AFRL-RI-RS-TM-2012-002

NETWORK MODELING AND SIMULATION ENVIRONMENT (NEMSE)

JULY 2012

INTERIM TECHNICAL MEMORANDUM

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REPORT DOCUMENTATION PAGE	*Form Approved* **OMB No. 0704-0188**

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
JULY 2012	INTERIM TECHNICAL MEMORANDUM	OCT 2010 – SEP 2011

4. TITLE AND SUBTITLE
NETWORK MODELING AND SIMULATION ENVIRONMENT (NEMSE)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER
23NE

5e. TASK NUMBER
IH

5f. WORK UNIT NUMBER
01

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory/Information Directorate
Rome Research Site/RITE
525 Brooks Road
Rome NY 13441-4505

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory/RITE
525 Brooks Road
Rome NY 13441-4505

CO Sponsor: AFOSR/RSL
875 N. Randolph, Ste 325
Arlington, VA 22203

10. SPONSOR/MONITOR'S ACRONYM(S)
N/A

11. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-RI-RS-TM-2012-002

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited. PA# 88ABW-2012-4035
Date Cleared: 19 July 2012

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The Objective of the Network Modeling and Simulation Environment (NEMSE) program is to facilitate the evaluation and maturation of fundamental research being conducted within the Air Force Office of Scientific Research (AFOSR) Complex Networks Program. In FY11, the NEMSE program investigated complex 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 for FY12.

15. SUBJECT TERMS
Complex Network, Emulation, EMULAB

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**HOWARD M. BEYER**
U	U	U	UL	23	**19b. TELEPONE NUMBER (*Include area code*)** **N/A**

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

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1.0 Summary

NEMSE's goal is to facilitate the evaluation and maturation of fundamental research being conducted within the AFOSR Complex Networks program. In pursuit of this goal in FY11 NEMSE has successfully:

1) Completed its investigation of network emulation techniques for the Information Directorate's EMULAB;

2) Completed the selection of compatible emulation techniques that allows working with all layers of the Open System Interconnect (OSI) reference model network stack;

3) Provided a simple method of defining EMULAB experiments in PowerPoint reducing the learning requirements for investigators;

4) Completed eight demonstrations that implement the emulation environment;

5) Developed three virtualizations for FY12 continuation that contain the demonstrations.

The emulation environment is available in FY12 for use by complex network investigators under NEMSE funding or to Information Directorate investigators under 6.2/6.3 funding.

2.0 Research Objectives

NEMSE's objective is to facilitate the evaluation and maturation of fundamental research being conducted within the Air Force Office of Scientific Research (AFOSR) Complex Networks program. In particular, NEMSE seeks to:

1) Bridge the gap between basic research and application by applying tools, techniques and algorithms to scenarios of military interest;

2) Serve as an honest broker for comparison of similar tools and techniques;

3) Identify paths along which interesting research can move to the next Research and Development (R&D) level within Air Force Research Laboratory (AFRL) or elsewhere in the Department of Defense (DoD).

Additional objectives are to facilitate and encourage the use of valuable modeling resources, such as the AFRL/Information Directorate's EMULAB test-bed, and to conduct verification and validation (V&V) of research models or hardware.

3.0 Technical Summary

Toward the goals of facilitating the use of the Information Directorate EMULAB and bridging the gap between basic research and practical application, much of the NEMSE effort in FY11 consisted of developing and demonstrating tools and techniques intended to extend EMULAB's functionality.

3.1 EMULAB

The Information Directorate EMULAB cluster is a functional copy of the pioneering EMULAB cluster at the University of Utah. While there are at least 37 DoD and University computer centers that have EMULAB clusters, only the Information Directorate EMULAB cluster currently has the NEMSE extensions.

The EMULAB cluster was designed to allow realistic testing of network designs in real-time with operators-in-the-loop. Demonstrations are performed on a designated portion of the cluster with individual users located at their separate geo-locations. An interface is created linking the operator's computer with the cluster. Each operator is able to install the software of his assigned computers in the experimental network and act as the administrator.

Figure 1: EMULAB

Operational hardware or a prototype can be incorporated in a specially designed NEMSE box and placed in the EMULAB cluster, a technique called hardware-in-the-loop or system-in-the loop. Standard stand-alone emulation packages and hardware can be incorporated into a node inside the EMULAB cluster.

Experiential networks are easy to set up in EMULAB. Current and future communication technologies can be emulated using a selected set of commercial and DoD emulation software packages. The Information Directorate EMULAB has been enhanced by the NEMSE team. This Environment allows incorporation of carefully selected university, commercial, and DoD standard emulation software packages. NEMSE enhancements have been designed to provide effective support for both operator-in-the-loop and hardware-in-the-loop.

Figure 2: FPLE NEMSE Box installed in EMULAB

3.2 Demonstrations

A series of demonstrations are summarized below and discussed in greater detail in Appendix B. The demonstrations have served to improve in-house skills, extend the capabilities of the Information Directorate EMULAB, and create paths for further research. For FY12, the NEMSE team will continue to work with the Information Dynamics in Networks MURI (Multi-University Research Initiative). Before expending further effort on other EMULAB demonstrations, however, the NEMSE team will seek renewed direction from the Complex Networks Program Manager.

3.2.1 Medium Scale Close Air Support (CAS) Demo

This emulated network demonstrates basic EMULAB features including use of NS2 (network simulator) agents to generate traffic at specified times. This demonstration required 27 physical nodes to emulate 16 experimental nodes and associated links. (The extra nodes serve as "delay nodes" used to implement the various transmission delays specified for the links). It is designed to represent a CAS scenario, including ground personnel, unmanned aerial systems, satellites, and a Tactical Operations Center (TOC). The original topology was provided by Architecture Technology Company (ATC) Rome, New York under a separate contract and modified by the NEMSE team. We also added a network testing utility from the Internet Performance Working Group (IPERF) to each node to facilitate bandwidth and error testing.

3.2.2 System-in-the-Loop Using OPNET Modeler Demo

OPNET Modeler is a highly-capable network simulation tool. Used with OPNET System-in-the-Loop (SITL) and EMULAB, it allows researchers to combine the realism of the emulated network with the power of the simulation tool. In the future, we anticipate connecting live data streams to the emulation for realistic experiments and evaluations. In order to make Modeler more available, we installed Modeler on the EMULAB cluster such that any authorized user can access the software (with concurrent use limited by the number of licenses). In FY11, the NEMSE team updated the FY10 demo.

3.2.3 COPE Demo

COPE is a forwarding architecture that substantially improves the throughput of wireless networks. COPE inserts a coding shim between the IP and MAC layers, which identifies coding opportunities and benefits from them by forwarding multiple packets in a single transmission. COPE is an element of the Information Dynamics in Networks MURI (Multi-University Research Initiative) sponsored by AFOSR. Our initial plan was to install and test COPE on the RI EMULAB. However, COPE is inherently wireless, whereas the RI EMULAB does not currently have wireless nodes. There were a number of attempts to compensate for the lack of wireless nodes on the RI EMULAB. All were unsuccessful. In addition the team had to deal with the restrictions placed on non-citizens when they access a DoD computer system. The NEMSE team and the MURI liaison, Dr. Markopoulou, determined the best course of act was to implement COPE on the Utah EMULAB and funded an in-house contractor to do so. That effort is underway. Once the implantation on the Utah EMULAB is complete, the NEMSE team will assist the MURI team in evaluating COPE modifications and reconsider the possibility of implementing it on the RI EMULAB. For background information on COPE, see *XORs in The Air: Practical Wireless Network Coding,* S. Katti, et al., *SIGCOMM'06,* September, 2006, Pisa, Italy.

3.2.4 FPGA Physical Layer Emulator (FPLE) Demo

The Field Programmable Gate Array (FPGA) Physical Layer Emulation (FPLE) demonstration is the implementation of a concept intended to both extend the capabilities of the Information Directorate EMULAB and make FPGA design more accessible to the researcher. The FPLE consists of an Altium Nanoboard 3000 installed in a standard rack drawer. There are connections to allow easy use at a lab workstation or direct physical connection to the EMULAB test-bed. Use of Altium Designer allows users to design, compile and test FPGA code without learning VHDL or a similar FPGA coding language. The simple physical interface allows a user to easily transfer the experiment between a desktop and a rack in the EMULAB test-bed. In principle, a “NEMSE box” such as this could also be transferred to and from a third party, such as a university researcher, for research in an outside environment.

3.2.5 GNU Radio Demo

GNU Radio (GNU is not Unix) is an open-source software package for building and testing software-defined radio systems. Used in connection with a suitable hardware device, such as the Universal Software Radio Peripheral (USRP), GNU Radio provides a simple, flexible means for emulating a variety of radio devices. As with the FPLE, the demonstration, consisting in this case of a USRP and microcomputer with the GNU radio software, are placed in a NEMSE box for ease of transition between desktop, EMULAB, and outside researchers.

3.2.6 Tech Warrior Demo

The Tech Warrior demonstration, named after the AFRL exercise, is intended to represent a field scenario with airborne surveillance and tactical communication between multiple ground units.

3.2.7 CASCON Demo

The CASCON (Close Air Support Connectivity) demonstration, springing from the Close Air Support (CAS)-Connectivity program, was a war-gaming scenario intended to demonstrate and test video-based CAS.

3.2.8 RAVC Demo

The Rate Adaptive Video Coding (RAVC) demonstration uses a commercial video encoder, the FastVDO SmartCapture device, to control the transmission (frame rate and resolution) and encoding (compression) characteristics of a video stream to adapt to changing bandwidth limitations.

3.3 Virtualizations

The eight demonstrations described in the previous sections have been combined into three virtualizations for FY12. A NEMSE virtualization uses real processors and real network components but the network itself is virtual.

These virtualizations are described in Appendix B. "Evaluation of Complex Network Abstract Geometry" (ECNAG).

4.0 NEMSE Elements

The NEMSE elements table, Figure 3, reconciles the various elements of NEMSE against the OSI stack and other functions.

OSI	Layer or Function	EMULAB	NS2	OPNET	CORE	Click	MadWiFi	GNU	FPLE	RAVC	MATLAB	IPERF	WireShark	Data Wall	Putty
7	Application		■	■						■	■	■			
6	Presentation	■		■						■	■			■	■
5	Session	■		■						■	■			■	
4	Transport	■	■	■	■					■	■				
3	Network	■	■	■	■										
2	Data Link	■	■	■	■	■									
1.2	Physical- MAC			■	■	■	■	■							
1.1	Physical-Hardware					■		■	■						
	Models		■	■	■	■									
	Protocols			■		■	■			■					
	Packet Stataistics			■							■	■	■		
	Hardware Eval							■				■			
	Prototype Hardware					■	■	■	■						
	Section	B1	B1	B4.2	B4.3	B3.1	B3.2	B4.4	B4.5	B4.7	B4.5	B2	B2	B4	B1

Figure 3: NEMSE Elements

5.0 Conclusions

The software environment defined by the NEMSE team is complete to the extent that is deemed to be in scope of the NEMSE project. It is now ready for use by AFOSR researchers to evaluate Complex Network Portfolio algorithms.

Network emulation plays an important role in evaluating next-generation complex network product designs. From the component level to the system-of-systems level, emulation enables evaluation in a real system context. Not all network simulators are capable of true emulation. To be a true replacement for a network, emulation must support real-time speed, full packet fidelity, and provide transparency. An EMULAB cluster with NEMSE extensions can supports true network emulation with parallel execution and the highest fidelity models and the scalability and interactivity required to test and evaluate the most advanced new network communications devices and architectures.

Under the NEMSE program, complex network emulation techniques have been investigated; compatible emulation techniques for all OSI network stack layers have been selected. Other significant accomplishments of the NEMSE program include 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 for FY12.

The NEMSE EMULAB emulation environment is available for continued use during FY12 to other DoD, industry, and academia researchers in need of a realistic network emulation environment.

Appendix A: In-House Activities

Personnel:

Name	Degree	Discipline	Involvement
Air Force Employees			
Dr. David Hench	Ph.D.	Electrical Engineer	1/5
Capt Craig Baker	M.S.	Physicist	1/5
On-site Contractors			
Ms. Geraldine Rogers	B.S.	Computer Science	1/5
Mr. Barry Fabrey	A.S.	Automatic Test Equipment Eng	1/5
Mr. Chester Wright	M.S.	Computer Engineering	1/20

Appendix B: NEMSE Demonstrations

B 1 Introduction

Rather than reinvent the wheel, NEMSE has concentrated on making a modeling and simulation environment where the best of current emulation techniques are available to users. NEMSE is now available in an easy-to-use, integrated form on the Information Directorate EMULAB. FY11 activities concentrated on ensuring that protocol development, packet statistics, and transition paths are available for all levels of the OSI protocol stack.

The eight NEMSE demonstrations were described in the body of this report. They have been grouped into three virtualizations for possible continuation in FY12. The first two virtualizations are for continuation of the Complex Network Portfolio collaboration. The third virtualization will be developed using 6.2 research funds. These three virtualizations are:

1. Evaluation of Complex Network Abstract Geometry (ECNAG): Batch mode network characterization. This virtualization includes the NEMSE Medium Scale CAS Demo. The researcher uses a methodology for designing network experiments and collecting data that does not require a Complex Network Investigator to know the details of EMULAB or even to sign on to EMULAB.

2. University of California, Irvine Collaboration (UCIC): Interaction with UC Irvine including part of the COPE Demo.

3. Virtualization of Tech Warrior (VTWar) which transitions the NEMSE Demos to 6.2 research. The NEMSE Demos were System-in-the-Loop (STIL) using OPNET Modeler, COPE, FPGA Physical Layer Emulator (FPLE), GNU Radio, CORE & EMANE, Tech Warrior, CASCON (CAS Connectivity), and Rate Adaptive Video Coding (RAVC).

The common network models, including wireless, are provided in either OPNET or in CORE with the EMANE class library. OPNET is mainly known as a simulation product but with the System-in-the-Loop (SITL) module it is an effective emulation package. The researcher is able to feed real packets in and receive real packets out. Multiple instantiations of OPNET are possible in a single experiment. Using a combination of multiple instantiations of OPNET with multiple instantiations of CORE and EMANE along with hardware-in-the-loop provides a unique capability for Verification and Validation (V&V).

OPNET and CORE development in NEMSE are described in Section B 3 along with other wireless physical layer techniques including 802.11 emulations using Atheros wireless cards, GNU radio, and an FPGA development platform. The Tech Warrior virtualization, Section B 4, shows how OPNET, CORE, and hardware-in-the-loop can be combined.

The sign on procedure for the Information Directorate EMULAB was developed by University of Utah and adapted by the Information Directorate's High Performance Computing group. This procedure is shown in Figure 4. The steps are:

1. Get a Kerberos (krb5) Ticket.
2. Make sure X-Win32 is enabled.
3. Get a Putty window.
4. Type "Firefox" in Putty window.
5. Login to the Project Design GUI.

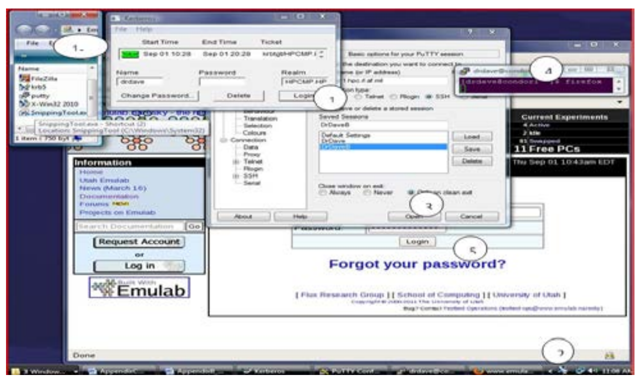


Figure 4: Log-On Procedures for EMULAB

B 2 Evaluation of Complex Network Abstract Geometry (ECNAG)

B 2.1 Description of Batch Mode Techniques

NEMSE Standard Symbols for Network Drawings, see Figure 5, shows a standard set of PowerPoint symbols that an investigator can use to design an experiment for EMULAB. The actual code is too simple to justify automating this procedure and a technician can easily transcribe the resulting Network Drawings into an EMULAB experiment.

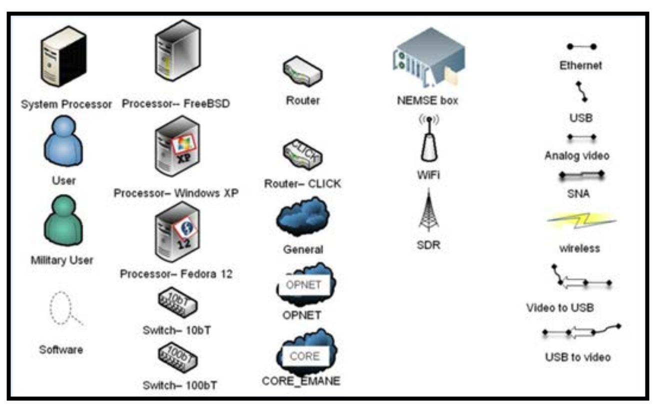


Figure 5: NEMSE Standard Symbols for Network Drawings

The Reduced Set of Network Symbols, Figure 6, can be used by a researcher who desires to work problems in OSI layers only above the MAC sub-layer of the Ethernet Physical Layer Protocol. In this case, the native Ethernet EMULAB hardware can be used instead of using one of the available NEMSE physical layer emulation techniques.

With the approval of the AFOSR program manager, the Complex Network Investigator provides:

1. A network drawing, Symbols Figure 6.
2. Any programs or shell scripts he wants to use.
3. A measurement template, Figure 7
4. An events template, Figure 8

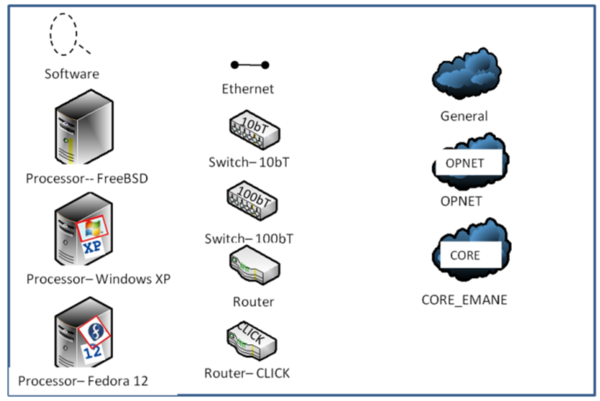


Figure 6: Reduced Set of Network Symbols

Then the NEMSE team can provide an EXCEL spreadsheet matching the measurement template. This technique minimizes the learning curve for the investigator. As a hypothetical example assume a Complex Network Investigator wishes to investigate Routing Protocols in the Link Layer. Since the Link Layer is above the MAC sub-layer, the Investigator uses the reduced set of symbols.

Time (min)	Event
10	Shutdown Node5
20	Link 6 80% packet loss
...	

Figure 7: Event Table Template

The Network Diagram for the example in Figure 9 shows the Network Drawing using the reduced set of network symbols. Each processor can have up to three Ethernet connections.

Time (min)	TCP Capacity Node1 – Node 10 (kbits/sec)	Ping time Node1- Node 2 (sec)	...	...

Figure 8: Sample Measurement Template

The Investigator defines various links:

- L12 is a 100 Mbps high quality trunk.
- L13 is a 500 kbps link subject to natural interruption.
- L14 is a 56 kbps link subject to natural interruption.
- L24 is a 200 kbps link subject to jamming.
- L23 is a 100 Mbps link subject to jamming.
- L34 is a 100 Mbps link subject to jamming.

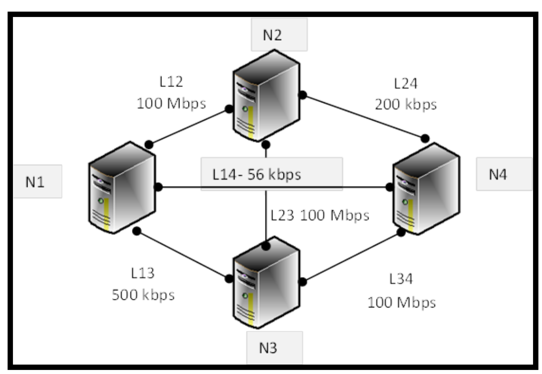


Figure 9: Network Diagram for the Example

It is assumed that jamming has the following level of risk:

- Jamming link L34 is low risk.
- Jamming links L34 and L23 or link L24 is medium risk.
- Jamming links L34, L23, and L24 is high risk.

The Investigator decides to use an IPERF server in node N1 using Fedora 12 nodes and an IPERF client in node N2 to measure the capacity in kbps. In this example the Investigator wants:

1. An initial run using the router built into Fedora 12.
2. Jamming to be either full on or full off.
3. Capacity measurements every 10 seconds.
4. Data delivered as concatenated IPERF readings.
5. Five minutes between events to ensure routing has settled down.
6. The event table, Figure 10.

Status: This example is currently in an advanced sate of debugging.

Time (min)	L12 100 Mbps	L13 500 kbps	L14 56 kbps	L24 200 kbps	L23 100 Mbps	L34 100 Mbps
0	@	@	@	@	@	@
5	@	@	X	@	@	@
10	@	X	X	@	@	@
15	@	X	X	X	@	@
20	@	X	@	X	@	@
25	@	@	@	@	@	@
30	@	@	@	@	X	@
35	@	@	@	X	@	@
40	@	@	@	@	X	@
45	@	@	@	@	X	X
50	@	@	@	@	@	@

Figure 10: Event List for the Example

B 2.2 NEMSE Medium Scale CAS Demo

During FY10, a 20-node tactical network developed by ATC New York for EMULAB was studied and exercised. This study included signing onto various nodes and becoming familiar with the programming, including the use of NS2 agents. This model was demonstrated to AFOSR. The models used in this network were in need of more accurate development.

During FY11 this model was transformed into a batch experiment with Fedora 12 nodes and IPERF in each node. A Wireshark network analyzer was also integrated.

It is considered that this demo puts the team in a good position to gather statistics to support geometric models from the AFOSR Complex Networks Portfolio.

B 3 University of California Collaboration (UCIC)

UC Irvine provided two techniques to be considered by NEMSE team. These two techniques are the Click router and the MadWiFi driver. The COPE experiment provides a network coding shim between the Link Layer and the MAC sub layer of the Physical Layer.

B 3.1 Click

Click is a software architecture for building flexible and configurable routers that was developed at MIT. A Click router is assembled from packet processing modules called elements. Individual elements implement simple router functions like packet classification, queuing, scheduling, and interfacing with network devices.

Users can program their own elements in C++ allowing greater flexibility. Alternately, a less sophisticated user can use preprogrammed elements.

Complete configurations are built by connecting elements into a graph; packets flow along the graph’s edges.

A typical Click router is meant to be used in the Linux kernel module. This means that a hardware implementation of the Click-developed router is a simple embedded Linux module with processing power matched to measured requirements in the emulation.

B 3.2 MadWiFi

The MadWiFi driver is an open source 802.11 Linux driver with well documented source code. A proprietary Hardware Abstraction Layer (HAL) in binary code is available for MadWiFi for the Atheros AR5210, AR5211, AR5212, RF5111, RF5112, RF2413, and RF5413 wireless cards with capability for PCI, miniPCI, and PC card bus interfaces. There are no known USB HALs. Since MadWiFi is an actual Linux driver, emulation can be ported to a Linux embedded system with an Atheros card. The Atheros cards are part of the University of Utah EMULAB and the RF physical-layer hardware emulator designed for NEMSE will be shown in the next section.

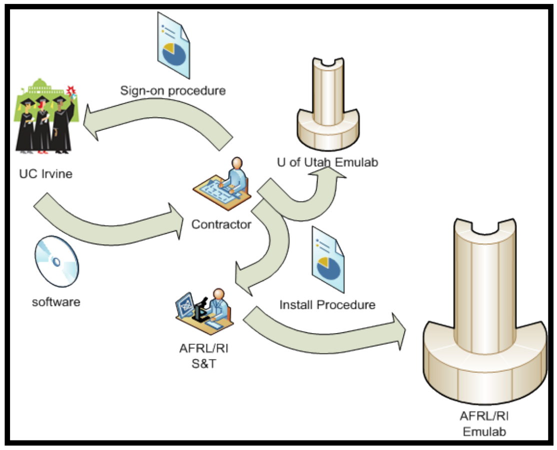


Figure 11: Work Flow for Porting COPE

A work flow diagram of the NEMSE COPE project is shown in the work flow for porting COPE Figure 11. The source code for COPE was provided by UC Irvine from the graduate student project. Since a foreign graduate will be continuing the research, the Information Directorate reinstalled the source code on the U of Utah EMULAB.

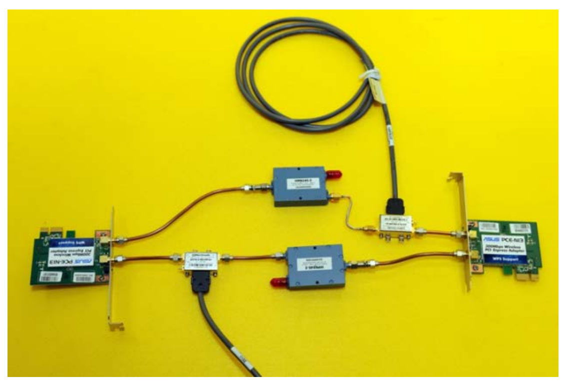


Figure 12: RF Channel Emulator

The RF Channel Emulator, Figure 12, uses two ASUS PCE-N13 802.11 b/g/n Wireless PCI – Express Adapter cards plus two fixed and two variable attenuators, a splitter/mixer, and rigid coax cables. This produces an analog RF channel emulator that is complete except for delay elements which can either be incorporated in analog or in digital in a modified MadWiFi adaptor. The connector and cable losses of this emulator can be calibrated in the RF laboratory using standard techniques.

If a Hardware Abstraction Layer was written for the FPLE (Section B 4.5 below), the Information Directorate would have the capability to emulate 802.11 Link and Physical Layer using either RF or FPLE emulation of the transmission.

B 4 Virtualization of Tech Warrior (VTWar)

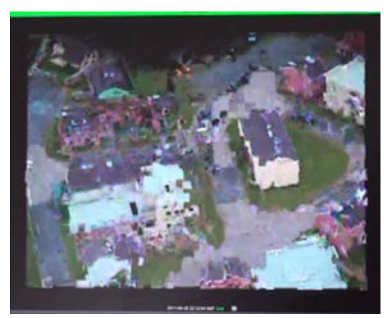
B 4.1 Tech Warrior exercise

Tech Warrior is an AFRL exercise that provides AFRL Company Grade Officers who have little or no operational experience with an intense field, mobility, and combat skills training opportunity. Tech Warrior also provides AFRL the opportunity to test, experiment, conduct data collection, and or otherwise showcase/demonstrate state-of-the-art war fighting technologies in a realistic operational environment.

The Small Unmanned Systems Exploitation (SUSEX), RYRA program, was participating in the Tech Warrior exercise. They were conducting flight testing with a variety of small unmanned platforms. These flights collected data, demonstrate sensor exploitation capabilities, and develop operations concepts using small UASs and unattended ground sensors in support of intelligence, surveillance, reconnaissance, and targeting activities.

The NEMSE team viewed SUSEX participation in Tech Warrior as an excellent opportunity to collect and process numerous video feeds in support of the continuing development of NEMSE. In addition to the video recorded, SUSEX provided us with a copy of their data collection files; 13,879 files, 79 GBytes. The data classification was FOUO and for limited distribution. We can use the data internal to RI, but we are unable to share it with AFOSR Complex Networks researchers. This inability to share the collected data with AFOSR researchers was a major disappointment.

The following sensor payloads were flown by SUSEX:
Gimbaled IR Video – LWIR, MWIR, & SWIR, WAMI – 1-5 frame/sec, large footprint,
Gimbaled EO Video – 26x zoom, AR – 1 ft Imagery, Targeting, Change Detection, and
SIGINT – Demodulation, Limited Direction Finding.



The picture on the right started out as a very high definition video feed from a SUAS to the SUSEX control van, over a 44 Mbps link. The communication link from the control van to the FOB was a 10 Mbps link. The video feed at the FOB was junk. The picture on the right is excellent example for making the case for more research by AFOSR in the area of reliable transfer of data in dynamic, hostile and high interference environments.

NEMSE considers the Tech Warrior Exercise to be a success because the data collected enable us to build the Tech Warrior Virtualization. This virtualization can potentially be used to design the FY12 Tech Warrior Exercises with enhanced capability.

B 4.2 Tech Warrior Virtualization

The Network drawing of the Tech Warrior Demo, Figure 13, shows the network drawing of the Tech Warrior Virtualization. This drawing uses the symbols of Reduced Set of Network Symbols and is produced by the investigator in PowerPoint.

The script file that implements this virtualization is shown below in its entirety to illustrate the reason that it was not considered time effective to automate the procedure. Such a script is relatively easy for a trained programmer to produce.

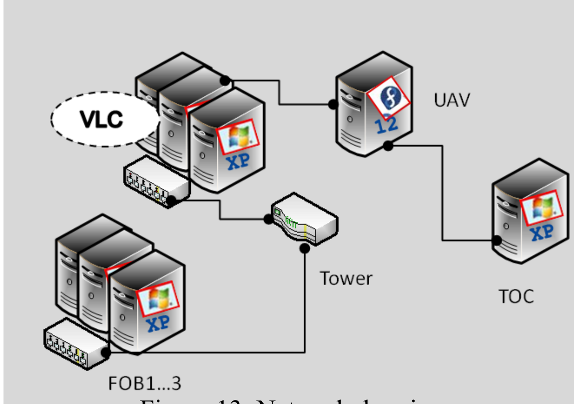
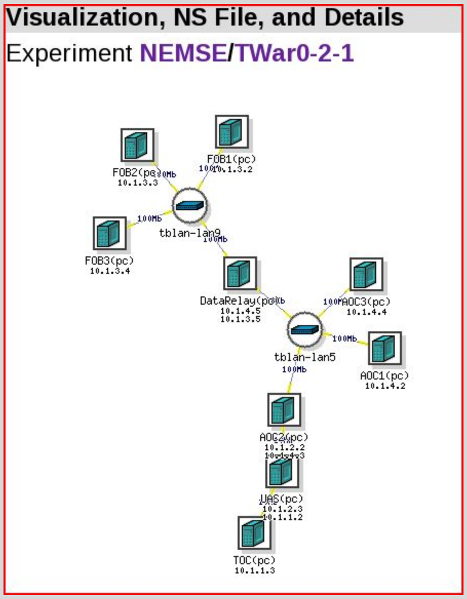


Figure 13: Network drawing Tech Warrior demo

```
# Start of script
set ns [new Simulator]
source tb_compat.tcl
# Allocate nodes
set DataRelay [$ns node]
tb-set-node-os $DataRelay WinXP-Modeler15-Svr
set AOC2 [$ns node]
tb-set-node-os $AOC2 WINXP-VLC
set AOC1 [$ns node]
tb-set-node-os $AOC1 WINXP-VLC
set AOC3 [$ns node]
tb-set-node-os $AOC3 WINXP-VLC
$ns  make-lan "$AOC1 $AOC2 $AOC3 $DataRelay" 100Mb 0ms
set FOB3 [$ns node]
tb-set-node-os $FOB3 WINXP-VLC
set FOB2 [$ns node]
tb-set-node-os $FOB2 WINXP-VLC
set FOB1 [$ns node]
tb-set-node-os $FOB1 WINXP-VLC
$ns  make-lan "$FOB1 $FOB2 $FOB3 $DataRelay" 100Mb 0ms
set UAS [$ns node]
tb-set-node-os $UAS FBSD73-STD
set TOC [$ns node]
tb-set-node-os $TOC TOC
set CommandLink [$ns duplex-link $AOC2 $UAS 10Mb 0ms DropTail]
set ROVERlink [$ns duplex-link $UAS $TOC 10Mb 0ms DropTail]
#tb-set-hardware $TOC pc3000
# Start!
$ns run
```

Figure 14, EMULAB Visualization of Tech Warrior, shows the visualization produced by EMULAB from the above script. OPNET will be described in Section B 4.3 OPNET, GNU Radio in Section B 4.4, FPGA Physical Layer Emulator (FPLE) in Section B 4.5, CASCON in Section B 4.6, and RAVC in Section B 4.7.



Node ID	Name	Type	Default OSID
pc6	AOC3	pc2950	WINXP-VLC
pc7	AOC2	pc2950	WINXP-VLC
pc11	FOB2	pc2950	WINXP-VLC
pc12	tbdelay1	pc2950	FBSD73-STD
pc18	UAS	pc2950	FBSD73-STD
pc20	tbdelay0	pc2950	FBSD73-STD
pc22	FOB1	pc2950	WINXP-VLC
pc23	TOC	pc2950	TOC
pc24	FOB3	pc2950	WINXP-VLC
pc25	DataRelay	pc2950	WinXP-Modeler15-Svr
pc28	tbdelay7	pc2950	FBSD73-STD
pc37	tbdelay4	pc2950	FBSD73-STD
pc62	AOC1	pc2950	WINXP-VLC
pc64	tbdelay2	pc2950	FBSD73-STD

Figure 14: EMULAB Visualization of Tech Warrior Demo

B 4.3 OPNET

OPNET Technologies, Inc. provides performance analysis for computer networks and applications. OPNET products address application performance management, network performance management, and network R&D. OPNET mixes Discrete Event Simulation (DES) and statistical flows. With its Wireless for Defense package, OPNET has excellent mobility and antenna modeling capability. OPNET is generally considered a modeling package with simulated packets in its DES simulation. However, with its System-in-the-Loop (SITL) models it becomes a real-time emulation package with real packets input to the computers Network Interface Card (NIC) and real packets out of another NIC. OPNET has excellent packet data collection and statistical analysis packages. OPNET, however, is not a source of real packets.

The FY10 final report described OPNET work in a demonstration called OpPhy that modeled a jammer scenario

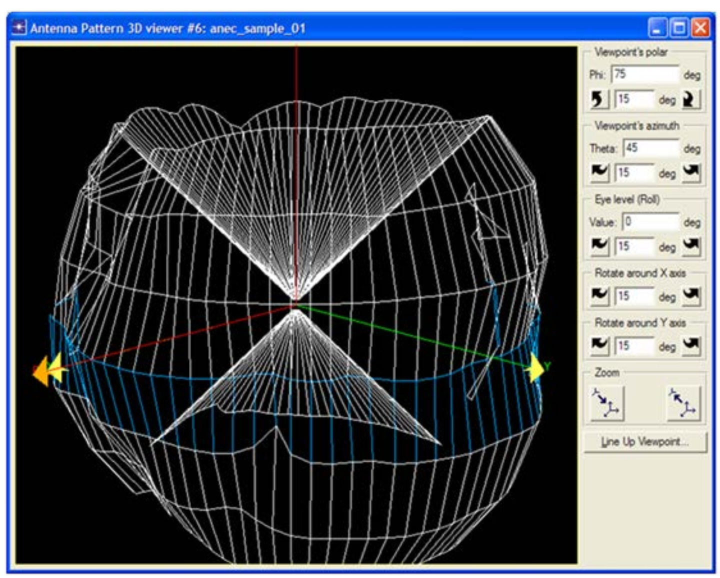


Figure 15: Antenna Pattern in OpNet

with antenna models as a variable component for anti-jam resistance. Figure 15 repeats an antenna pattern that was taken from measurements in the Information Directorate Anechoic chamber.

In addition to mobility and antenna modeling, the OPNET installation allows physical level modeling through a series of pipeline stages with the C++ code in each stage open for modification with well documented interface structures.

Six stages on the transmitter side are:

- Receiver group
- Transmission delay
- Link closure
- Channel match
- Tx antenna gain
- Propagation delay

Eight stages on the Receiver side are:

- Rx antenna gain
- Received power
- Interference noise
- Background noise
- Signal-to-noise ratio
- Bit error rate
- Error allocation
- Error correction

The OPNET demonstration has been placed in the VTWar Data Relay node.

Status: OPNET is currently fully supported and detailed modeling is out of scope for the NEMSE program.

B 4.4 GNU Radio

GNU Radio is a free software development toolkit that provides the signal processing runtime and processing blocks to implement software radios using readily-available, low-cost external RF hardware and commodity processors. All of the code is under copyright, by the Free Software Foundation. It is widely used in hobbyist, academic, and commercial environments to support wireless communications research as well as to implement real-world radio systems.

GNU Radio applications are primarily written using the Python programming language, while the supplied, performance-critical signal processing path is implemented in C++ using processor floating point extensions where available. Thus, the developer is able to implement real-time, high-throughput radio systems in a simple-to-use, rapid-application-development environment.

While not primarily a simulation tool, GNU Radio does support development of signal processing algorithms using pre-recorded or generated data, avoiding the need for actual RF hardware.

The Universal Software Radio Peripheral™ (USRP) product family allows you to create a software defined radio using any computer with a USB 2.0 or Gigabit Ethernet port. Various plug-on daughterboards allow the USRP and USRP2 SDRs to be used on different radio frequency bands. Daughterboards are available from DC to 5.9 GHz at this time. The entire design of the USRP family is open source.

The USRP product family works with GNU Radio, a free-software (open source) framework for the creation of software defined radios. GNU Radio works on the FreeBSD operating system such as is used in the VTWar UAS node.

The NEMSE Box for GNU with NTSC ROVER Camera, Figure 16, shows a NEMSE box constructed to house up to two USRP 2 radios. At the present time there is only one radio installed. The camera shown by the side was built to calibrate ROVER IV units in the field and a USRP, GNU radio pair has been used to decode NTSC analog video that could be displayed by a ROVER. The built-in processor can run an Access IO component such as those shown in a RF channel emulator, Figure 12.

Figure 16: NEMSE Box for GNU with NTSC ROVER Camera

B 4.5 FPGA Physical Layer Emulator (FPLE)

This demo is currently a standalone experiment that can be used to link the VTWar AOC1 node to the UAS node.

The FPLE objectives were:

1. Prototype an FPGA interconnect between two computers that can be used to emulate physical layer and channel effects.
2. Integrate an FPGA development and testing environment into the EMULAB cluster to allow simple design by any Information Directorate engineer.
3. Develop C language Mix drivers for MATLAB.
4. Investigate methodology for FPGA interconnection between computers.

An effective and simple FPLE has been demonstrated that utilizes the Altium Nanoboard 3000 hardware and Altium designer software. This combination provides an integrated hardware development environment, FPGA hardware interfaces, and testing for hardware and software in MATLAB. The hardware provides access to most standard computer interfaces.

Graphical development using standard electrical engineering techniques avoids use of layout languages such as VHTML. These techniques make FPGA design accessible to any electrical engineer.

The FPLE has been integrated into a 2U high standard rack for potential use in the EMULAB cluster. USB connections from each of two computers can be used. A simple prototyping area is included.

Use of IP cores is emphasized. The cores used may be built-in to Altium Designer, obtained from a third party, or developed in-house with the techniques built into Altium

Designer. Cores for many logic components are included as are cores for memory, processors and DSPs, and the Wishbone bus interconnects.

The software diagram for FPLE, Figure 17, illustrates the software concept. The FPLE utilizes two Digital I/O modules (USB-DIO-32 by Access). These modules are the same as the module used in the GNU radio variable attenuator controller RF channel emulator, Figure 12. These devices were selected primarily because of the flexibility of the driver software. This flexibility has allowed it to include a MEX C function and can be compiled into MATLAB as a C language extension.

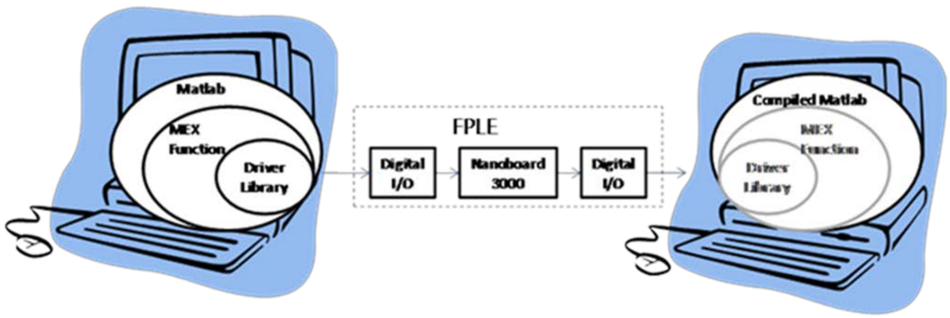


Figure 17: Software Diagram for FPLE

Figure 18 shows the FPLE NEMSE box mounted in the Information Directorate EMULAB. A standard 19" x 21" rack tray, with ball bearing sliders, is utilized to mount the required components. This tray assembly is designed to be quick-disconnect so that it may also be used on a lab bench or in another rack oriented system. The FPLE tray's purpose is to provide a flexible development platform for engineers and designers of FPGA based systems. The FPLE tray contains the following items:

Figure 18: FPLE NEMSE Box Installed in EMULAB

1. Altium NB3000XN Nanoboard Development System, used to develop FPGA functional code on a Xilinx 3AN platform.
2. Cosel R25A-5-N five (5) volt power supply. This unit supplies 5 volt DC power to the on board units, eliminating the use of several modular 120vAC/5vDC plug units (for each tray item).
3. Access I/O Products USB-DIO-32 (2 each) Digital Serial / Parallel IO unit. One unit connects the "A" user computer USB port to the "A" data parallel input to the NB3000 system. The other unit connects the "B" data parallel output of the NB3000 system to the "B" user computer USB port. Power for these units is supplied via the USB connection.
4. USB Hub (generic), used to connect the "A" computer to the "A" DIO unit and the NB3000 development system (for JTAG down loading of FPGA configuration files).
5. Break-Out Board, (in-house design/build). This facilitates the use of a Data Analyzer in the parallel data paths between the DIO and the NB3000 data paths (A and B).
6. Rear Panel Assembly. This is a 2U panel at the rear of the tray. On it is located the Power Entry Module, with switch and the "A" and "B" USB panel mount connectors.

Figure 19, shows the FPLE NEMSE box ruggedized and placed in the prototype CASCON rack. This box was hard wired and used for NEMSE development before the EMULAB was available.

Figure 19: FPLE in CASCON Box

B 4.6 CASCON

CASCON was a series of field experiments preceding Tech Warrior. Photos, videos, maps, and ConOps were accumulated to develop a War Game Virtualization. The CASCON work has been joined with the Tech Warrior virtualization.

B 4.7 Rate Adaptive Video Coding

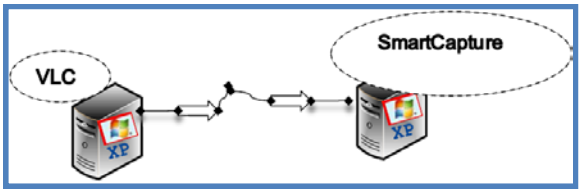


Figure 20: RAVC Network drawing

This demo is hardware connected between VTWar Nodes TOC and UAS. Figure 20 shows the hardware diagram with USB video converted to NTSC (analog) video and then back to USB video. Figure 21 shows the hardware that actually converts the monitor video to analog and then uses the FastVDO Universal Video Stick to create RAVC video.

Figure 21: Hardware for RAVC

B 5 Conclusions

The software environment defined by the NEMSE team is complete to the extent that is deemed in scope of NEMSE. It is now ready for either universities for collecting data to evaluate Complex Network Portfolio algorithms or for 6.2/6.3 funded programs.

B 6 References

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2. *The Click modular router,* Robert Morris, Edie Kohler, John Jannotti, and M. Frans Kaashoek, MIT Laboratory for Computer Science, s.l.: 17th ACM Symposium on Operating Systems Principles (SOSP '99).

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ACRONYMS

AFOSR	Air Force Office of Scientific Research
AFRL	Air Force Research Lab
API	Application Programmer Interface
ATC	Architecture Technology Company
CAS	Close Air Support
CASCON	Close Air Support Connectivity
ConOPS	Concept of Operations
CORE	Common Open Research Environment
DES	Discrete Event Simulation
DoD	Department of Defense
DSN	Defense Switched Network
ECNAG	Evaluation of Complex Network Abstract Geometry
EMANE	Extensible Mobile Ad-hoc Network Emulator
FPGA	Field Programmed Gate Array
FPLE	(FPGA) Physical Layer Emulation
FPLE	FPGA Physical Layer Emulator
FY	Fiscal Year
GNU	(GNU's not Unix)
GUI	Graphical User Interface
HARBS	Hierarchical AFRL Research for Battlefield Support
HPCMO	High Performance Computing Management Office
IPERF	Internet Performance Working Group
JCSS	Joint Communications Support Squadren
MAC	Media Access Control
MURI	Multi-University Research Initiative
NEMSE	Network Modeling, Simulation and Emulation
NETWARS	Network Warfare Simulation
NIC	Network Interface Card

MURI	Multi-University Research Initiative
NEMSE	Network Modeling, Simulation and Emulation
NETWARS	Network Warfare Simulation
NIC	Network Interface Card
NRL	Naval Research Lab
NS2	Network Simulator 2
OPNET	Optimized Network Evaluation Tool
OSI	Open System Interconnect
PI	Principle Investigator
R&D	Ressearch and Development
RAVC	Rate Adaptive Video Coding
RDT&E	Research, Development Test & Engineering
RF	Radio Frequency
ROVER	Remotely Operated Video Enhanced Receiver
SITL	System-in-the-Loop
TCL	Tool Command Language
TOC	Tactical Operations Center
TPP	Technology, Practices, and Procedures
UAS	Unmanned Aerial System
UCIC	University of California Irvine Collaboration
UGV	Unmanned Ground Vehicle
USRP	Universal Software Radio Peripheral
V&V	Verification and Validation
VHDL	Very High-level Design Language
VTWar	Virtual Tech Warrior
WiMax	Worldwide Interoperability for Microwave Access