Implementing Emulated Communication Models for Hybrid and Dynamic Network Topologies

by

Joseph Murphy

A Thesis
Submitted to the Faculty
of the
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Master of Science
in
Electrical and Computer Engineering
by

December 2022

APPROVED:

Professor Alexander Wyglinski, Committee Member

Professor Carlo Pinciroli

Professor Bashima Islam

Abstract

In this thesis, network emulation is presented as a solution to testing, developing, and extending communication systems in a time- and cost-effective manner. Complex hybrid and dynamic wireless networks require extensive testing that is not easily conducted in hardware testbeds and may not be modeled accurately enough in network simulation tools. Network emulation provides the benefits of both hardware testbeds and simulation tools while also minimizing the shortcomings of each. This thesis evaluates the Extendable Mobile Ad-hoc Network Emulator (EMANE) as a network emulation tool by assessing its ability to emulate several complex network models. These models include hybrid wireless rural broadband deployments, an intelligent routing software development environment, and dynamic robot swarm networks. The emulated models were determined to be accurate enough to their hardware counterparts such that EMANE can be used as an effective tool for prototyping and testing communication systems.

Acknowledgements

Thanks: Wyglinski, Pinciroli, Islam, US Ignite, US Army DEVCOM, the WiLab community, friends and family

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Motivation

As the need Internet and wireless communications grow, more solutions for deploying networks are being conceived. Networks are expensive to deploy and test, especially in rural environments where hybrid combinations of wireless technologies must be used and when using special networks (MANET) This creates a need for a low-cost, easy method to do initial testing on networks and network technologies to validate viability before spending money on hardware deployments and testing Use network simulation and emulation for preliminary testing as it can require little to no hardware, can be conducted in a lab, and costs less than building physical networks for each new experiment

1.2 State of the Art

Many software and combination software-hardware platforms exist for testing networks. ns-3, NetSim, OPNET (now owned and operated by Riverbed)

1.3 Current Issues

Why are these simulators not as good?

- Many are not free or open-source (expensive to use and possibly not as customizable)

- Can be complex to set up
- Often only focus on network layer and abstract MAC/PHY layer, OR model the MAC/PHY layer but does not allow for integration with network software and protocols

1.4 Thesis Contribution

- EMANE is proposed as a valuable testing tool that addresses issues with other similar networking simulation tools. An overview of installing and using the tool is provided.
- Develop an initial simple program for maximizing bandwidth in constrained networks and showed how EMANE can be used as a valuable development environment.
- Basic integration between the robot swarm simulator, ARGoS, and EMANE allowing for more complex communications simulation between robots.

1.5 Thesis Organization

The remainder of this thesis is organized as follows: Chapter 2 presents an overview of the network emulator EMANE and the motivation behind the selection of this tool. An overview of the how to use EMANE and its subsystems is presented. Three different use-cases for the EMANE tool are considered to evaluate the effectiveness of the tool. Chapter 3 proposes the first use case for testing with EMANE, testing rural broadband deployments. Two similar network topologies are proposed and tested with the help of EMANE. Chapter 4 explores a second use case for utilizing EMANE, development of networking technologies and systems. In this case a program for more intelligent allocated limited bandwidth is developed. Chapter 5 finally details a third use case for EMANE, integrating with other simulation tools to provide more accurate communication models. The paper is concluded with a summary of work completed and recommendations for future work in Chapter 6.

Chapter 2

Overview on Network Emulation and Simulation

Before utilizing the EMANE tool and presenting several situations the tool can be used in, it must first be understood why it was selected and why network emulation is used over simulation or hardware testbeds in this thesis. After justifying the choices behind selecting EMANE, we will provide an in-depth tutorial on the installation, configuration, and operation of the tool. A brief overview of mobile ad-hoc network (MANET) routing protocols is presented. These protocols are essential to understand because EMANE operates its networks as if they were MANETs and uses these protocols to route between nodes. Lastly, an overview of network resource scheduling is presented to provide essential understanding for one of the use cases EMANE is tested in.

2.1 Testing Communication Networks

There are typically three ways new network architectures, technologies, and protocols are developed and tested. These are network simulation, network emulation, and hardware testbeds [1]. As expected each of the three methods has pros and cons. Hardware testbeds are the most accurate since they encompass the devices expected to be used in the network once development and testing is done. Hardware, however, is expensive to purchase, time-consuming to deploy, and often difficult to troubleshoot if errors do not consistently appear [2]. This makes hardware testing not accessible to users that have a low budget.

Network simulation is one solution to testing that appears to solve many of the issues with testing on hardware. Several free and open-source network simulators like ns-3 [3] or OMNeT++ [4] are commonly use and provide a solution to the high costs of hardware. Like most network simulators, these simulators operate on the concept that the behavior of a network and its components can be modeled via statistical and mathematical models. Creating models for network behavior allows simulators to run faster than real time since the models do not need to wait for effects to actually happen. The caveat to this, however, is that simulation models need to be highly accurate when developed or else results from the simulation will not match expected hardware behavior. Researchers creating new simulation models must ensure the models are validated against the expected hardware behavior [5]. Simulation also has the benefit of being highly repeatable since the behavior of the network can be more tightly controlled and any random processes can be set up to repeat previous random outputs [1].

Network emulation exists somewhere between testing on hardware and testing inside a simulation. These emulators are still software that gets used to mirror the behavior of a testbed like simulators, but emulators operate on real network data instead of modeling the behavior of a network. Because emulation testbeds operate on actual network traffic, they also have the ability to interface with hardware allowing hardware testing without building a full hardware network. This characteristic of operating on real network traffic also has the downside of introducing more computation overhead.

Table 2.1 summarizes the pros and cons of testing in hardware, simulation, and emulation.

2.2 Evaluation of Network Testing Tools

One of the most well known, and most used network simulation tools is ns-3. ns-3 is a discrete-event network simulator that was developed to simulate and research wireless and IP networks. ns-3 is not limited to wireless and IP-based networks, as thanks to its

Table 2.1: Pros and Cons of Different Types of Network Testing

Testbed Type	Pros	Cons
Hardware	• Highly accurate • Does not require modification of networking software	• Expensive to build • Time consuming to deploy and configure • Errors can be sporadic
Simulation	• Free tools available • Can run faster than real time • Easy to reconfigure and modify	• Models must be designed to be highly accurate • Software must be translated to a simulation model
Emulation	• Free tools available • Can run native implementations of network software • Can interface with hardware	• Must run in real time • Requires higher computational overhead

open-source nature, many models for simulating other types of networks are also available. This option was inevitably not selected as the software to be used for this research as the physical technologies modeled

The Extendable Mobile Ad-hoc Network Emulator (EMANE) is a network emulation tool originally developed by the Naval Research Lab and currently maintained by AdjacentLink LLC. The software was developed with the intention of creating a platform that could emulate the physical and data link layers of the OSI network model. This focus on the customization of the physical and data link layers is one of the main draws of EMANE because it allows for highly customizable models of physical channels to be used. EMANE consists of several subsystems and components required to create a fully functional testbed. This creates an initial steep learning curve when using the software, and despite being open-source, the online community around EMANE is rather small with very little active discussion happening about the tool. Despite all this, once the user forms a core understanding of the tools and systems within the software, the tool can be used to effectively and quickly create model wireless networks. For this reason EMANE and combined with the details of the other network simulation tools.

2.3 Using EMANE

There are several ways EMANE can be installed for use. The primary two methods are to install the bundle of pre-built binaries provided by AdjacentLink or build the tools from source. The precompiled bundle is sufficient for the work completed in this thesis. Compiling the software from source is typically only necessary when

As previously mentioned, there are several systems that make up EMANE. The main three subsystems of note are the emulation processing system, the emulation transport boundary processing system, and the event processing system.

2.3.1 Emulation Model Processing

2.3.2 Transport Boundary Processing

2.3.3 Event Processing

2.4 Routing in Mobile Mesh Networks

EMANE was designed primarily to work with mobile ad-hoc networks, also known as MANETs. This special classification of network is characterized by its dynamic topology that often rapid changes due to the mobility of network nodes and the tendency of the wireless links to not be reliably connected. This lack of a fixed topology means that any node that exists in the network must be able to communicate without help from centralized infrastructure or a gateway and therefore must be able to independently make routing decisions [6]. EMANE's ability to move nodes freely around and reestablish links on the fly makes MANET routing protocols perfect for ensuring the emulated mesh is traversable. These types of routing protocols can be separated into two categories, proactive protocols and reactive protocols [7].

2.4.1 Proactive Mesh Routing

The first category of MANET routing protocol is the proactive protocol. Proactive protocols are similar to traditional routing protocols in the sense that they create and maintain a routing table. By maintaining a routing table, any transmission that needs to be sent can be done so immediately since the most efficient route is known. This allows proactive protocols to operate with less latency than reactive MANET routing protocols as they do not need to wait for route discovery at the time of transmission [7].

2.4.2 Reactive Routing

2.5 Network Resource Scheduling

2.6 Chapter Summary

Chapter 3

Hybrid Wireless Rural Broadband Networks

3.1 What was implemented?

3.1.1 OVERCOME Testbed

3.1.2 ZoomTEL Testbed

3.2 How was it implemented?

3.3 Why was it implemented this way?

3.4 Compare EMANE results to real testbed?

3.5 Chapter Summary

Chapter 4

Networking Software Development Environment

4.1 Intelligent Method of Bandwidth Distribution

4.2 Implementation Methodology

4.3 Why was it implemented this way?

4.4 Effectiveness of the Program

4.5 Chapter Summary

Chapter 5

Dynamic Robot Swarm Networks

5.1 Extending Existing Software

5.2 Integrating the Software

5.3 Integration Design Decisions

5.4 Integration Results

5.5 Chapter Summary

Chapter 6

Conclusion

6.1 Research Outcomes

6.2 Future Work

Bibliography

[1] S. Guruprasad, R. Ricci, and J. Lepreau, "Integrated network experimentation using simulation and emulation," in *First International Conference on Testbeds and Research Infrastructures for the DEvelopment of NeTworks and COMmunities*, 2005, pp. 204–212.

[2] M. Neufeld, A. Jain, and D. Grunwald, "Nsclick: Bridging network simulation and deployment," in *Proceedings of the 5th ACM International Workshop on Modeling Analysis and Simulation of Wireless and Mobile Systems*, ser. MSWiM '02. New York, NY, USA: Association for Computing Machinery, 2002, p. 74–81. [Online]. Available: https://doi.org/10.1145/570758.570772

[3] nsnam, "What is ns-3?" 2022. [Online]. Available: https://www.nsnam.org/about/

[4] O. Ltd., "What is omnet++?" 2019. [Online]. Available: https://omnetpp.org/intro/

[5] P. A. B. Bautista, L. F. Urquiza-Aguiar, L. L. Cárdenas, and M. A. Igartua, "Large-scale simulations manager tool for omnet++: Expediting simulations and post-processing analysis," *IEEE Access*, vol. 8, pp. 159 291–159 306, 2020.

[6] S. Puri and V. Arora, "Routing protocols in manet: A survey," *International Journal of Computer Applications*, vol. 96, no. 13, 2014.

[7] S. Kaur and K. Arora, "Performance evaluation of diverse manet routing protocols-a review," *International Journal of Computer Applications*, vol. 107, no. 17, 2014.

Appendix A

Installation of EMANE