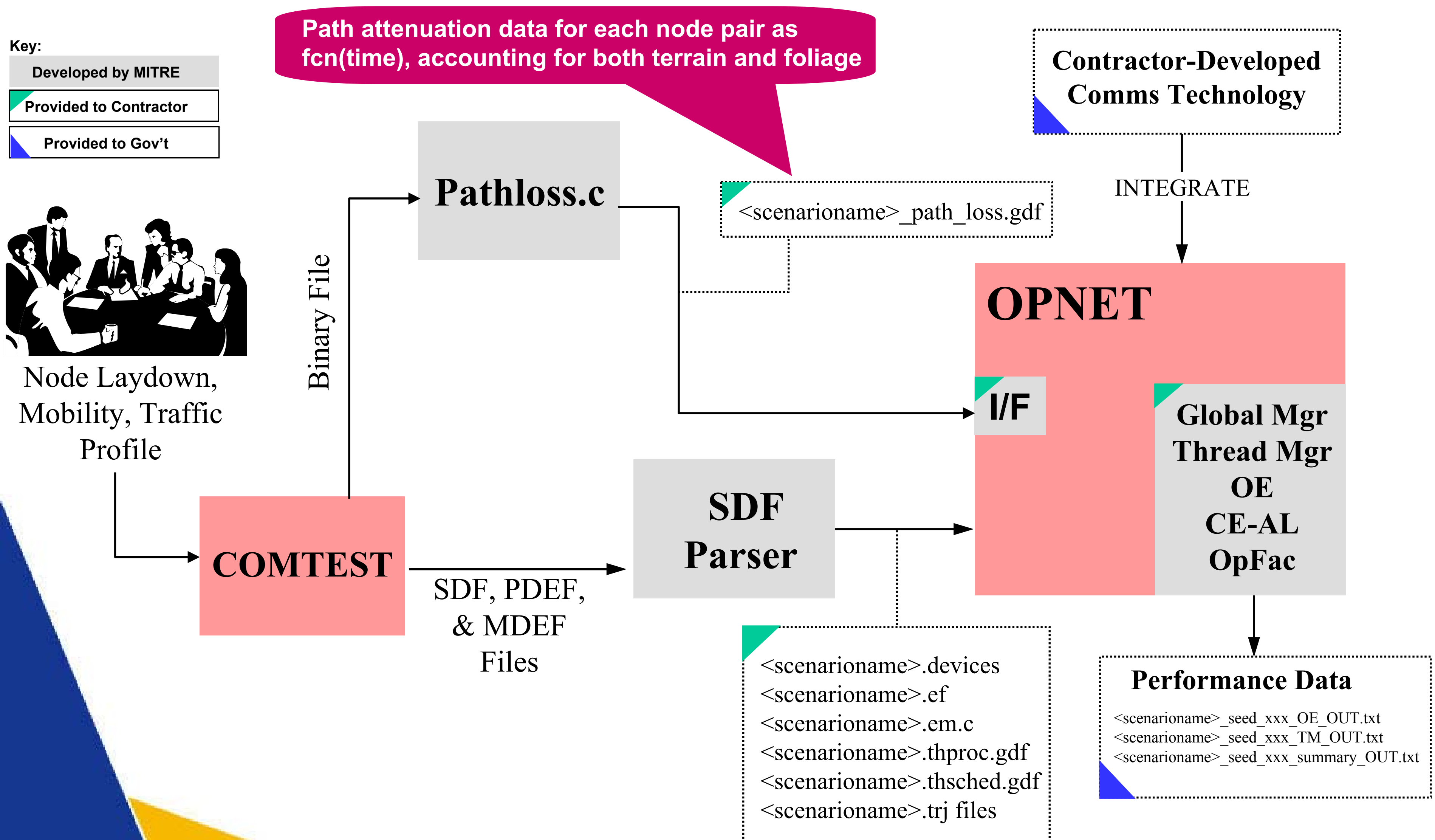
M&S Environment = "simulation kernel" + "stuff"

  - The "stuff" includes middleware to support such things as:
    - Scenario generation
    - File manipulation and format translation
    - Enhanced data collection
    - External (a priori) processing
  - It may also include other COTS tools

In our case, the "simulation kernel" is OPNET and the "stuff" includes all of the above

M&S Environment (MSE) Overview

(Being used to support JTRS WNW)



M&S Enviro

(Being used to su

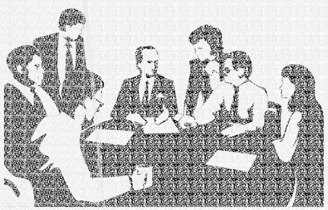
Path attenu
fcn(time), a

Key:

Developed by MITRE

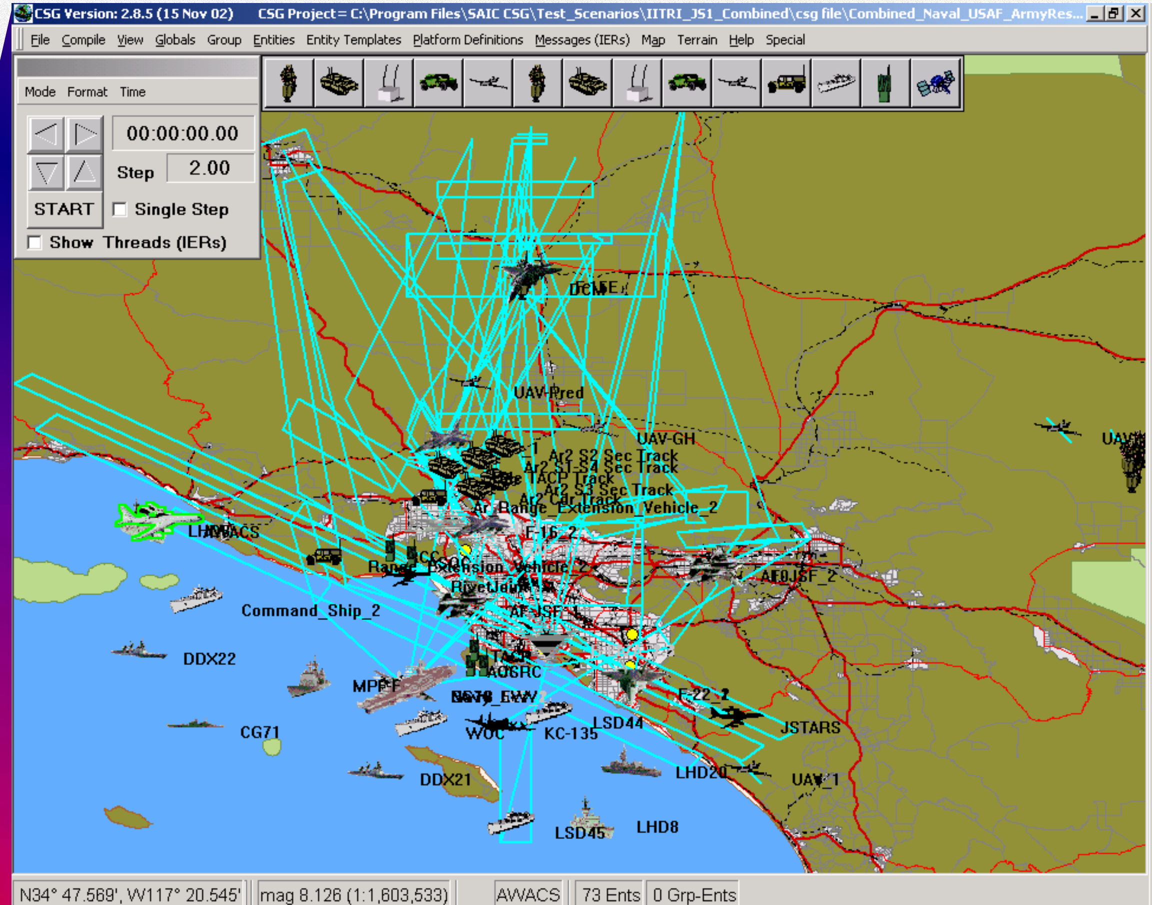
Provided to Contractor

Provided to Gov't



Node Laydown, Mobility, Traffic Profile

Binary File



COMTEST

...I, TDEF, & MDEF Files

...arser

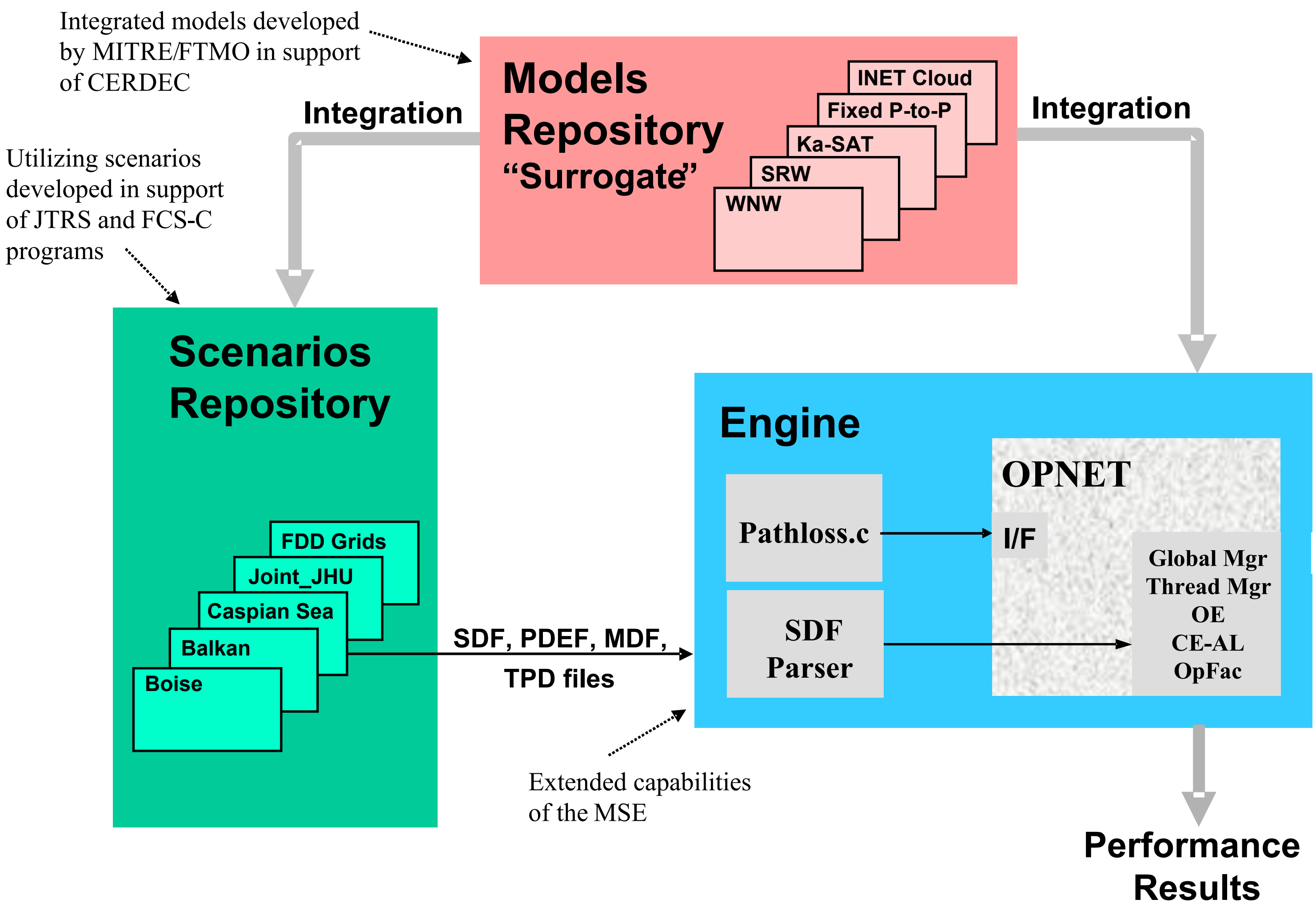
CE-AL OpFac

<scenarioname>.devices
<scenarioname>.ef
<scenarioname>.em.c
<scenarioname>.thproc.gdf
<scenarioname>.thsched.gdf
<scenarioname>.trj files

Performance Data

<scenarioname>_seed_xxx_OE_OUT.txt
<scenarioname>_seed_xxx_TM_OUT.txt
<scenarioname>_seed_xxx_summary_OUT.txt

EMAST – Phase I



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EMAST Capabilities

Phase I (Sept '04)

- 10 to ~100 nodes
- Heterogeneous (wired & wireless) networks
- Multiple radios devices
- Operational scenarios
- Static and mobile ground-based, air-based, and satellite-based nodes
- OPNET-based version 9.1
- Multicast traffic via flooding
- Transport – TCP or UDP
- Stryker Force scenario

Phase II (Sept '05)

- >100 nodes
- OPNET-based version 10.5
- Multicast traffic via PIM-SM
- Integrate PEP/SCPS models
- Support QoS (limited DiffServ)
- Support HAIPE (Spec vs2)
- Additional scenarios and analyses

What Can We Do With EMAST?

- Investigate the performance capabilities and/or impact of any comms network technology that can be modeled in OPNET
- Measures of performance include
  - E/E delay
  - Throughput
  - Completion rate
  - All on a packet, IER or Thread basis
- Example investigations
  - Modulation/coding and antenna design alternatives
  - TDMA vs CSMA MAC layer design alternatives
  - Unicast/multicast routing protocol design alternatives
  - Impact of different transport mechanisms (TCP, UDP, SCPS, etc. and combinations)
  - Impact of alternative QoS mechanisms or HAIPE

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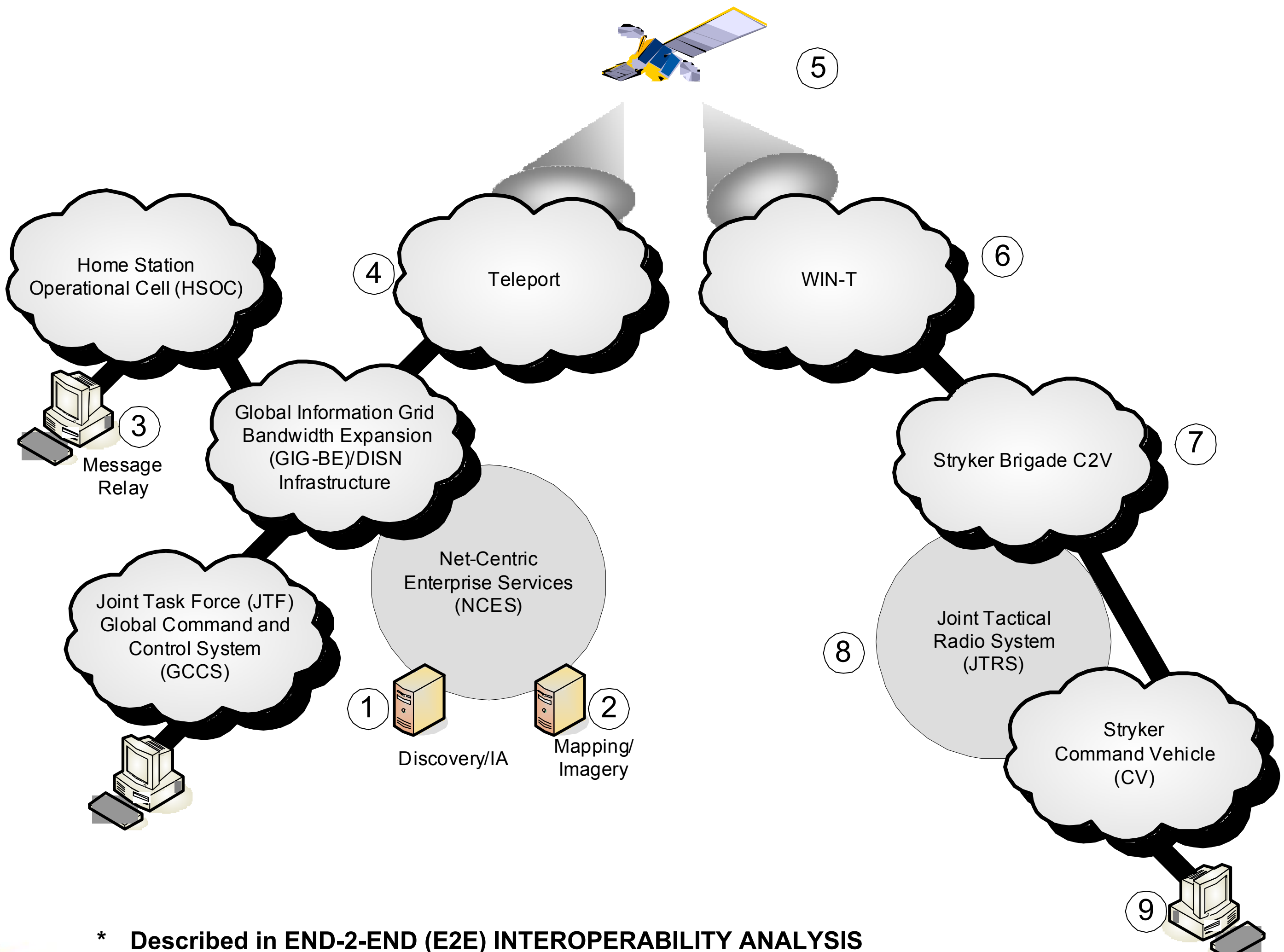
EMAST Proof-of-Concept (POC) Study

- Purpose
  - To validate the functionality of the EMAST Phase I capability
  - To demonstrate the use of the EMAST Phase I capability within the context of a "realistic" application
    - Leverage END-2-END (E2E) INTEROPERABILITY ANALYSIS report (DRAFT), June 2004 in defining study scenario
      - Focus on the transport service

Key GiG Systems Involved in Stryker Brigade Thread*



*** Described in END-2-END (E2E) INTEROPERABILITY ANALYSIS report (DRAFT), June 2004**

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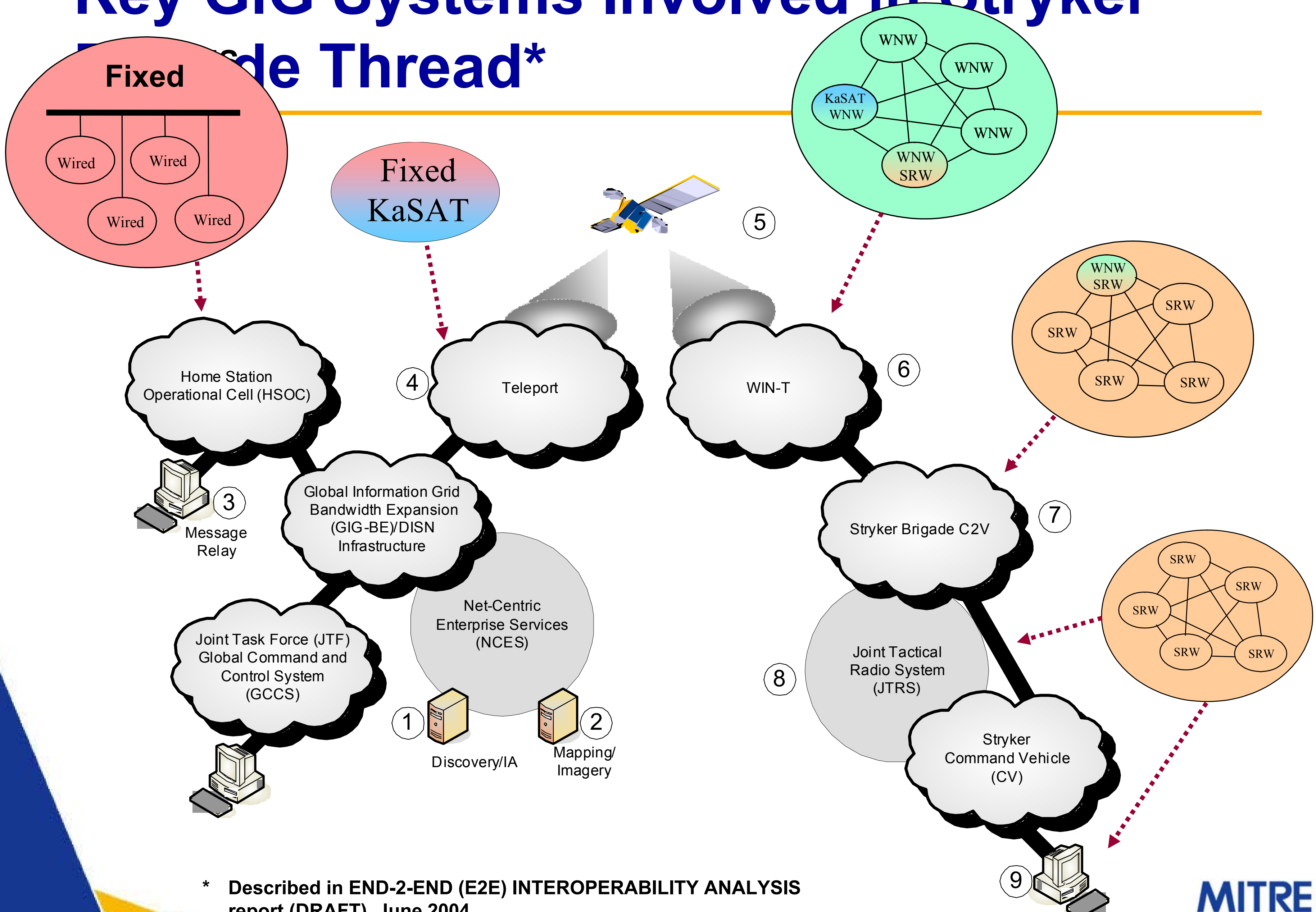
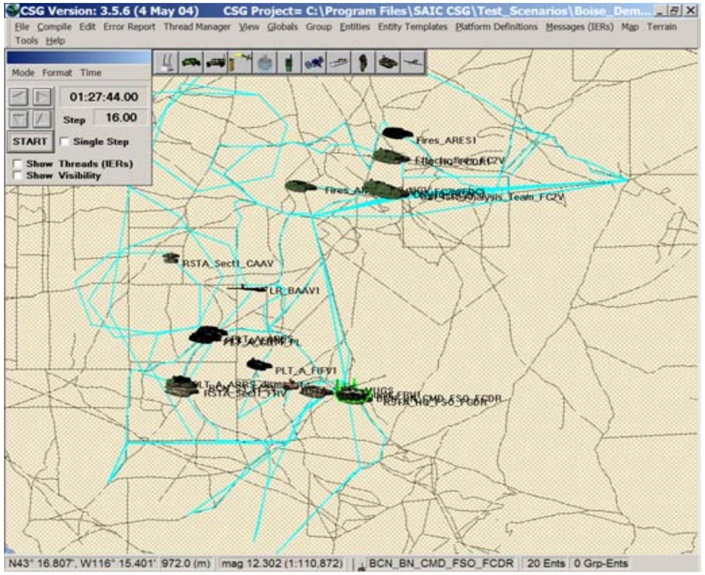
Key GiG Systems Involved in Stryker Brigade Thread*



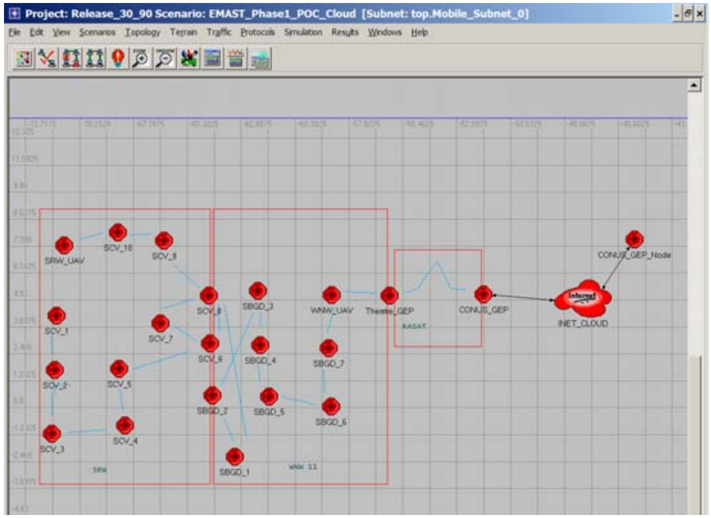
* Described in END-2-END (E2E) INTEROPERABILITY ANALYSIS report (DRAFT), June 2004

EMAST Phase I Stryker Force Scenario

- Modify “Boise” scenario developed in support of FCS-C program
  - 21 nodes
  - Mobility
  - Terrain-induced LOS blockage
  - Add Washington DC “CONUS” component and internet “cloud”
  - Unicast & Multicast traffic
  - Data, voice, video, and multimedia traffic



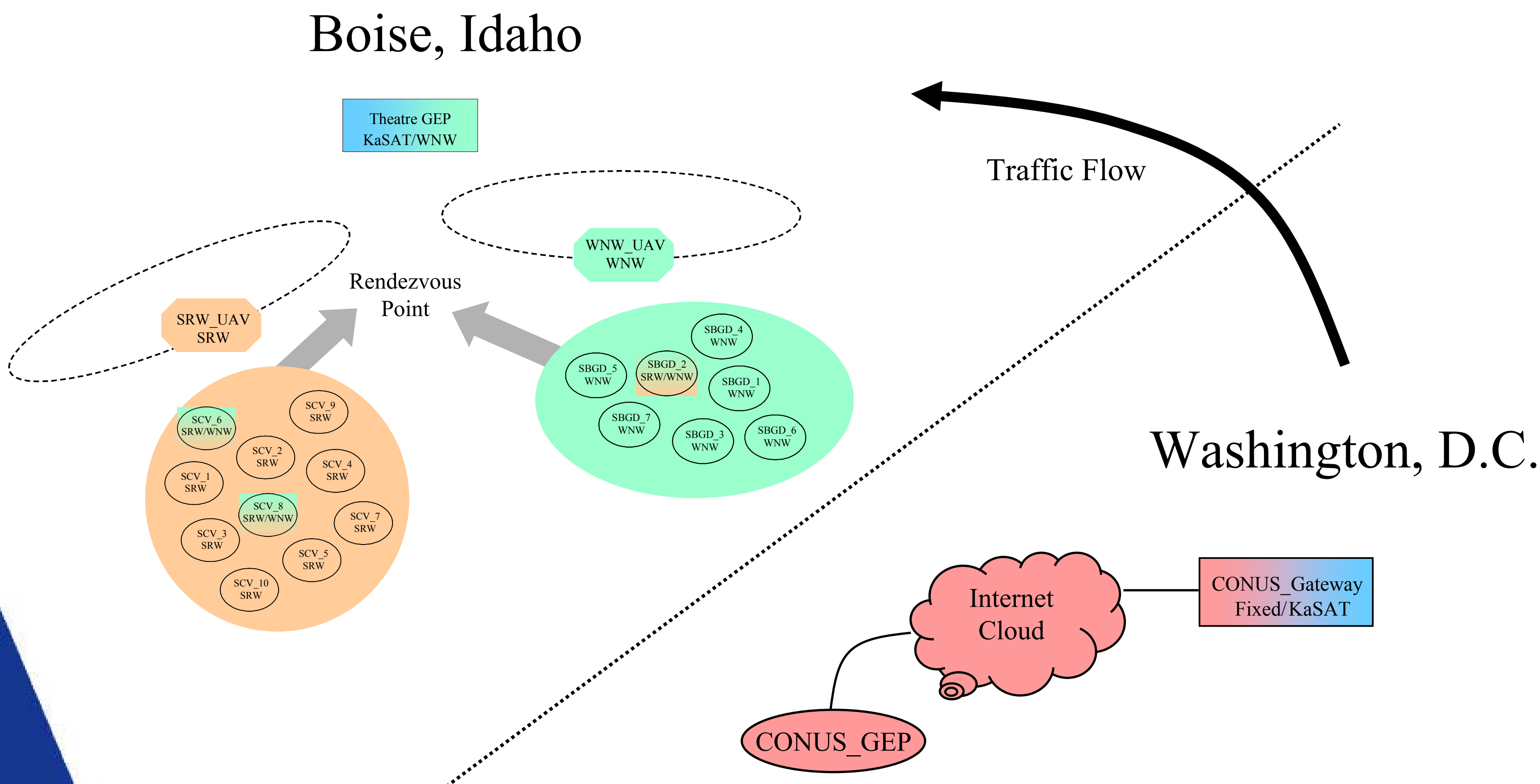
COMTEST



OPNET

MITRE

EMAST Phase I Stryker Force Scenario
(Concluded)



Leverage FCS-C Demo 3 Boise Scenario

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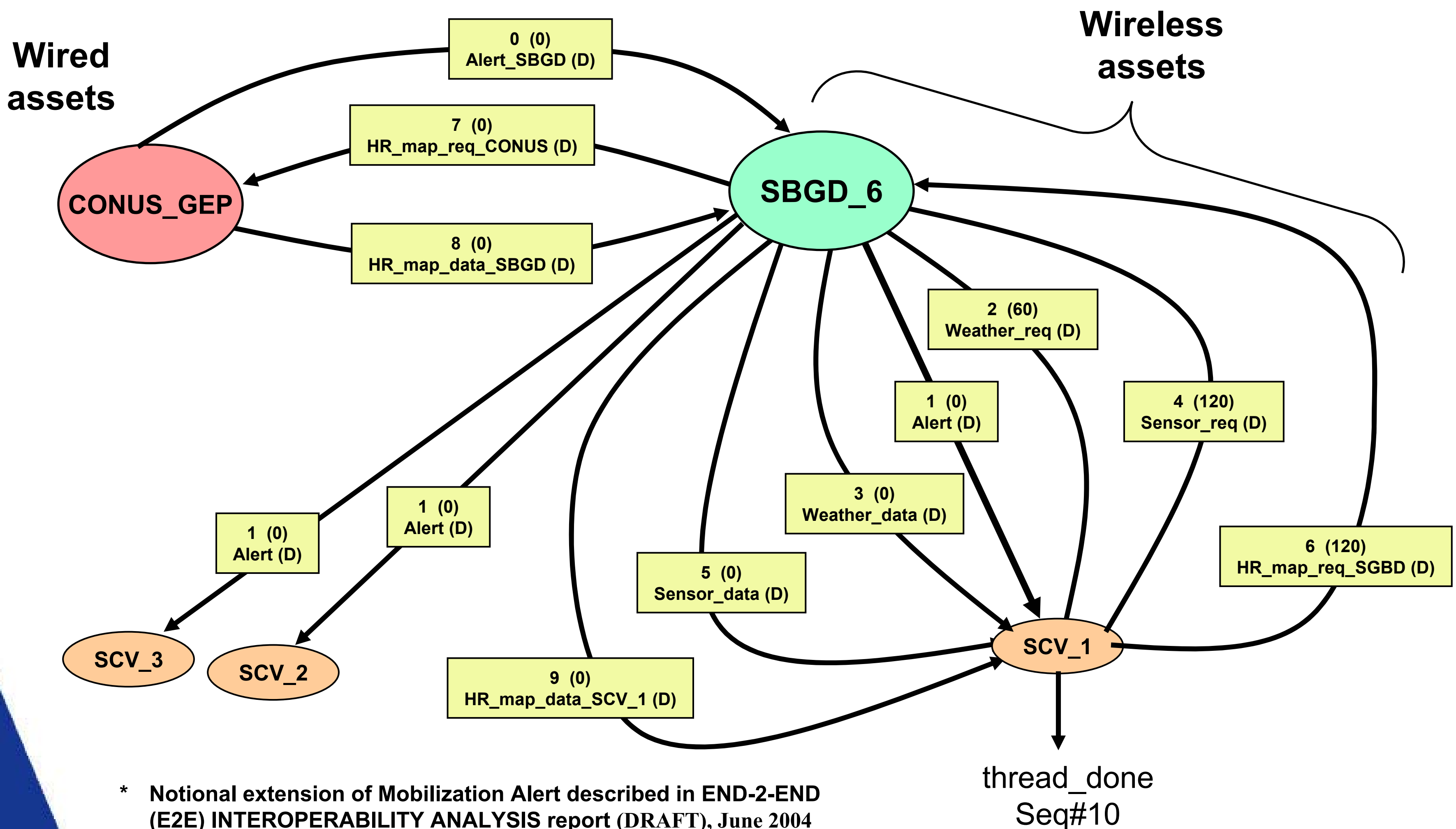
Proof of Concept Study Thread*

SATCOM



* Notional extension of Mobilization Alert described in END-2-END (E2E) INTEROPERABILITY ANALYSIS report (DRAFT), June 2004

SCV: Stryker Command Vehicle
SBGD: Stryker Brigade HQ

"req" IERs are 8kbytes; all others are 100 kbytes

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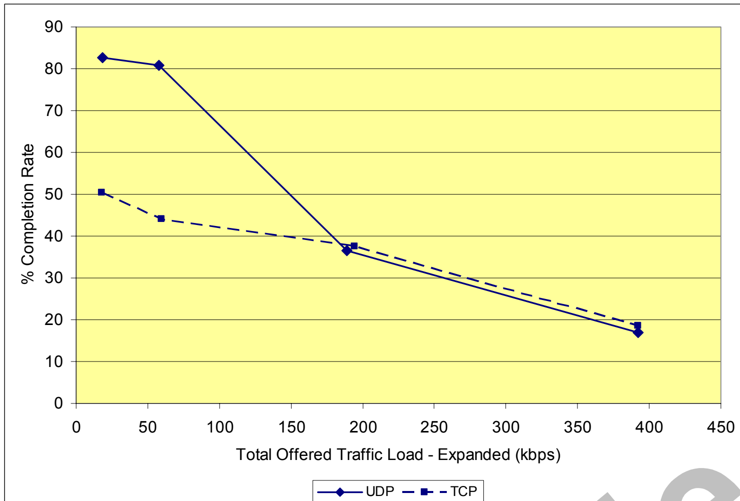
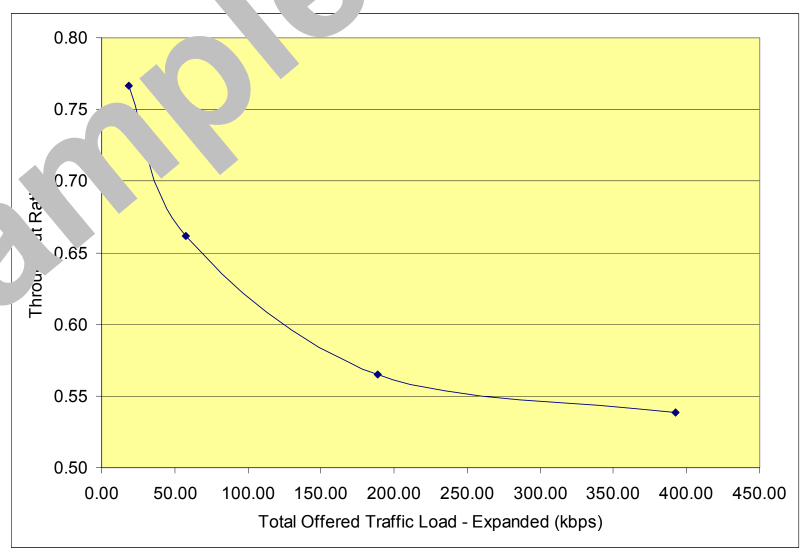
EMAST Phase I Stryker Force Analysis
(% Completion Rate, E/E Delay, Throughput Ratio)





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EMAST Status

- EMAST Phase I completed 30 Sept 04
- Proof-of-Concept Analysis completed 30 Nov 04
- On schedule to complete Phase II by 30 Sept 05
  - >100 nodes
  - OPNET-based version 10.5
  - Multicast traffic via PIM-SM
  - Integrate PEP/SCPS models
  - Support QoS (limited DiffServ)
  - Support HAIPE (Spec vs2)
  - Additional scenarios and analyses