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NETWORK MODELING AND SIMULATION ENVIRONMENT (NEMSE)

JULY 2013

FINAL TECHNICAL REPORT

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INFORMATION DIRECTORATE

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14. ABSTRACT
The Network Modeling and Simulation Environment (NEMSE) program investigated complex network emulation techniques and selected compatible emulation techniques for all OSI network stack layers. Other significant accomplishments included formulation of a simple method of defining EMULAB experiments in PowerPoint reducing the learning requirements for investigators, the completion of eight demonstrations that implement the emulation environment, and the development of three virtualizations.

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1 SUMMARY

The Network Modeling and Simulation Environment (NEMSE) Laboratory Research Independent Research (LRIR) task 10RI02COR sponsored by the Air Force Office of Scientific Research (AFOSR) has:

1. Made an exhaustive study of emulation techniques to evaluate their potential to more rapidly transition university research into Air Force Research Lab (AFRL) 6.1/6.2/6.3 research.
2. Defined a paradigm for transitioning technology, both tech push and tech pull, from basic research into operational assets utilizing emulation techniques in conjunction with operator and hardware-in-the-loop.
3. Implemented the NEMSE paradigm, a research environment that features the best of multiple emulation, modeling, and simulation software applications embedded in an EMULAB environment.
4. Demonstrated scalability by implementation of the paradigm in a high performance computing (HPC) cloud environment.

A tendency was noted in the literature for emulation techniques to converge through their Application Programmer's Interface (APIs), file structures, and GUI look and feel. As a result of this convergence, instead of reinventing the wheel, NEMSE concentrated on integrating the best parts of each of these techniques and their software packages into an interoperable environment that supports the NEMSE paradigm. In order to devise a fully successful paradigm, NEMSE assembled a team with depth in all phases of Research and Development (R&D). The team included, at various stages in the program, Department of Defense (DoD) specialists with expertise in software, hardware, and military operations.

NEMSE provided emulation and development support for each of the OSI layers along with supporting models, protocols, packet statistics, hardware evaluations, and hardware prototypes.

The Ross and Hench paper "Complex Network Modeling with an EMULAB HPC" [1 ROSS] discussed how future military network emulation environments can profitably employ the NEMSE model. This emulation environment was able to support war-gaming with operator-in-the-loop to allow for system performance evaluation by military personnel. This environment enabled the rapid prototyping of new hardware that can be taken to the field and tested, generating new data to validate and verify new models.

The High Performance Computing Modernization Office (HPCMO) software along with the Emulab software integrated into the Information Directorate (RI) EMULAB provided the capability to do cloud computing with programmed networks. The interface was via the HPCMO office Kerberos. The EMULAB system performs emulation, assigns individual computers to each node of the experiment, and connects the nodes with programmable routers set up for the experiment. Processors can then be dedicated to the user with downloadable operating systems.

The NEMSE environment allows the researcher to take advantage of the capabilities offered by the Optimized Networking Engineering Tool (OPNET) with their system-in-the-loop toolbox, Joint Communication Simulation System (JCSS), generalized wireless Common Open Research Emulator (CORE) modules, hardware components, wireless cards with links modifiable using Radio Frequency (RF) cabling and variable attenuators, and GNU radios.

2 NEMSE Overview

This section is an overview of NEMSE program as presented at the 2012 IEEE High Performance Extreme Computing Conference (HPEC) poster session [1 Ross].

Motivation

- Air Force Research Lab needs
  - Capability to merge emulation with system development and test
  - Method to reuse model code and operational code throughout the R&D research and development process
  - Facility for rapidly integrating and evaluating code, hardware, and emulation models from various code development systems
  - Method of verifying and validating emulation models with parallel hardware and operator–in-the-loop
  - Variable fidelity emulation with:
    - High fidelity emulation close to the System Under Test using actual software applications
    - Medium fidelity emulation using discrete event simulations
    - Low fidelity emulation using statistical flows and demands
- Emulation status in 2012: focus was on
  - Convergence
  - Integration
  - Interoperability
- NEMSE paradigm (Figure 1)

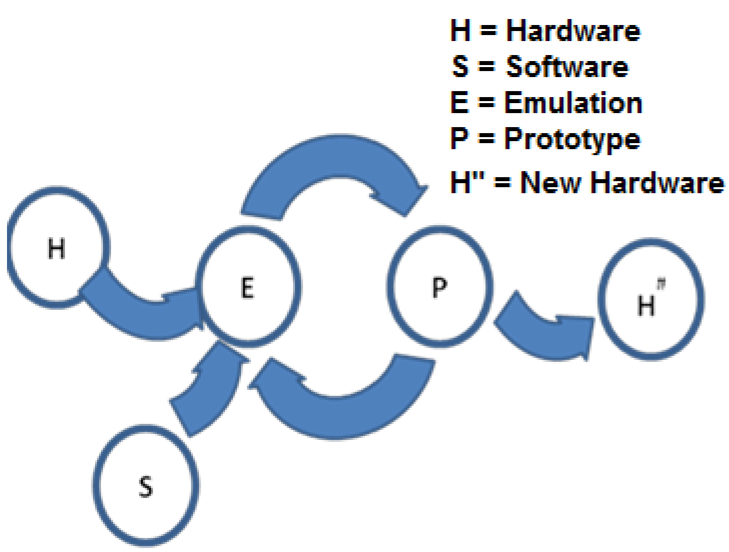


Figure 1 - Work Flow of NEMSE Paradigm

- Typical Experiment (Figure 2)
  - The experiment is designed in PowerPoint using standard symbols
  - Symbols are translated into a standard set of software scripts

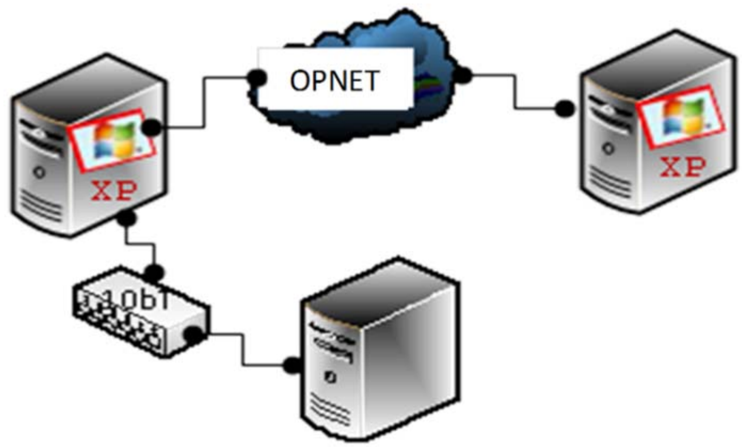


Figure 2 - Typical Design from Standard Symbols

2.1 EMULAB HPC

The Air Force Research Lab Information Directorate EMULAB employs the University of Utah's network emulation software which is accessed through the Joint Communication Simulation System (HPC) infrastructure. Processors are assigned to users from a pool and are connected using a programmable router. Operating systems are then downloadable for experimentation.

Figure 3 - AFRL/RI EMULAB

- Specifications:

  - 86 experimental nodes, each with
    - 3.0 GHz Quad Core Intel Xeon E5450 processor
    - 12 MB cache
    - 16 GB of memory
    - 500 GB hard drive
    - Six Network Interface Cards
  - Three dedicated servers for EMULAB set up and control
  - Test networks set up using Cisco 6509E programmable router

- Hardware-in-the-Loop (Figure 4):

  - Hardware integrated into NEMSE boxes
  - NEMSE boxes inserted into EMULAB (see example below)
  - NEMSE boxes can be easily ruggedize for field use

Figure 4 - NEMSE Box for Hardware-in-the-Loop

- NEMSE Allows:
    - User access to standard emulation tools
    - Easy of learning
    - User administrative privileges on network processors via remote VPN
    - Working at all layers of the OSI stack
    - NEMSE is built on the AFRL/RI EMULAB and consists of
        - Library of easily installed applications
        - Databases of models, exercise videos and photographs, and maps
        - Support for Operator-in-the-Loop and Hardware-in-the-Loop
    - Palette of Network Symbols

Software Components:

Table 1: Software Layers or Functions and Tools

OSI	Layer or Function	EMULAB	NS2	OPNET	CORE	Click	MadWiFi	GNU	FPLE	RAVC	MATLAB	IPERF	WireShark
7	Application		■	■						■	■	■	
6	Presentation	■		■						■	■		
5	Session	■		■						■	■		
4	Transport	■	■	■	■					■	■		
3	Network	■	■	■	■								
2	Data Link	■	■	■	■	■							
1.2	Physical- MAC			■	■	■	■	■					
1.1	Physical-Hardware					■		■	■				
	Models		■	■	■	■							
	Protocols			■		■	■			■			
	Packet Statistics			■							■	■	■
	Hardware Evaluation							■				■	
	Prototype Hardware					■	■	■	■				

- **Emulab:** Network test bed, giving researchers a wide range of environments in which to develop, debug, and evaluate their systems. The name Emulab refers both to a facility and to a software system (EMULAB is AFRL facility with Emulab software).
- **NS2:** Free emulation tool, discrete event simulator targeted at networking research.
- **OPNET JCSS:** (Optimized Networking Engineering Tool/ Joint Communication Simulation System) Modeling software for analyzing and designing communication networks, devices, protocols, and applications.
- **CORE:** Common Open Research Emulator (CORE) is a tool for emulating networks on one or more machines.
- **Click**: Software architecture for building flexible and configurable routers.
- **MadWiFi:** (Multiband Atheros Driver for WiFi), Linux driver for 802.11a/b/g universal Network Interface Card (NIC) cards - Cardbus, PCI, or miniPCI.
- **GNU radio:** Free & open-source software development toolkit that provides signal processing blocks to implement software radios.
- **FPLE:** Emulator that allows prototyping computer interconnection.
- **RAVC:** Rate-Adaptive Video Coding technique with hardware.
- **MATLAB compiler:** Enable MATLAB compiling and instantiation on nodes.
- **IPERF:** Network performance measurement tool; reports bandwidth, delay jitter, and datagram loss.
- **WireShark:** A network protocol analyzer; Open source packet sniffer.

2.2 Typical Use Case (Virtual Stockbridge)

- Simulation using OPNET terrain models demonstrated for radio towers located in Rome, Newport, and Stockbridge, NY
- Ideal site for verifying and validating terrain models as they interact with tactical radio waveform models
  - Long valley surrounded by mountains
  - Urban, farmland, and forest terrain
  - Four seasons
  - RF evaluation facilities
- AFRL/RI facilities, in diagram below (Figure 5)
  - Rome Research Site; blue color icon
    - Primary Facility – stationary wireless node
  - Newport Research Facility; green color icon
    - Far Field Antenna Research Site
  - Stockbridge Research Facility; red color icon
    - Multi-use Research Site

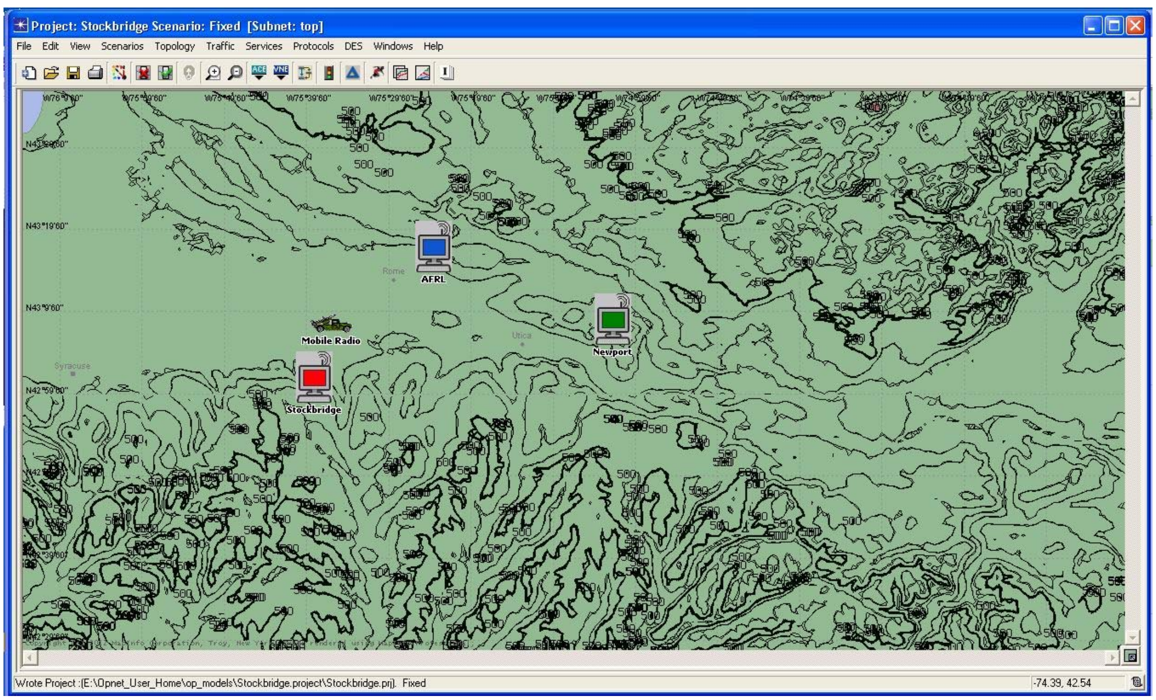


Figure 5 - OPNET Wireless for Defense Terrain Model Simulation

- Simulation results below (Figure 6) predict connectivity failure between Rome and Newport due to an intervening mountain
- Connectivity was tried and failed

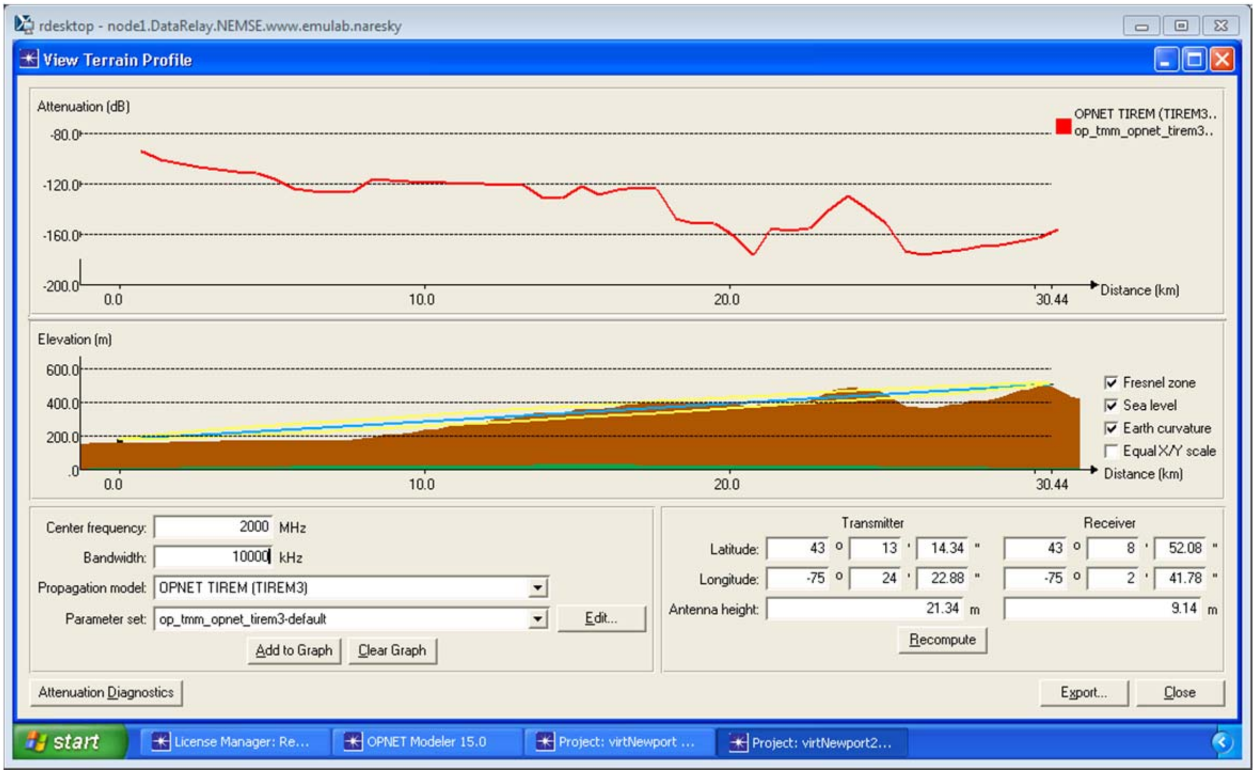


Figure 6 - Attenuation from Rome to Newport

- Simulations predicted connectivity between Rome and Stockbridge (not shown) and via Stockbridge to Newport, Figure 7, will succeed
- Connectivity was tried and succeeded
- Additional verification and validation tests of the model under a variety of conditions and locations are planned
- Extending the simulation to an emulation with system-in-the-loop is also planned

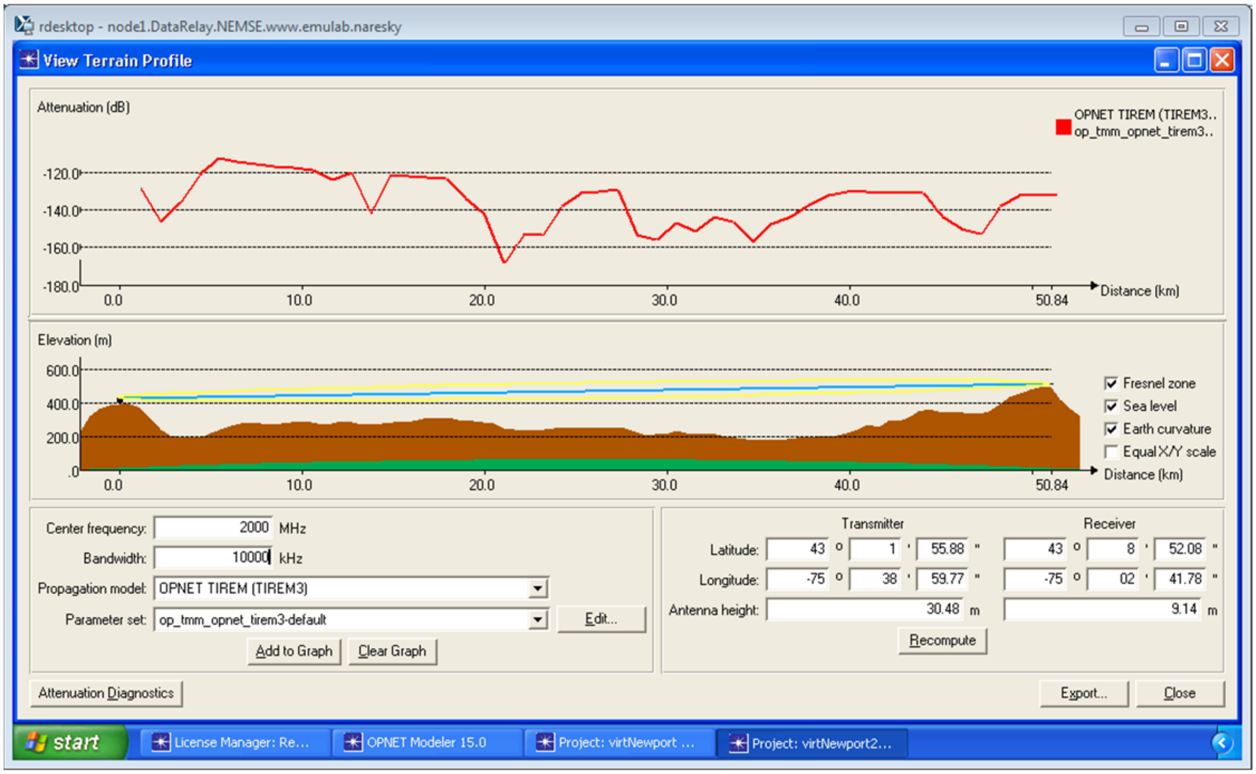


Figure 7 - Attenuation from Stockbridge to Newport

3 INTRODUCTION

The abstract of the NEMSE proposal stated:

> *We propose to utilize a new Network Modeling and Simulation Environment (NEMSE) as an in-house tool to assist Air Force Office of Scientific Research (AFOSR) in assessing promising technologies within the Complex Networks portfolio and to enable their transition to advanced research. We will work with the AFOSR Program Manager (PM) and AFOSR Principe Investigators (e.g., university investigators) to 1. identify candidate projects and select those with the greatest promise for transition and potential for benefit to the Air Force, 2. develop and implement specific evaluation plans, and 3. facilitate the transition to 6.2 and 6.3 research and the warfighter, where appropriate. Where possible, we will insert model developments into industry Modeling and Simulation (M&S) toolkits, such as OPNET Modeler. NEMSE will leverage existing M&S resources (Close Air Support Connectivity [CASCON], and the EMULAB cluster), education partnerships with various universities, and contacts with advanced research programs and potential end-users of network technology, along with the experience of the NEMSE team to ensure the success of the proposed effort. The EMULAB cluster will be enhanced with the addition of MATLAB optimization tools and parallel processing capability for OPNET, giving it even greater potential in support of AFOSR Complex Networks goals. Development of techniques such as optimization, co-simulation, System in the Loop (SITL), and Three-Dimensional (3-D) visualization, along with expertise with tools such as Optimized Networking Engineering Tool (OPNET) Modeler,*

the Joint Communication Simulation System (JCSS/NETWARS), and MATLAB, will also serve to strengthen our in-house capabilities.

The proposal was closely followed in the research and serves as a good introduction to the program.

The body of this report concentrates on the final implementation of the environment and AFRL experience with the NEMSE paradigm.

The Complex Network Modeling with an Emulab HPC paper [1 Ross], page 7 and 8, described NEMSE and discussed the transitioning of laboratory research into field capabilities by enabling simulations, code and prototypes to be used in iterative development of new network and communication equipment. In addition, data from the field can be sanitized and used in emulation by non-DoD researchers. This capability will lead to quicker design of networked communication systems.

NEMSE defined a new paradigm for DoD networked communications research starting with simulations on legacy hardware, proceeding through multiple iterations of emulation employing hardware-in-the-loop testing on a variable fidelity emulation test bed and finishing with field testing of new hardware. This approach, shown as a development flow diagram in Figure 8, is expected to reduce the long lead-time for communication equipment development and testing by employing verification and validation of models over a variety of terrain, weather, and crop cover conditions. This approach is anticipated to save time and money by enabling reuse of simulations, prototypes, and code or multiple applications and simulations.

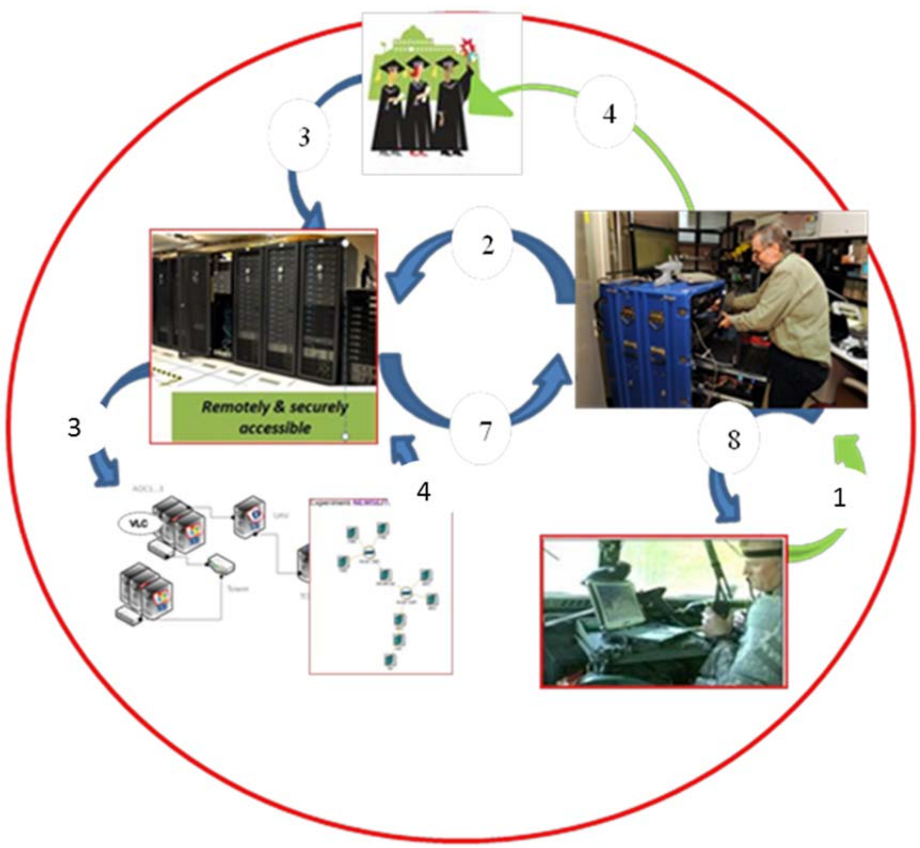


Figure 8 - Development Flow of the NEMSE Paradigm Implementation Cycle

Proceeding counter-clockwise around Figure 8 the pictures represent:

- Academic researcher or other investigator
- The Information Directorate EMULAB cluster
- A PowerPoint network diagram
- The EMULAB virtualization of the network
- A field experiment using prototype equipment.
- The CASCON terminal

Blue arrows denote tech push (R&D AFRL is pursuing without warfighter sponsorship) and green arrows denote tech pull (warfighter has identified a need that results in a R&D program).

The NEMSE test bed implementation, performed on the AFRL/RI EMULAB [2 TR12] allows easy access by users in an integrated form. This integration includes: 1) user-friendly installation of software and emulation tools on individual processors, 2) the ability to interact with other tools and the tool's own application programmer interface (API), and 3) license management. NEMSE provides model development, protocol development, packet statistics, hardware evaluation, prototype, hardware development and transition paths for all levels of the Open Systems Interconnection (OSI) protocol stack of a network architecture. The EMULAB test bed enables concept scalability demonstration.

The Complex Network Modeling with an Emulab HPC paper [1 Ross] pointed out ways that future military network emulation environments can benefit from following the NEMSE model. The emulation environment ability to support war-gaming with operator-in-the-loop will allow for system performance evaluation by military personnel. This environment will aid in rapidly prototyping of new hardware that can be taken to the field and tested, generating new data to validate and verify new models, restarting a new iteration of the cycle. This is the NEMSE paradigm.

The Complex Network Modeling with an Emulab HPC paper [1 ROSS] described the research conducted during the first part of FY 11. Included is the motivation for the NEMSE paradigm, a discussion of the emulation tools given in table 1, and preliminary results for the Virtual Stockbridge Use Case using OPNET simulation.

A FY11 AFOSR interim report [2 TR12] documents eight virtualizations developed mainly on a standalone network environment called the "CASCON Terminal" and ported to the EMULAB cluster. A NEMSE virtualization uses real processors and real network components but the network itself is virtual.

These eight virtualizations were: System-in-the-Loop (SITL) using OPNET Modeler, COPE, Field Programmable Gate Array (FPGA Physical Layer Emulator (FPLE), GNU Radio, CORE & EMANE, Tech Warrior, CASCON (CAS Connectivity), and Rate Adaptive Video Coding (RAVC). Also described is the porting into the EMULAB cluster.

The FY10 NEMSE Interim Report [17 FY10 TM] describes the initial assessment of techniques and includes an OPNET study. In the final work, this study was extended.

Figure 9 shows a network drawing of both pertinent system nodes and exercise nodes using the standard symbols of Table 2. In Figure 9, system computers are shown in tan and exercise computers are shown in grey. The user, shown at the bottom of this figure, tunnels through the Internet using a Virtual Private Network (VPN) technique to one of the front end "Condor " computers. The VPN connections are shown as heavy lines. Information Assurance (IA) considerations are handled between the Condor machines and "Ops", "Tips", and "Boss" machines on the 10.0.x.x subnet. The Ops machine is then connected through the 192.168.0. X subnet that is a control network for the experiment.

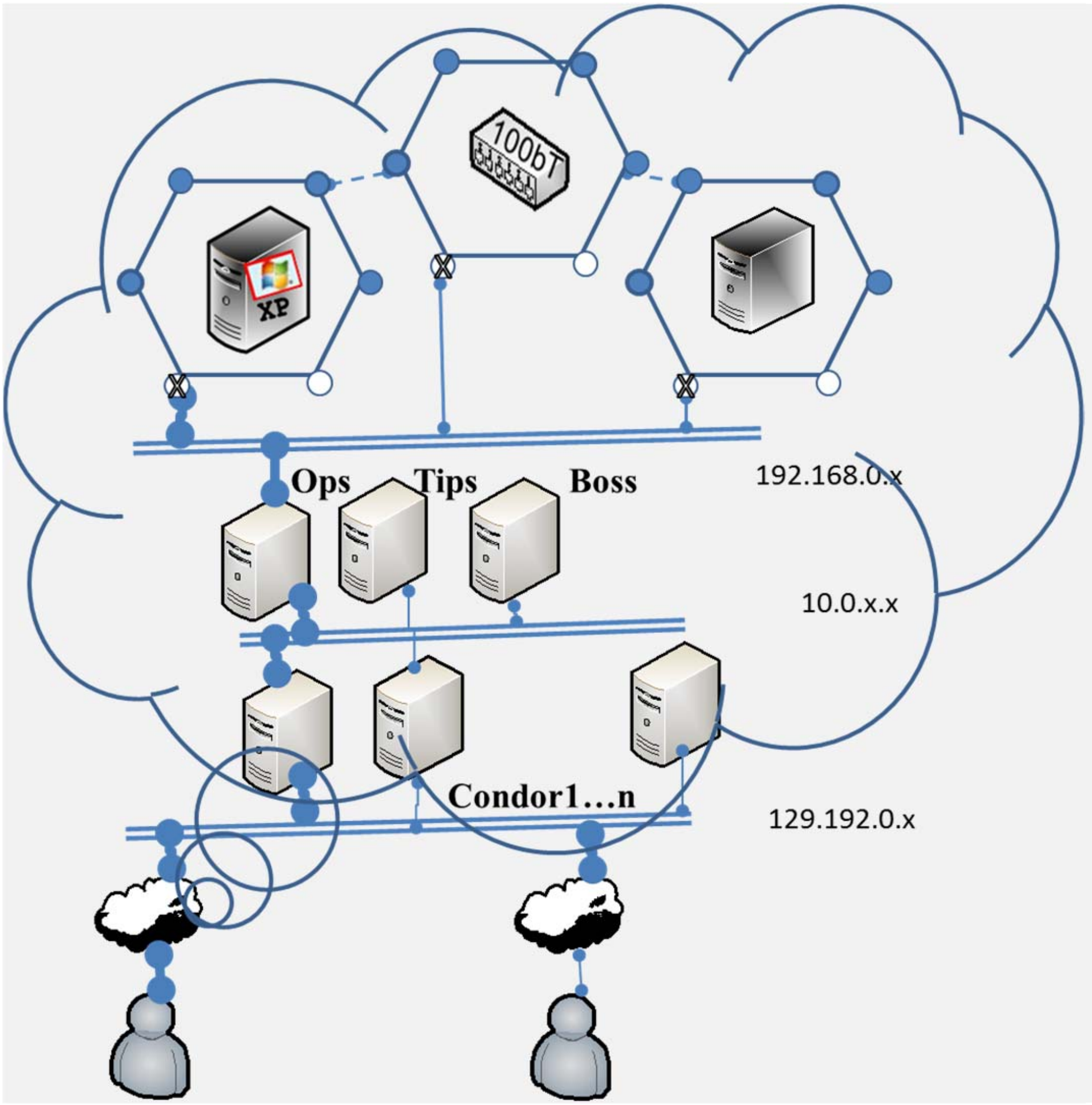


Figure 9 - Overall Network Drawing

Screen captures of some of the applications used to VPN into the EMULAB through the HPC are shown in Figure 10. From upper right to lower left are shown:

1) University of Utah provided FireFox webpage using XWin-32 for VPN,

2) Remote desktop tunnel into a Windows XP processor, and

3) Splash sheet on a remote command window.

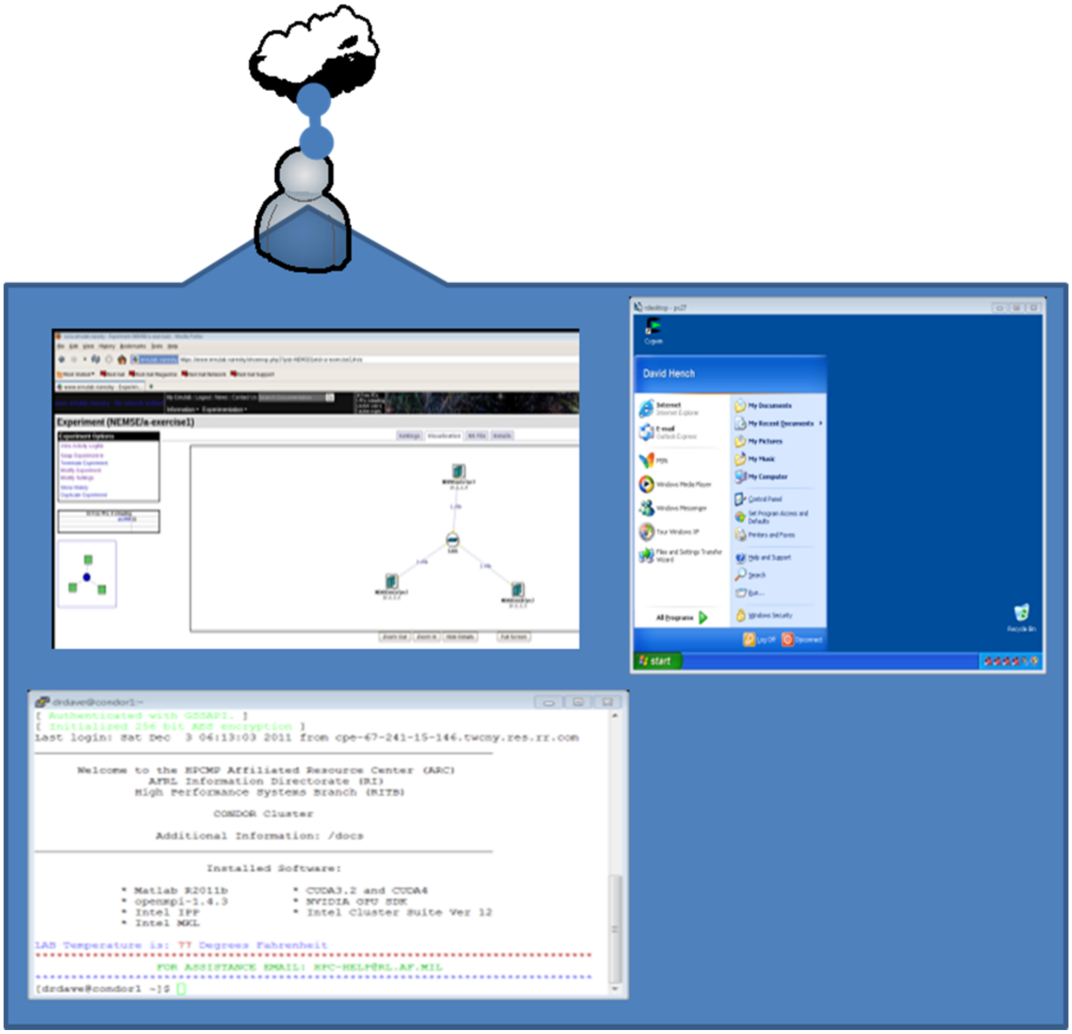
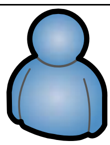
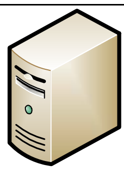
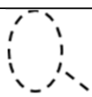
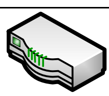
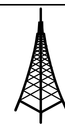
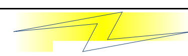


Figure 10 - Software Application for VPN into HPC

For definition and documentation purposes, the PowerPoint symbols that a user can use to model his network are shown in Table 2. These symbols are used in Figures 2 and 9.

Table 2: Standard NEMSE Symbols

Symbol	Description
	User
	System computer
	Experiment computer, FreeBSD
	Experiment computer, Windows
	Software
	NS-2 switch
	NS2 router
	Click router
	Internet
	OPNET SITL general network (four terminal)
	CORE general network (four terminals
	GNU radio
	WiFi
	Experiment Ethernet
	System Ethernet
	VPN tunnel
	Ethernet bus with switches
	Wireless

The user can control his experiment by remote login over the VPN. They have administrative control over Windows machines and root access on UNIX and Linux machines. The experiments can be swapped in, saved, and swapped out to make maximum use of the EMULAB facilities.

4 METHODS, ASSUMPTIONS, AND PROCEDURES

A historical flow diagram representing the team's experience of employing the NEMSE paradigm for applied research was shown earlier in Figure 8.

The tech pull (need that results in R&D) path 1 in Figure 8 represents an effort that grew out of RAVC field experiments that were part of training exercises [3 ROVER] for Remotely Operated Video Enhanced Receiver (ROVER) technology. This led to a tech pull in Close Air Support Connectivity (CASCON). The CASCON terminal was built to support this need.

The NEMSE paradigm was designed, along with the CASCON terminal and the Information Directorate EMULAB, to aid in the technology development of Complex Network Portfolio projects, though to-date this has not occurred. The emulation environment was developed mainly on the CASCON terminal (path 2) and ported back to EMULAB as the EMULAB became increasingly available.

The CASCON terminal is also used to develop experiments for field exercises (paths 7 and 8). This brings operational data into the CASCON Terminal and the data is ported back to EMULAB. A virtualization can be created as a PowerPoint slide, translated into an EMULAB virtualization that uses all aspects of the NEMSE environment. The virtualization can be used for software and hardware development and for war games to define the exercise.

This cycle will undergo iteration when hardware, software, and ConOps (paths 5 and 6) from the virtualization are brought back into a redesigned CASCON terminal for potential future exercises.

A tech push (R&D without sponsorship) path was initiated by University of California, Irvine who provided the CORE software [4 CORE] allows performing protocol and hardware development in the Link and MAC (Media Access Control) ISO (International Organization of Standardization) stack layers as well as providing a specific network coding shim between the link and MAC layers.

Another tech push, path 4, in the Evaluation of Complex Network Abstract Geometry (ECNAG) started in FY10 with Florida Atlantic University. EMULAB was not available when Florida Atlantic University started in FY11 but the FY11 NEMSE report [2 TR12] describes preparation for FY12 and a tech pull to the Universities.

5 NEMSE Paradigm Methodology

The NEMSE Paradigm methodology was developed by the team in order to meet the program's stated objective. The stated objective is to provide tools and talent to facilitate the evaluation and transition of fundamental research being conducted within the AFOSR Complex Networks Portfolio.

The NEMSE Paradigm methodology's motto is, from 6.1 to 6.3+, "we bring the scientist to the fight".

The NEMSE Paradigm methodology was developed to support the tech push to move research & development (R&D) products out of the laboratory into the hands of the war-fighters. An advantage of the

NEMSE Paradigm methodology is that it uses only individual proven techniques. The manner in which the team supported the tech push for the AFOSR Complex Networks Portfolio is as follows: NEMSE Paradigm methodology (Figure 11) first provided an efficient transition path from the university researchers into the Information Directorate. Then second, it provides a means to test the technology with experienced war-fighters.

The NEMSE Paradigm also supported a tech pull from war-fighters that utilize networks and communications systems. This tech pull will enable the Information Directorate to design basic and applied research programs to answer challenges faced by warfighters. As necessary, the challenges were repackaged as abstracted problems to enable universities to conduct research.

The NEMSE Paradigm methodology provided a smooth transition from abstract 6.1 research to directed 6.2 research, to system specific 6.3 research and finally to operational testing with experienced war-fighters. The progression of levels of research is reversible allowing problems to be defined at the higher levels and transmitted back to lower levels.

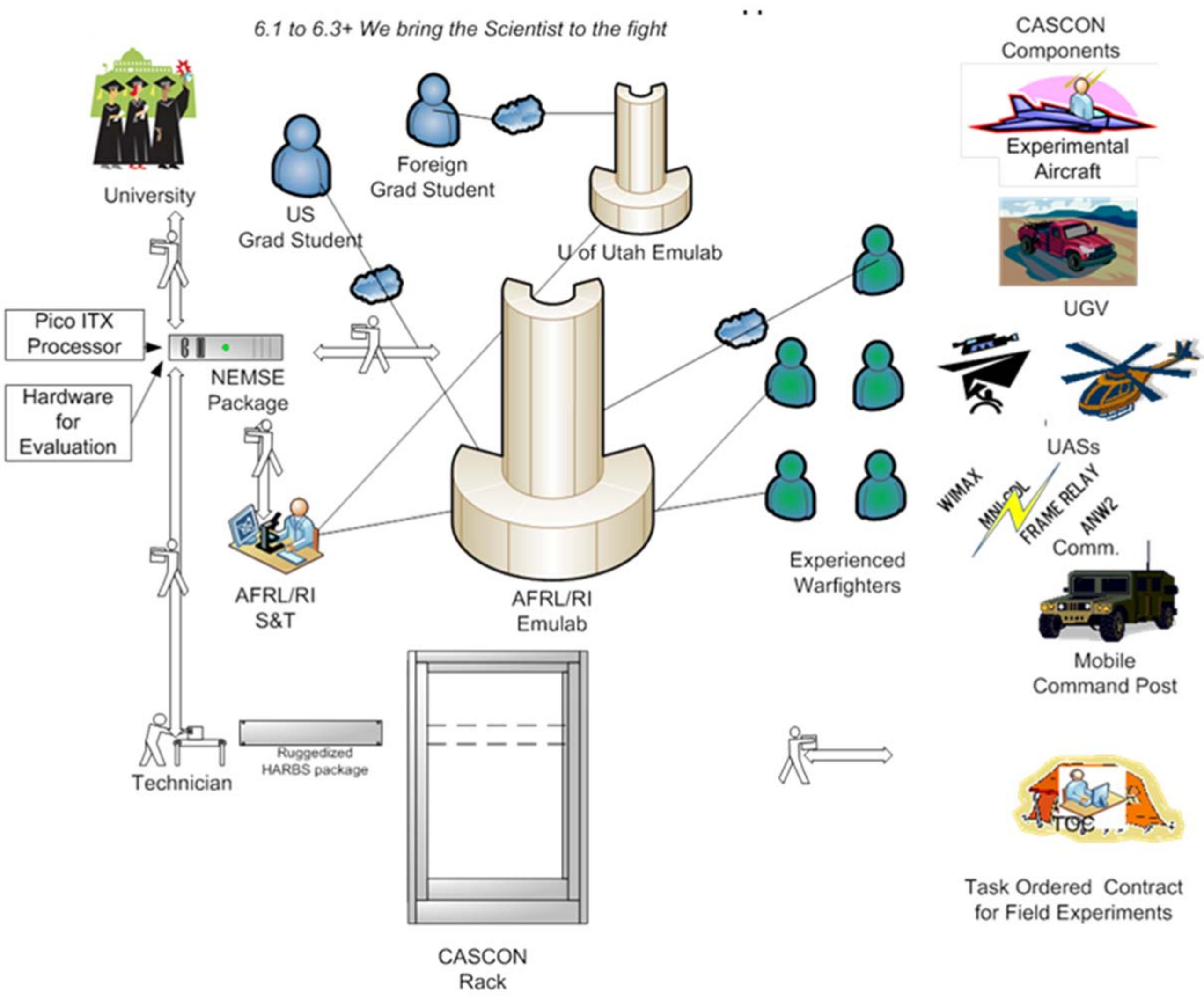


Figure 11 - Work Flow Representation of NEMSE Paradigm Methodology

6 RESULTS AND DISCUSSIONS

Three geographically-close AFRL facilities were utilized to demonstrate the effectiveness of the developed capability. The AFRL Information Directorate is comprised of the main complex (Rome Research Site) in Rome, NY and two remote research facilities, Newport and Stockbridge. The Newport Research Site, a far-field antenna test range, is located 30 miles southeast of Rome. The Stockbridge Research Site, a multifaceted communications research facility, is located 23 miles southwest of Rome. These facilities and their locations make the Information Directorate the ideal site for verifying and validating communication systems models. Verification answers the question "Is the model right?" While validation answers the question “Is it the right model?” The geographic features found locally, such as valleys and hills containing mixed urban, farmland and forest areas, with a four-seasons climate are all important to terrain testing.

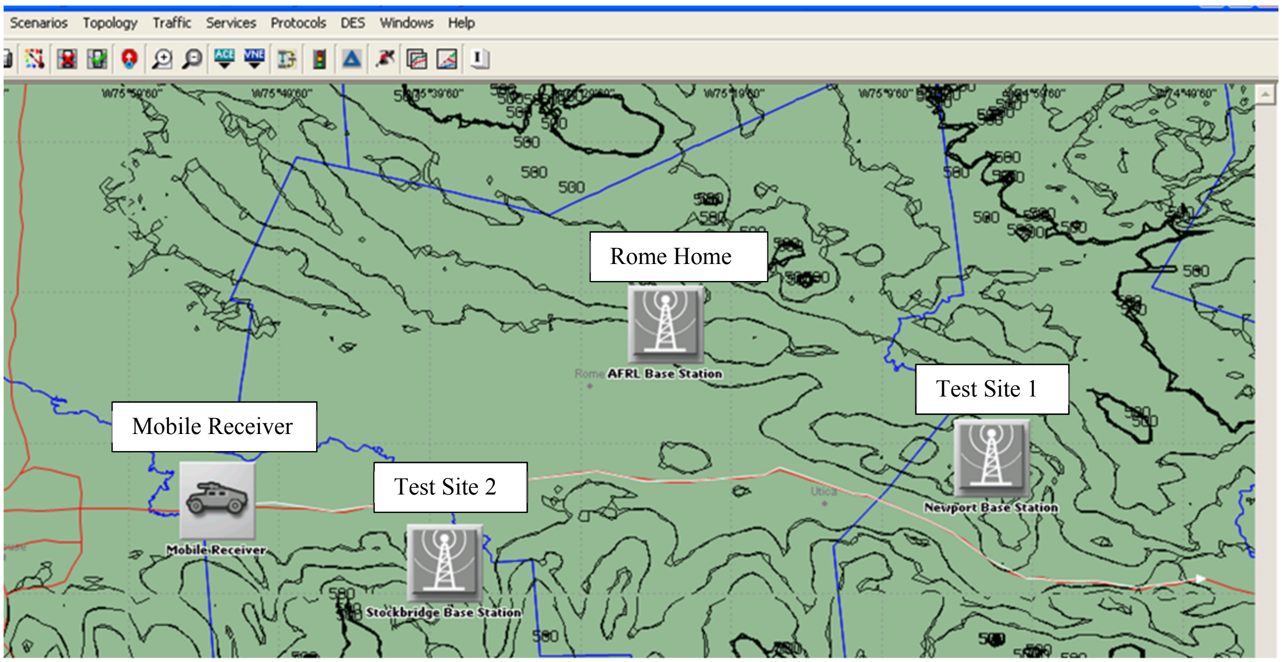


Figure 12 - Topological View of Test Sites Taken from OPNET 15 Topological Editor

The test site locations are shown in Figure 12. This figure is a screen shot from the topological editor for the OPNET 15 model and is an update to the model presented by Ross and Hench [1 ROSS]. This model has been updated to work with JCSS 12 applications. Mobil receiver trajectories were limited to Interstate 90 due to the limited capability of vector maps in OPNET 15. The JCSS application added Map Interchange Format (MIF) vector maps and a mapping capability using Census Bureau maps [5 CENSUS]. This map was developed as shown in Figure 13, but not integrated into the model at this time.

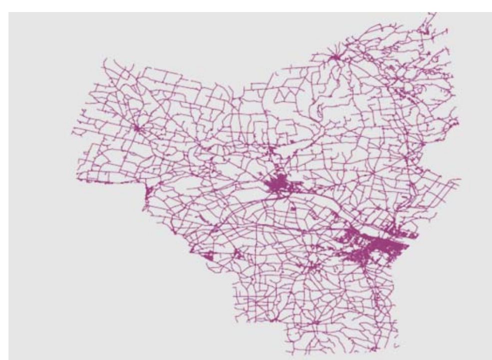


Figure 13 - New Vector Maps

Topographic map data and field experience have shown that a direct line of sight connection between the Rome Research Site and the Newport Research Site is not possible. However, a viable link can be established between Rome and Newport using Stockbridge as a relay. The topology is evident and practical for developing Verification and Validation (V&V) of topological models of transmission as well as providing realistic tactical data. Validation and verification ensure that the communication system models expose the true expected characteristics of the system under design. The model user must have confidence in the model in order to reduce the resultant hardware V&V phase.

The DISA supported JCSS desktop application provides many organizations an M&S capability for strategic, tactical and operational networks. This application contains a library of both commercial and DoD specific models.

By contributing to JCSS, the Information Directorate supported many organizations that conduct various types of acquisition, military planning, as well as R&D analysis. These uses included:

- Propagation effects
- Topology and terrain effects
- Radio characteristics
- Protocols across the ISO stack
- Network processes
- Network traffic from general or specific applications
- Routing
- Network availability
- System growth
- Device failure and movement
- "What-if" scenarios
- Military Capacity analysis
- Impact of acquisition strategies on future systems.

The JCSS recommended steps for modeling are:

1. Scope the model and set objectives and goals
2. Collect supporting data
3. Develop methodology and run matrix
4. Design and develop network topologies
5. Design and develop network traffic
6. Integrate network topology and traffic
7. Execute simulation
8. Analyze results
9. Develop conclusions and finalize

7 Conclusion

This research successfully developed and tested a way to minimize the time and costs for network testing. The Network Modeling and Simulation Environment (NEMSE) employ a coordinated testing and emulation approach and provide a capability for rapid technology transition utilizing an emulation environment. This environment, capitalizing on the best features of various software tools, including OPNET, JCSS, CORE, MATLAB, and SQL, and using AFRL/RI's EMULAB high performance computer, has demonstrated a step forward in network testing, enabling users to avoid the high learning curves of using these software tools. Three geographically close test ranges collaborated to demonstrate the effectiveness of the developed capability. Models from DISA's Joint Communication Simulation System (JCSS) and from OPNET were surveyed and used as the basis for specific models development employing NEMSE. The developed models were verified and validated against the JCSS models. Predictions were made of what would be seen in experiments at the test ranges.

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ACRONYMS

3-D	Three Dimensional	M2TS	MPEG 2 Transport Stream
AFRL	Air Force Research Laboratory	MAC	Media Access Control
AFOSR	Air Force Office of Scientific Research	M&S	Modeling and Simulation
API	Application Programmer's Interface	MISP	Motion Imagery Standards Profile
CAS	Close Air Support	MIF	Map Interchange Format
CASCON	Close Air Support Connectivity	MPEG	Moving Pictures Experts Group
CORE	Common Open Research Emulator	NEMSE	Network Modeling and Simulations Environment
COTS	Commercial off the Shelf	NIC	Network Interface Card
DISA	Defense Information Systems Agency	NIIRS	National Imagery Interpretability Rating Scale
DoD	Department of Defense	OPNET	Optimized Networking Engineering Tool
ECNAG	Evaluation of Complex Network Abstract Geometry	OSI	Open Systems Interconnect
EMULAB	Emulation Laboratory	PCI	Peripheral Computer Interconnect
FPGA	Field Programmable Gate Array	PM	Program Manager
FPLE	FPGA Physical Layer Emulator	PI	Principle Investigator
FY	Fiscal Year	RAVC	Rate Adaptive Video Coding
GNU	GNU is not UNIX (recursive acronym)	R&D	Research and Development
GOP	Group of Pictures	RF	Radio Frequency
GOTS	Government off the Shelf	RI	Information Directorate
GUI	Graphical User Interface	SBIR	Small Business Initiative Research
JCSS	Joint Communication Simulation System	SC	Superposition Coding
HPC	High Performance Computing	SCATOV	Superposition Coded Adaptive Transmission of Video
HPCMO	High Performance Computing Modernization Office	SITL	System in the Loop
HPEC	High Performance Extreme Computing Conference	TCP	Transmission Control Protocol
IAI	Intelligent Automation Incorporated	UEP	Unequal Error Protection
IEEE	Institute of Electrical and Electronic Engineers	UDP	User Datagram Protocol
IP	Internet Protocol	V&V	Verification and Validation
LLC	Limited Liability Company	VGA	Video Graphics Adaptor
LRIR	Laboratory Research Independent Research	VPN	Virtual Private Network
MATLAB	Matrix Laboratory	WiFi	Wireless Fidelity (802.11b)
MadWiFi	Multiband Atheros Driver for WiFi		