Design of Simulation-Based Laboratories for Teaching Wireless Network Technologies

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Abstract

Five wireless network labs were developed and used in a wireless communications undergraduate course. The labs were designed using the simulation software Optimized Network Engineering Tools (OPNET) Modeler. The software was installed in a number of virtual desktops within a desktop virtualization environment for students conducting lab experiments. The labs provided students with hands-on experience in terms of wireless network configuration, implementation, and evaluation. The complete procedure provided a strong theoretical knowledge in the field of wireless networks and enhanced students’ practical skills for advancement in the current and future wireless communication job market.

1. Introduction

Wireless communication technologies are a huge part of our daily lives. People use their personal laptops to surf the Internet and cell phones to send emails and text messages. Well-trained professionals with knowledge of wireless networks are in high demand. We developed a set of laboratories in wireless networks to provide students with hands-on experience in terms of wireless network configuration, implementation, and evaluation. The exercises not only provide a strong theoretical knowledge in the field of wireless networks, but also enhance students’ practical skills for advancement in current and future wireless communication job markets.

In a university environment, wireless network experiments that use physical devices are constrained by limited resources, the high cost of actual hardware devices, and the problems associated with potential conflicts with the university production wireless environment. In contrast, simulation tools provide a simulated experimental environment for carrying out hands-on lab activities [1-3]. In this project five labs were designed using the simulation tool OPNET Modeler [4]. This approach not only saved money in purchasing real physical wireless devices, but also reduced development time in the creation of different wireless networks. With the use of a simulation tool, a complex wireless network infrastructure can be easily implemented and its topology can be quickly changed when needed.

The licensed OPNET Modeler software was acquired at no charge from Riverbed under its University Teaching Program. It was installed in a number of virtual desktops within VMware
View [5], a desktop virtualization environment. With its remote desktop capabilities to users, the lab benefits both on-campus and distance education (DE) students by enabling them to perform lab experiments anytime and anywhere, without competing for limited laboratory classroom space available on campus, thus increasing efficiency and effectivity.

This paper is organized as follows: Section 2 presents the developed labs. Section 3 discusses the online survey statistics result. Conclusions and future work are described in the last section.

2. Project Design

In previous wireless communications courses, a variety of assignments were included to help students understand wireless technologies. Examples include investigation of access point (AP) signal strength, research of wireless security, Wi-Fi site surveys, wireless packet analysis, evaluation of wireless network analyzers, and analog and digital signal modulation techniques. In order to enhance students’ understanding of topologies of wireless networks, a project consisting of a series of labs was implemented during the fall 2013 semester. Detailed instructional lab manuals were developed so that students could carry out hands-on activities in a step-by-step fashion. These activities included wireless network creation, network parameter customization, network simulation, and simulation result analysis. The complete procedure not only provided students with a strong theoretical knowledge in the field of wireless communications but also included challenging exercises that students could investigate and solve. In addition, the project offered students’ hands-on skills for adaptation to the current and future wireless communications job market.

This project included only five wireless labs but more will be developed in the future. It included three basic network architectures of IEEE802.11 Wireless Local Area Network (WLAN) configurations: Basic Service Set (BSS), Extended Service Set (ESS), and Independent Basic Service Set (IBSS). All of the five labs were designed using OPNET Modeler. The software was installed in a number of virtual desktops hosted by VMware View thus allowing access to any student logged into any one of the desktops supplied by the pool of virtual desktops.

The implementation of each lab is divided into three steps: network creation, statistics collection, and result analysis. In general, three methods can be used to create a network topology model in the first step: importing the topology, using rapid configuration, or dragging objects from the active palette into the displayed workspace. In each lab, the third method (dragging objects) is used to select the desired network topology, define the network size, and include preferable wireless devices. The application definition model and the traffic profile definition model are included for specifying what application and what traffic volume are to be used in the network (e.g. heavy/light web browsing, email, telnet, and ftp). Additionally parameters such as application supported services, IEEE WLAN standards, data rate, routing protocols, and transmitter power are configured by the student. After building the network architecture, network simulation begins and statistics of individual wireless devices (object statistics) and statistics of the entire network (global statistics) are collected in the second step. Example statistics include the following: data dropped, data traffic received and sent, delay, load, and throughput. Finally, the results are analyzed when the simulation is completed.
2.1. WLAN BSS Lab

WLAN technology provides connections between wireless mobile devices and an AP. It is defined in the IEEE 802.11 standards but often marketed under the term Wi-Fi based on certification of the Wi-Fi Alliance. The most popular standards include 802.11a, 802.11b, 802.11g, and 802.11n that operate in the unlicensed 2.4GHz ISM band and the 5GHz U-NII band. With the variant of standards, the WLAN technologies have been successfully applied to a variety of applications, such as home use wireless routers, temperature monitoring and smoke detection systems in factories, and Internet access Wi-Fi hotspots located in public places such as hotels, restaurants, and airports.

For this lab the learning objectives are:

- Understand the technologies of IEEE 802.11 standard used in WLAN
- Observe the behavior of AP, fixed and mobile wireless devices in WLAN

The lab involves simulations of WLAN configuration BSS. BSS network, also called infrastructure mode, includes a single AP that associates with multiple wireless devices. The AP acts as a central transmitter and receiver to control all the traffic inside the BSS. The lab is divided into two sub-labs. In sub-lab 1, students study the simplest BSS network configuration that includes a single AP and one fixed wireless device. In sub-lab 2, students study a geographical area of a BSS that includes a group of fixed wireless devices and a mobile wireless device all served by a single AP. In the lab exercise, the mobile wireless device moves relative to the fixed AP; therefore, students can study the changing signal strength between the device and the AP. During the simulation, the “discrete event simulation” option is utilized to record the behavior of all the events occurring in every device within the network. Figures 1 and 2 show the network architectures of the two sub-labs.

Figure 1. Network Architecture of the WLAN BSS Sub-Lab 1
2.2. WLAN Roaming Lab

A network comprised of a set of two or more interconnected BSSs is called an ESS. This architecture consists of more than one interconnected AP over a wider area. Inside an ESS, the wireless devices are capable of roaming from one BSS to another, therefore extending their range of mobility.

The learning objectives of this lab are:

- Simulate the behavior of roaming and handoff among APs
- Observe the data traffic of APs and wireless device in ESS

In this lab, the wireless network is an ESS consisting of four BSSs. The network is comprised of a central bridge connecting four APs and a destination host. A mobile wireless device generates packets sent to the destination host. The device is set to initially associate with an AP and travels in a clockwise direction to visit the other three APs. At the end of the simulation, the device finishes its tour and goes back to the original starting point. During the roaming, the wireless device is expected to connect to all four APs while it is traversing the trajectory. Figure 3 illustrates the network architecture.
2.3. WLAN Jamming Lab

Wireless networks are vulnerable to attacks and have become one of the major targets of hackers today. In wireless networks, malicious attacks can easily be launched due to a lack of a packet filtering mechanism in network traffic. Among different kinds of attacks, a Denial of Service (DoS) attack is simple to implement. This kind of attack attempts to disrupt a target in order to restrict access by legitimate users to the network. If a wireless network encounters a DoS attack, the attack will progressively reduce the functionality of the victim and negatively impact the overall performance of the network.

The learning objectives of this laboratory are:
- Simulate DoS attack to crush a target by using jamming technique
- Study the efforts of a DoS attack to mobile devices

In this lab, a DoS attack using a frequency-swept jammer provided by OPNET Modeler is studied. The jammer is designed to emit a continuous radio signal using the same spectrum of the APs. Different power levels of the jammer are set to study the behavior of the mobile device and APs before and after jamming. Parameters, such as delay, dropped packets, throughput, and load, are examined. Figure 4 demonstrates the network architecture.
2.4. Wireless Ad-Hoc Network Lab

IBSS is a type of ad-hoc network. It is a decentralized wireless network that excludes the APs. Wireless devices communicate with each other in a peer-to-peer fashion without involving a central management point. Devices can also act as routers to forward data from one network node to another.

The learning objectives of this lab are:
- Learn to implement a mobile ad-hoc network (MANET) using the IEEE 802.11 standard
- Gain an understanding of different routing algorithms in wireless ad-hoc networks
- Evaluate and analyze network performance

A wireless mobile ad-hoc network (MANET) can be implemented with an IBSS network. It includes a set of mobile wireless devices. Each device can move freely and independently in any physical direction. Also, each is capable of forwarding received traffic by reconfiguring its link to other devices. In this lab the MANET in an office of size 100 meters by 100 meters is studied. A group of mobile wireless devices are included in the network and connected wirelessly to a Gateway using the IEEE802.11n standard at 65Mbps. An IP Cloud is included to simulate data flow over a Wide Area Network (WAN). Three applications, video conferencing (high resolution), ftp (high load), and http (heavy browsing) are hosted by a Point-to-Point (PPP) Server. The Gateway communicates over the IP Cloud to the PPP Server via PPP T1 duplex links. Five routing protocols (Ad Hoc On-Demand Distance Vector Routing (AODV), Optimized Link State Routing Protocol (OLSR), Temporally-Ordered Routing Algorithm (TORA), Gateway Routing Protocol (GRP), and Dynamic Source Routing (DSR)) are compared and analyzed. Figure 5 displays the network architecture.
3. Evaluation

The online survey shown in Table 1 was administered during the end of the fall 2013 semester. Five categories were designed in the survey and a total of 17 questions were included. The objective of the survey was to evaluate the project’s effectiveness in order to improve the lab instructional manual in the future. A five-level Likert scale was used. Available responses were: strongly disagree, disagree, neutral, agree, and strongly agree. At the end of the semester 12 questionnaires from the on-campus class and 15 questionnaires from the DE class were successfully collected. Figures 6 and 7 summarize the results.

<table>
<thead>
<tr>
<th>Category 1</th>
<th>Lab Environment</th>
</tr>
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<tbody>
<tr>
<td>Q1.1</td>
<td>I have no difficulties logging into the lab environment to conduct the lab activities.</td>
</tr>
<tr>
<td>Q1.2</td>
<td>This VMWare View provides a simulated realistic network environment.</td>
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<tr>
<th>Category 2</th>
<th>Lab Manual</th>
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<tr>
<td>Q2.1</td>
<td>The steps shown in the instructional lab manuals are clear and easy to follow.</td>
</tr>
<tr>
<td>Q2.2</td>
<td>The lab manual provides all of the necessary information in order to conduct lab activities.</td>
</tr>
<tr>
<td>Q2.3</td>
<td>The learning objectives of labs are clearly described.</td>
</tr>
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<tr>
<th>Category 3</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q3.1</td>
<td>I understand how to select statistics parameters (e.g. load, delay, and throughput) in order to generate simulation diagrams.</td>
</tr>
<tr>
<td>Q3.2</td>
<td>I know how to configure required network attributes (e.g. application definition and supported profile) for simulating a wireless network.</td>
</tr>
<tr>
<td>Q3.3</td>
<td>I understand how to extract useful information by analyzing the simulation diagrams.</td>
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<tr>
<td>------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Category 4</strong> Overall Project</td>
<td><strong>Category 5</strong> Wireless Network Technologies</td>
</tr>
<tr>
<td>Q4.1</td>
<td>I feel the learning objectives of labs are achieved.</td>
</tr>
<tr>
<td>Q4.2</td>
<td>I feel the final project outcome met my initial expectations.</td>
</tr>
<tr>
<td>Q4.3</td>
<td>I would rate the overall quality of the project as high.</td>
</tr>
<tr>
<td>Q4.4</td>
<td>I am satisfied with the overall outcome of the project.</td>
</tr>
<tr>
<td>Q4.5</td>
<td>I would rate the technical difficulty of the labs as difficult.</td>
</tr>
<tr>
<td>Q4.6</td>
<td>I spent excessive time working on the labs.</td>
</tr>
</tbody>
</table>

**Figure 6. Survey Result of On-Campus Class**

**Figure 7. Survey Result of the DE Class**

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The frequent responses of all five categories fell onto strongly agree and agree for both the on-campus and DE classes. Overall, students had very positive attitude toward the lab exercises and the learning objectives of the project. Students expressed that they neither had issues logging in nor experience slow connections. They agreed that OPNET running in the VMware View environment provided a detailed and realistic experimental environment. They indicated that the lab manuals were complete and easy to follow. After finishing the OPNET project, students were acquainted with creating wireless network topologies, understood the setup of the required parameters, and understood how to analyze the simulation results. Also, they agreed that the project provided useful information pertaining to wireless network technologies and the information would benefit them if they decide to pursue a career in wireless network design or implementation.

In addition to the 17 questions, students were asked to provide one example where they have added to their knowledge from this project. Some of the responses were: “In theory, I learned how to set up a network topology and simulate performance in order to determine what if any improvements should be made or what considerations for interference should be given. Specifically, I learned through the diagrams how to interpret throughput and delay.”, “There was a lot learned with these labs, such as measuring statistics such as throughput, delay, number of hops per second etc. I also became a lot more familiar with the Opnet Modeler; if I were to use it again I would be comfortable creating and simulating as well as gathering the results.”, “The entire experience was all new to me. I thought that the OPNET software was very helpful and amazing.”, and “The mobile roaming node taught me a great deal about how a mobile device such as a smartphone interacts with a WLAN when moving through an environment. I had never quite understood what was referred to as “roaming” before doing the lab.”

4. Conclusions and Future Work

This paper presented a project that included five wireless network labs used in an undergraduate course. In each lab, a wireless network was analyzed using the OPNET Modeler simulator. Different scenarios of wireless networks were created, wireless traffic was generated and the behavior of the networks and individual wireless devices were inspected. The labs helped students develop their capabilities in creating and analyzing wireless network activities in real world scenarios.

In the future, continuous revision of the labs and the instructional lab manuals will be made according to the feedback from students. Also, based on the experience of this project, more wireless labs related to networks (such as WiMax and Zigbee) and network issues (such as channel interface and the hidden node problem) may be developed.

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References


Biographies

Te-Shun Chou is an Associate Professor in the Department of Technology Systems at East Carolina University. He received his Bachelor degree in Electronics Engineering and both Master's degree and Doctoral degree in Electrical Engineering at Florida International University. His research interests include machine learning, wireless communications, and network security, especially intrusion detection and incident response.

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Keith Thomson has been working in IT field for more than 20 years and served as a help desk analyst, field service engineer, and system administrator. Presently he works as an instructional technology consultant in the IT department of the College of Engineering and Technology at East Carolina University. He is one of the team members whose mission is to support the College’s highly-virtualized IT infrastructure and enterprise storage.