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THE IMPACT OF HANDS-ON SIMULATION LABORATORIES ON TEACHING OF WIRELESS COMMUNICATIONS

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ABSTRACT

Aim/Purpose	To prepare students with both theoretical knowledge and practical skills in the field of wireless communications.
Background	Teaching wireless communications and networking is not an easy task because it involves broad subjects and abstract content.
Methodology	A pedagogical method that combined lectures, labs, assignments, exams, and readings was applied in a course of wireless communications.
Contribution	Five wireless networking labs, related to wireless local networks, wireless security, and wireless sensor networks, were developed for students to complete all of the required hands-on lab activities.
Findings	Both development and implementation of the labs achieved a successful outcome and provided students with a very effective learning experience. Students expressed that they had a better understanding of different wireless network technologies after finishing the labs.
Recommendations for Practitioners	Detailed instructional lab manuals should be developed so that students can carry out hands-on activities in a step-by-step fashion.
Recommendation for Researchers	Hands-on lab exercises can not only help students understand the abstract technical terms in a meaningful way, but also provide them with hands-on learning experience in terms of wireless network configuration, implementation, and evaluation.
Impact on Society	With the help of a wireless network simulator, students have successfully enhanced their practical skills and it would benefit them should they decide to

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	pursue a career in wireless network design or implementation.
Future Research	Continuous revision of the labs will be made according to the feedback from students. Based on the experience, more wireless networking labs and network issues could be studied in the future.
Keywords	wireless communications, wireless simulation, wireless network, wireless security, course design

INTRODUCTION

Teaching wireless communications is a challenging task not only because it covers a broad range of topics but also because it is difficult to help students to understand abstract technical terms in a meaningful way. Hence, educators have been trying to illustrate theoretical concepts by providing students with the opportunity of hands-on learning experiences, and the results reveal that student performance was superior to lecture only in the education of wireless technologies (Chenard, Zilic, & Prokic, 2008; Davids, Forrest, & Pata, 2010; Guo, Xiang, & Wang, 2007; Hegde, Manjunath, & Nagabushana, 2014; Jentzsch, & Mohammadian, 2004; Sarkar & Craig, 2006).

Physical devices can be used for setting up a wireless network infrastructure. However, this approach is impractical because different types of wireless networks require distinctive devices and configurations. Moreover, this approach will be very pricey and time consuming. In addition, electromagnetic interference is always an issue with wireless networks. The interface could possibly cause other wireless devices nearby to degrade the signal transmission or render it totally non-functional. Hence, a more realistic solution is to use simulation tools to mimic the behavior of actual wireless communication networks. This way, not only can it reduce the cost in buying physical equipment but also eliminate the threat of electromagnetic interference. With the use of simulation tools, complex wireless network infrastructures are possibly implemented and the topologies can be quickly modified when needed.

In order to offer students the opportunity for hands-on learning experiences of wireless networks simulation, labs have been designed using Riverbed Modeler software in a wireless communications course offered in the Information Computer Technology undergraduate program in the Department of Technology Systems at East Carolina University (ECU). The licensed software was acquired at no charge from Riverbed under its University Teaching Program. This method of including practical activities compensated the deficiency of theoretical concepts and therefore significantly provided students with a comprehensive learning environment within the context of wireless communications.

This paper focused on the lab development supporting the learning of wireless communications and the evaluation of students' survey responses. Different wireless network simulators are first discussed. The next section presents the design of the course and is followed by a description of the labs in detail. The following section discusses the survey statistics results. Conclusions and future work are described in the last section.

WIRELESS NETWORK SIMULATORS

There are many simulation tools available for the research of wireless networks. Some of them are open source software, which allows users to download freely and implement their own algorithms. For example, NS-2 is an object based tool for the research of communication networks (Issariyakul & Hossain, 2008). With the combinational use of C++ and Tcl, users are able to develop and configure the nodes and the network topology. J-Sim is another free of charge discrete-event simulation software built in Java (Hou et al., 2006). With its component-based compositional network simulation environment, it can simulate Wireless Sensor Networks in real time.

Simulators are also developed by researchers as their own educational tools to help students study the subjects of wireless communications. For example, MSPsim is a framework for modelling and simulating Wireless sensor network (WSN) nodes (Eriksson, Dunkels, Finne, Sterlind, & Voigt, 2007). It uses Java to simulate Texas Instruments MSP430 series microcontroller and display a visual representation of the whole sensor board. Wireless Fidelity Simulator (WiFiSim) is developed to enhance students' learning in the study of the wireless local area networks (WLANs) (Sanguino, Lopez, & Hernandez 2013). It is designed with the Eclipse framework, and its graphic user interface (GUI) was developed using Java Swing. It is designed using Java Swing and students can use its GUI to configure the parameters of the network being studied and find potential problems after the simulation process.

In addition, commercial companies develop modeling and simulation tools. For example, QualNet is a commercial software based on GloMoSim (Chhetri & Pradhan, 2015). It provides an environment for designing wireless applications and statistical analysis after simulation. OMNEST is another example of the commercial simulation tool (Imam & Poole, 2013). Based on its object-oriented discrete event framework, it can simulate the behavior and performance of wired and wireless communication networks.

In the past, a variety of wireless networking issues have been researched using those simulators, such as performance evaluation (Malik & Singh, 2013; Yang, Yao, Jin, & Yang, 2016), wireless attacks (Darra, Skouloudi, & Katsikas, 2015; Gupta & Mehrotra, 2013), behavior analysis (Lawal, Said, & Mu'azu 2013; Sooki, & Korosi, 2016), and intrusion detection (Butun, Ra, & Sankar, 2015; Safia, Aghbari, & Kamel, 2016). Among those different types of simulators, Riverbed Modeler has been popularly used in academia and industry. It provides a nice GUI that enables users to easily manage network devices and configure the network topologies with desired formats. By collecting a group of wireless protocols, users are able to simulate the behavior of different wireless applications and models. For analysis, it displays graphs and statistics of simulation results in a way that allows users to easily interpret the parameters and performance of individual wireless devices and of the entire network.

Course Design

The major goal of the course of wireless communications was to prepare students with both theoretical knowledge and practical skills in the field of wireless communications networks and systems. To achieve this goal, we combined lectures, labs, assignments, exams, and readings as the pedagogical method, as shown in Figure 1. The lecture acted as a teacher-centered teaching tactic, whereas both labs and assignments acted as student-centered learning activities. This combination would offer students a comprehensive study within the context of wireless communications and thus lead to academic success.

Lecture sessions were based on the textbook chapters, which covered a broad range of topics dealing with wireless technologies and networking. The course studied fundamental concepts of wireless communications. Existing and emerging wireless networks and applications were discussed, which included WSN, WLAN, wireless personal area network (WPAN), wireless metropolitan area network (WMAN), wireless wide area network (WWAN), radio-frequency identification (RFID), cellular technology, wireless standards, wireless security, satellite, and microwave. Commonly used wireless standards and protocols were presented. The potential security concerns of utilizing wireless systems and the methods used to deal with them were also introduced.

The lecture addressed theoretical aspects of wireless technologies. Homework assignments were given that complemented the contents of lectures. Some of the assignments are based on real world examples, such as investigation of access point (AP) signal strength, Wi-Fi site surveys, wireless packet analysis, and evaluation of wireless network analyzers. Some of the assignments were questions relevant to the course materials, such as research of wireless security, analog signal modulation, and digital signal modulation. Both lectures and assignments complemented each other and helped students comprehend the key concepts of the course content. Exams were used to assess student learning. Questions were designed to ask students about important topics that deserve attention.

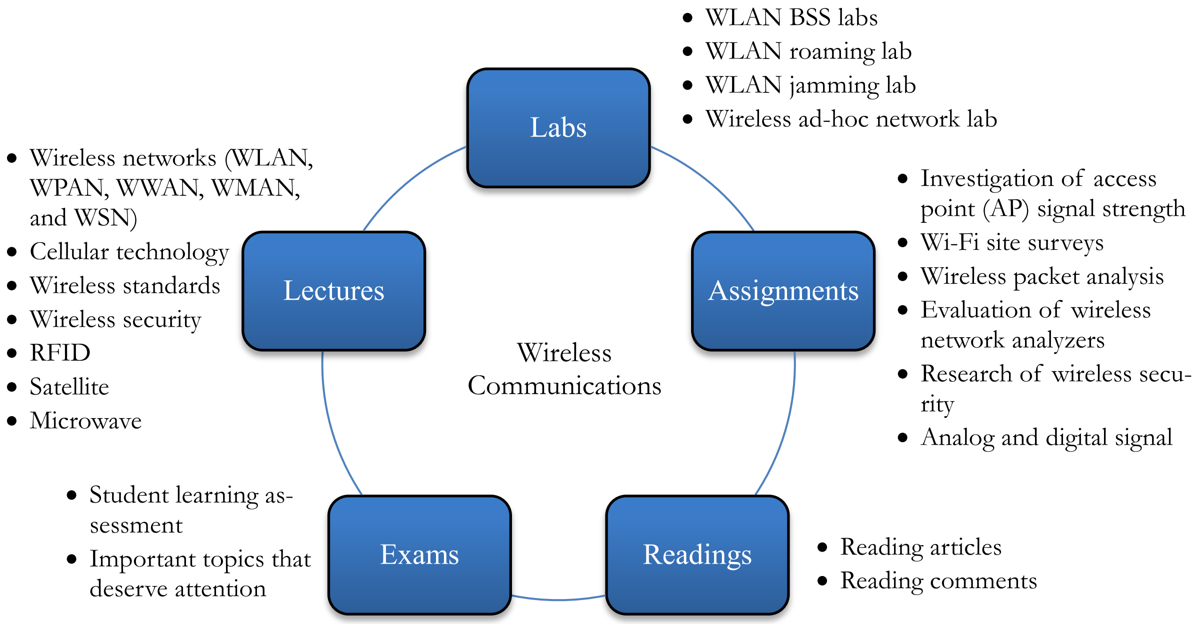

Figure 1. Course structure

Additionally, students were instructed to read an article every week. The articles were selected from relevant literature but were not covered in the lectures. Students were asked to leave a comment of the reading by the end of that week. The comment included a summary of the article, what they learned, and which part of the article they believed could be improved or emphasized. Reading the article broadened students' perspectives of wireless communications while the comments developed students' abilities to grasp key ideas in the articles.

A set of labs in wireless networks were developed by using the Riverbed Modeler software and it was installed in a number of virtual desktops within VMware View. With its remote desktop capabilities, both on-campus and distance education (DE) students were able to perform lab activities anytime and anywhere without competing for limited laboratory classroom space on campus. This approach enabled students to have ample opportunities in the involvement of hands-on learning experiences and thus increase the effectiveness of their learning.

The labs were designed to provide students with hands-on experience in the field of wireless communications. Detailed instructional lab manuals were developed so that students could carry out hands-on activities in a step-by-step fashion. The activities of wireless network implementation, network parameter configuration, network simulation, and result evaluation were included. The complete procedure helped students to understand the theoretical knowledge in greater depth and also enabled them to adapt to the current and future wireless communications job market.

Lab Details

We focused on developing WLAN IEEE802.11 protocol labs and included three basic network architectures: Basic Service Set (BSS), Extended Service Set (ESS), and Independent Basic Service Set (IBSS). Five wireless networking labs have been developed and the level of difficulty was from the easiest to the hardest in order to help students get familiar with the simulator gradually. Each lab was divided into three phases: network creation, statistics collection, and result analysis. By following the detailed steps indicated in the lab manuals, students can complete all of the required lab activities of the three phases.

Normally three methods could be used to build a network topology: importing the topology, using rapid configuration, or dragging objects from the active palette into the displayed workspace. In the first phase, students were asked to use the third method to create a network model. The activities involved in this phase included selection of the desired network topology, definition of the network size, inclusion of the preferable wireless devices, and specification of the required parameters such as application, traffic, services, IEEE WLAN standards, data rate, routing protocols, and transmitter power. Having completed the setup of network architecture, students could then move on to the second phase to configure object statistics of individual wireless devices and global statistics of the entire network. The statistics examples were data dropped, data traffic received and sent, delay, load, and throughput. Lastly, students could explore the behavior of the model after running a simulation. In the stage of evaluation, the values and diagrams of output statistics were summarized, visualized, and analyzed. The definitions of input parameters played a key role in the simulation analysis. Therefore, modifying the values of those parameters and multiple trails of simulation may be required for achieving outcomes of interest.

WLAN BSS Lab 1

BSS network, also called infrastructure mode, is the basic architecture for an 802.11 WLAN. In this mode, only a single AP is associated with wireless devices in the network. The AP acts as a master to control all the traffic within the BSS. Because the students did not have any experience in using the simulator, the lab started with the simplest BSS network that consisted of only one AP and one wireless device as shown in Figure 2. We expected this initial lab to help students feel comfortable with the simulation environment. Having gained confidence and knowledge about the usage of the simulator, more complicated scenarios were designed in the following labs. Two learning objectives have been set in this lab: (1) Understand the technologies of IEEE 802.11 standard used in WLAN and (2) Observe the behavior of AP, fixed and mobile wireless devices in WLAN.

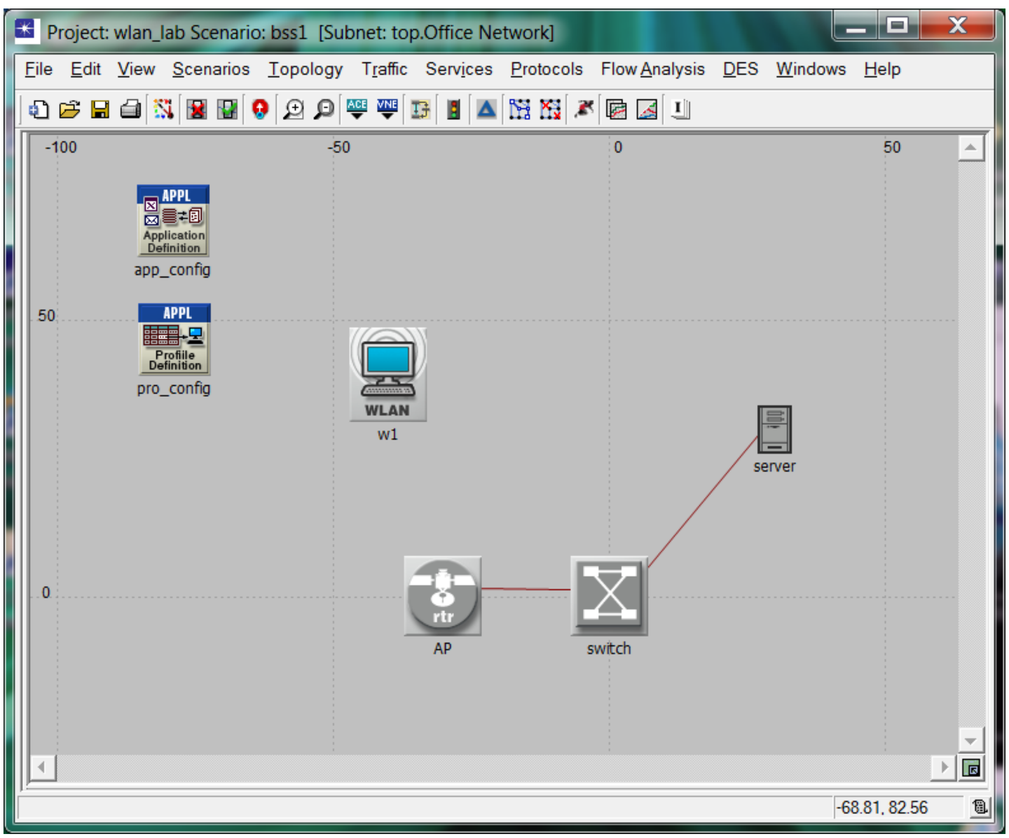

Figure 2. Network architecture of the WLAN BSS

During this lab activity, students were first asked to configure the simulated network environment using the GUI and menu system. The configuration not only added the nodes into the environment, but also configured individual characteristics of some of the nodes. Figure 3 is an example that shows the attributes of the AP. Among the specific attributes shown for AP, the node was set to simulate 802.11g with a data rate of 24 Mbps and transmit power of 0.005W.

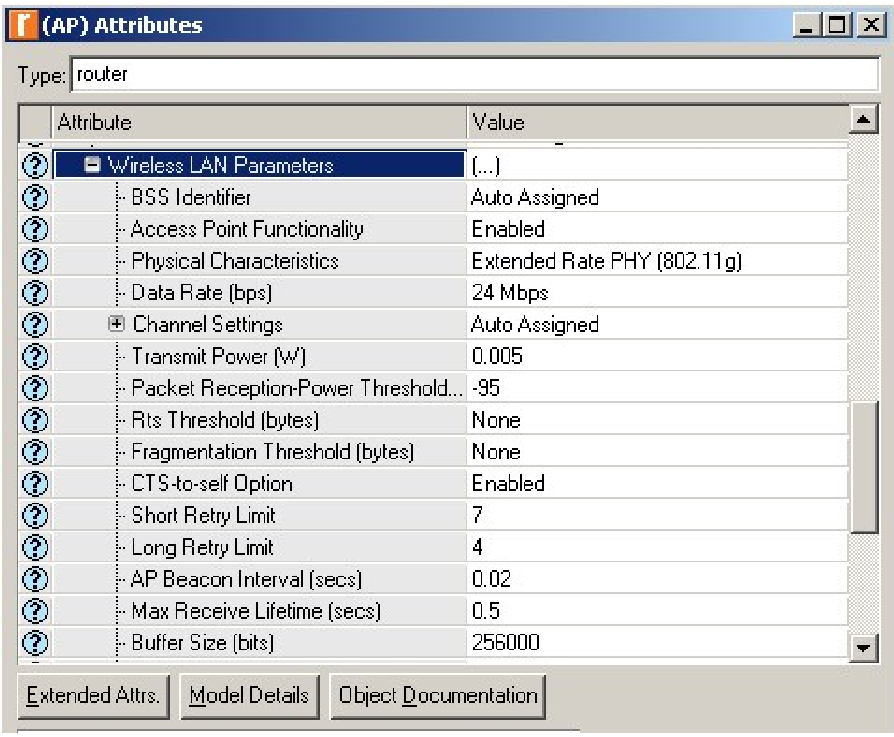

Figure 3. Wireless AP attributes

Students also configured application and profile definitions to be used in the simulation, setting "video" as one of the supported services. In addition to setting up the environment for later simulation and testing, these steps allowed students to become more familiar with the application's interface, which facilitated the process in subsequent labs.

A number of statistics based on this established configuration could be collected once the configuration of the environment and simulation were complete. During the simulation, the "discrete event simulation" option was utilized to record the behavior of all the events occurring in every device within the network. Both global and node statistics were collected for later analysis. The global statistics included data dropped, delay, network load, and throughput. The node statistics included data traffic received, data traffic sent, delay, load, and throughput. The simulation results are shown in the figures below.

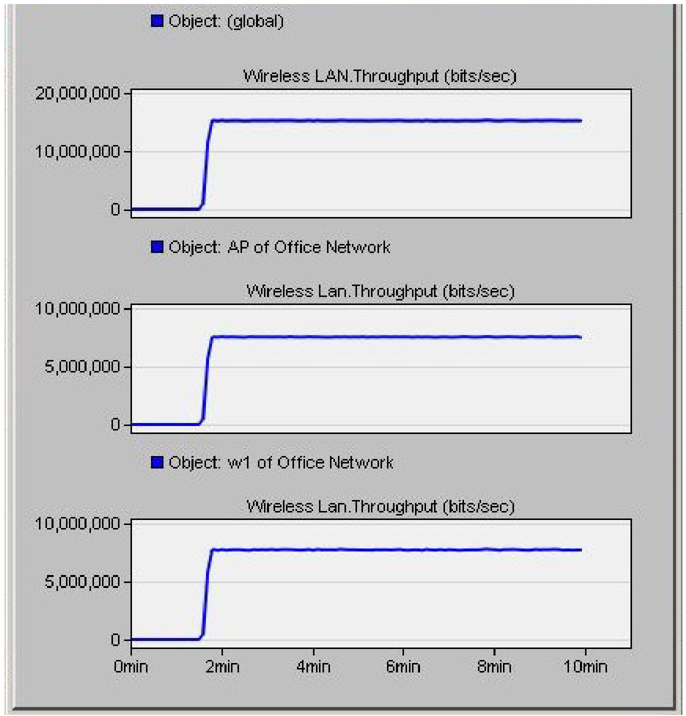

Figure 4. Wireless LAN throughput

Figure 4 shows global wireless LAN throughput, as well as the throughput statistics for the AP and w1 nodes. The results indicated that despite the data rate of 24 Mbps attributed to the AP being used in the simulation, we had a global throughput of approximately 15 Mbps, with each of the wireless stations (the AP and w1) accounting for roughly half of the global throughput. The global wireless LAN throughput would be considered the aggregate throughput.

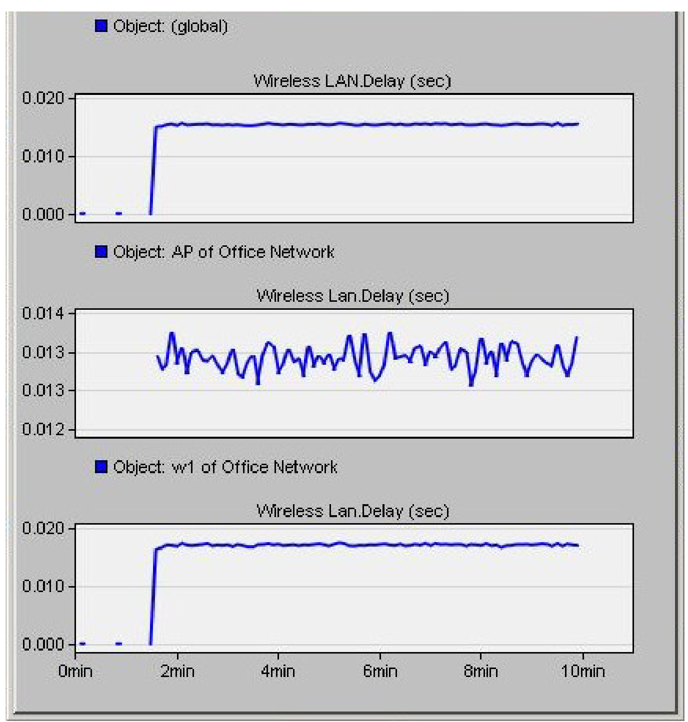

Figure 5. Wireless LAN delay

Figure 5 shows the global wireless LAN delay along with the delay of both the AP and w1 nodes. There was a bit of variation between the two devices themselves, whereas the global wireless delay hovered at approximately 0.015 seconds. The delay of the AP varied slightly around the 0.013 second mark, whereas the delay of w1 appears to hover midway between the 0.015 and 0.020 second marks. This suggests that the global delay was an average between the two, as opposed to the throughput, which was aggregated.

Through this activity, students were able to simulate this simplest network topology. This not only reinforced students' concepts of delay and throughput, but also gave students an opportunity to become familiar with the Riverbed Modeler software, providing useful in later wireless labs.

WLAN BSS Lab 2

Next, students studied a geographical area of a BSS that included a group of fixed wireless devices and a mobile wireless device, all served by a single AP. In this lab exercise, the mobile wireless device moved relative to the fixed AP, thereby allowing students to study the changing signal strength between the device and the AP. Figure 6 shows the network architectures of the lab.

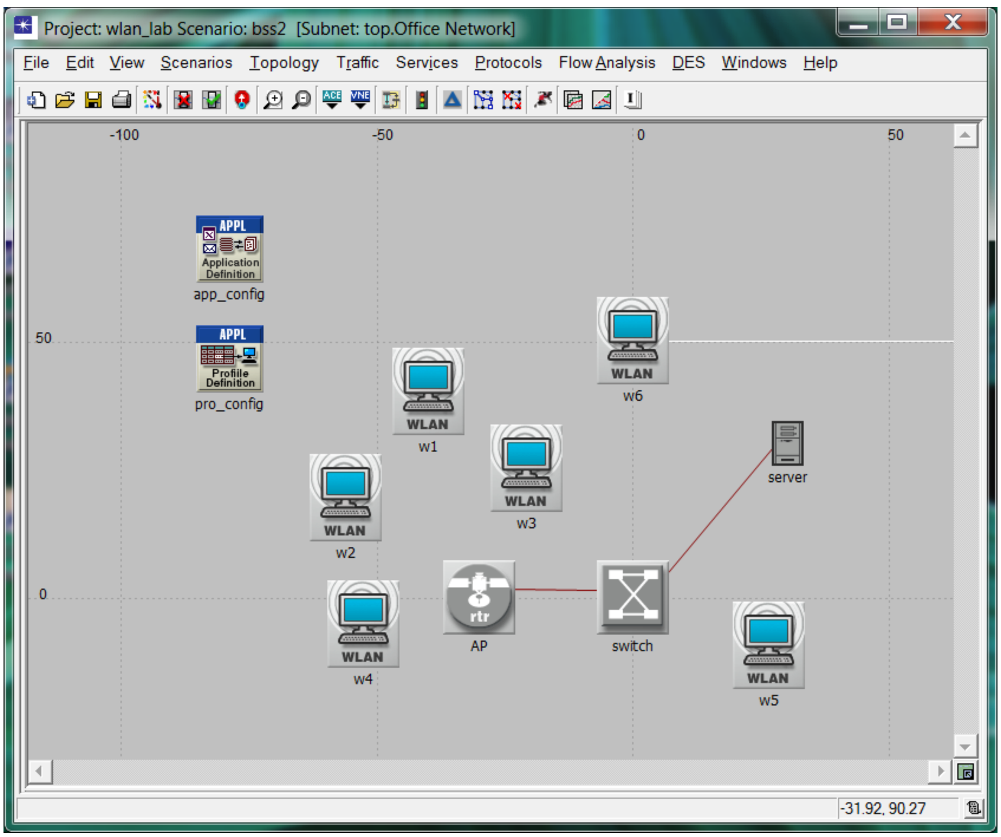

Figure 6. Network architecture of the WLAN BSS

This lab built on the previous configuration of Lab 1 as a duplicate scenario, adding additional workstation nodes as well as a mobile node. The settings for the additional workstations were identical to those set on w1, and the mobile device was configured to support video services. Once the additional nodes were in place, students could run a simulation to collect statistics for future analysis since the configuration was already handled in Lab 1. Figure 7 shows the comparison of wireless LAN throughput of w1 in Lab 1 (left) and Lab 2 (right).

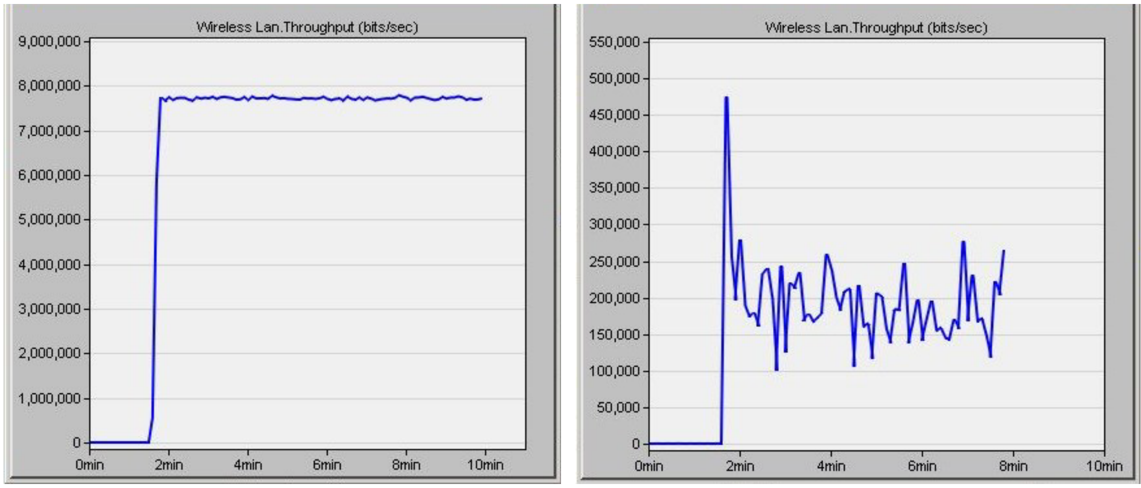

Figure 7. w1 throughput comparison between Lab 1 (left) and Lab 2 (right)

As discussed in the first portion of this lab, the global throughput is an aggregation of throughput values for all of the terminals in the wireless network. In the first scenario, there were only two wireless stations (the AP and w1) so there was less competition for the entire throughput capability of the wireless LAN as a whole. In the second scenario, however, there were more wireless clients on the network (the AP and six workstations), which means more "competition" and reduced throughput to each of the wireless devices.

Differences in global wireless LAN delays were compared in each of the scenarios. It is noted that the wireless LAN delay was smaller (hovering around 0.015 seconds) in the first scenario than it was for scenario 2, which fluctuated between approximately 0.19 and 0.26 seconds. This observation let students understand that there was a greater delay with additional wireless clients in the office space as the AP must deal with communications from a larger number of wireless clients connecting to it. Additionally, the mobility of a mobile device (w6) may have also played a role in the delay experienced by the wireless LAN. From this lab, students observed two consequences of increasing the number of wireless devices added to a wireless LAN. First, a reduction in both overall and individual throughput and secondly, an increase in the delay.

By adding fixed and mobile wireless devices, students were able to compare the network performances between the network topologies created in WLAN BSS Labs 1 and 2. The comparison helped students understand that bandwidth utilization control is an important consideration element when deploying a WLAN.

WLAN Roaming Lab

Having understood the basic operations of a BSS netwrok, the lab activity was moved to ESS network, which is a network architecture that is comprised of a set of two or more interconnected BSSs. Inside a BSS, there is still an AP associated with it. However, wireless devices are capable of roaming from one BSS to another, therefore extending their range of mobility.

In this lab, four BSS were included in the ESS network. The network was comprised of a central bridge connecting four APs, a destination host, and a mobile wireless device. Figure 8 illustrates the network architecture. The device was configured to initially associate with AP1 before travelling in a clockwise direction to visit the other three APs. At the end of the simulation, the device finished the tour and went back to its original starting point. When traversing the trajectory, the mobile wireless device generated packets sent to the destination by connecting to the four APs. Two learning objectives were defined for this lab, which were (1) Simulate the behavior of roaming and handoff among APs and (2) Observe the data traffic of APs and wireless devices in the ESS network.

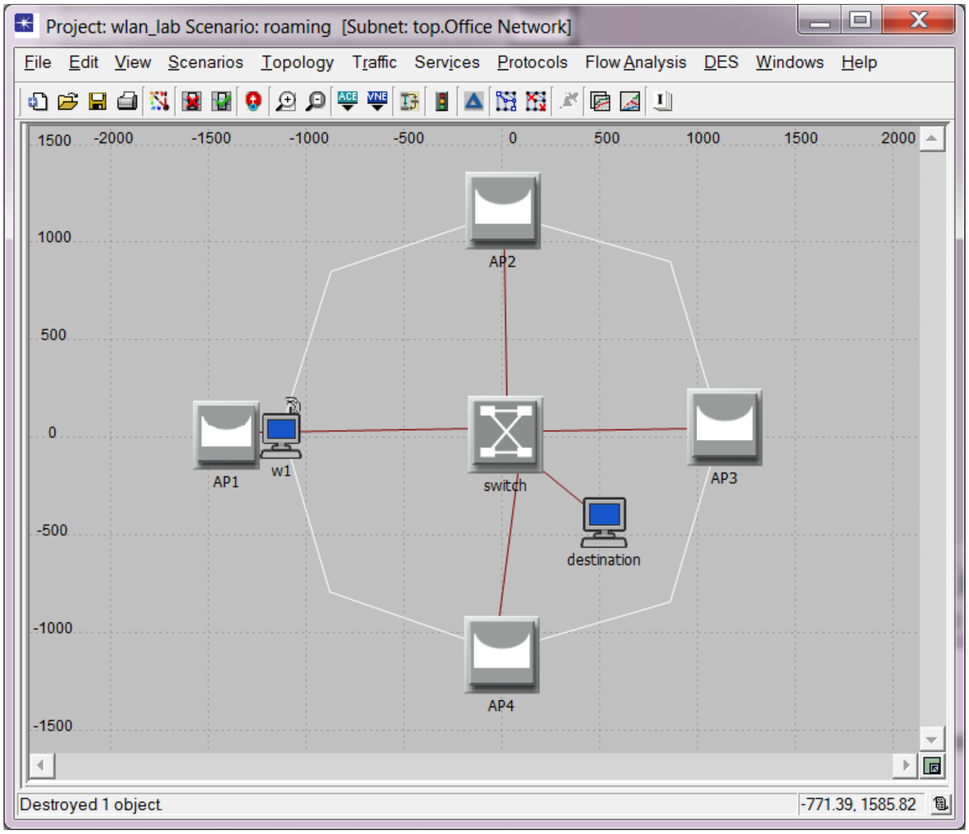

Figure 8. Network architecture of the WLAN roaming lab

The parameter setting for each node was similar to the configuration process in the previous lab. Global and node statistics were collected and the results are shown in the figures below. Figure 9 shows the global statistics for wireless LAN throughput. Fluctuations appeared in throughput due to the handoff from one AP to another. Figure 10 shows the network load for each of the APs in the environment.

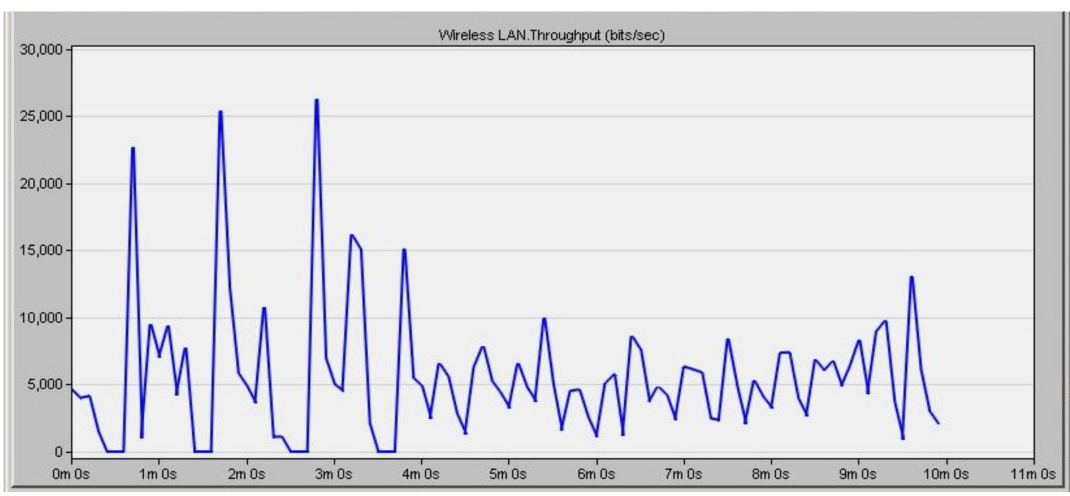

Figure 9. The global statistics for wireless LAN throughput

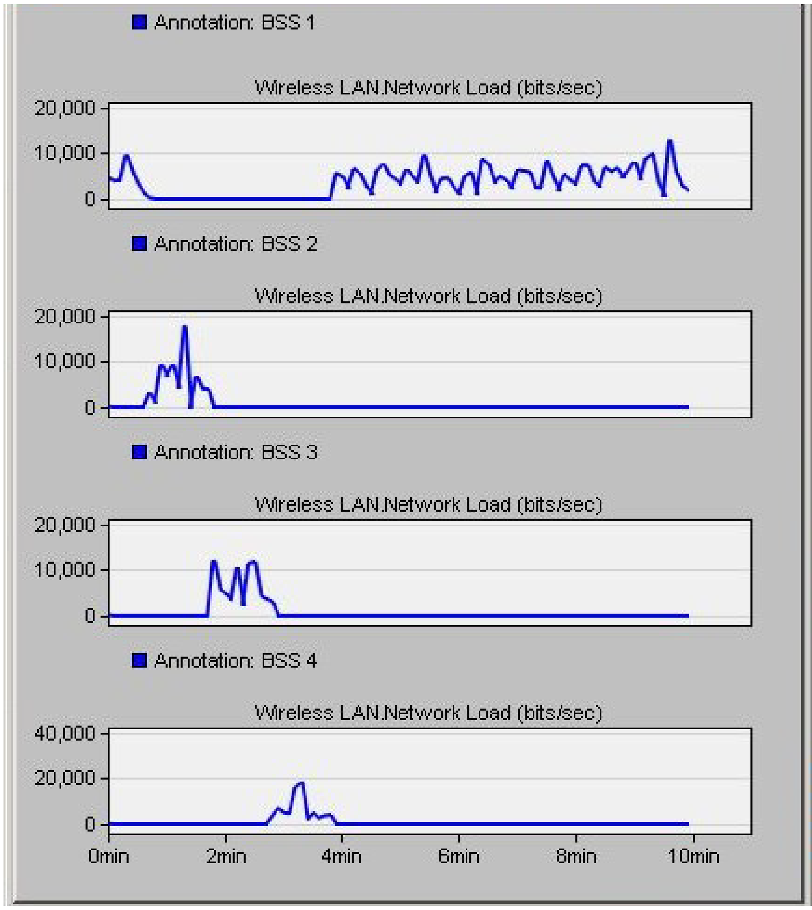

Figure 10. Network load of APs

Similar to the spikes seen in the global throughput in Figure 9, a spike in network load appeared on each AP as the wireless client roamed and was handed off to each successive AP. The findings presented in the graphs echo the scenario presented in the directions for the lab, in which the mobile device was moving in a clockwise motion, starting near AP1 (with the BSS ID of 1), and moving past AP2 (BSS 2), then AP3 (BSS 3), and finally AP 4 (BSS 4), before returning to its starting point. As the mobile node came within range of each AP, a corresponding increase in that AP's network load appeared, with BSS 1 experiencing an increase in network load, followed by BSS 2, then BSS 3, then BSS 4 until finally a prolonged network load in BSS 1 once the mobile device came back within its range.

From the observation of the network load of APs, students understood the changes of signal connection while the mobile wireless device roamed from one BSS to another. The simulation helped students visualize complex ideas of roaming and handoff among APs.

WLAN Jamming Lab

Wireless security is a serious issue in wireless networks. The detection and prevention of malicious attacks have been the main focus of many researchers. Therefore, it is necessary to offer an exercise that allows students to visualize how an attack is implemented and the impact to the system being attacked.

In this lab, students studied a Denial of Service (DoS) attack launched by a frequency-swept jammer as shown in Figure 11. The jammer was designed to emit a continuous radio signal using the same spectrum of the APs to disrupt the network access of legitimate wireless devices. Different power levels of the jammer were set to study the functionality of the victim and to negatively impact the overall performance of the network. Parameters such as delay, dropped packets, throughput, and load were examined. The learning objectives of this lab were to (1) Simulate a DoS attack to crush a target by using a jamming technique (2) Study the efforts of a DoS attack to mobile devices.

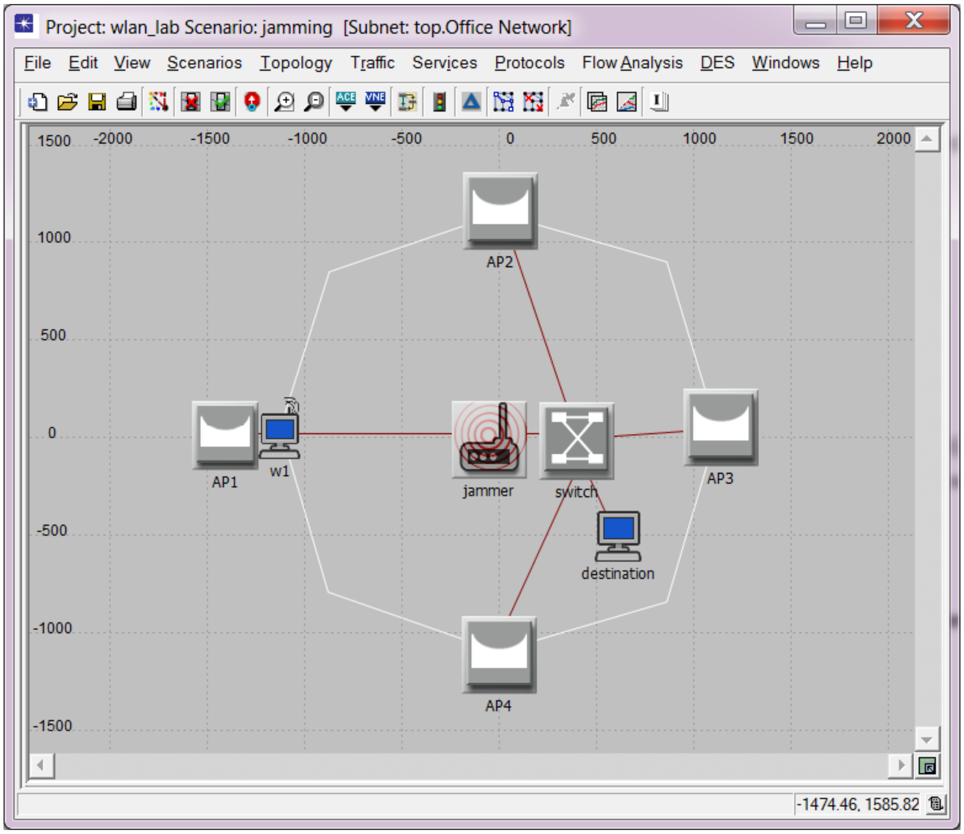

Figure 11. Network architecture of the WLAN jamming lab

The network complemented the previous activity that covered the concept of roaming, with the notable addition of a jammer introduced into the wireless LAN environment. Once the jammer had been added to the environment and configured accordingly, a 10-minute long discrete event simulation was performed to simulate the presence of a device that caused a denial of service to legitimate nodes on the wireless network.

Figure 12 provides a comparison of the global wireless LAN throughput both without (top) and with (bottom) the presence of a jamming device. In the first scenario, global throughput activity reflected the movement of a mobile device among APs that were a part of an ESS, where global throughput spiked each time the mobile device associated with a different AP in the ESS.

Due to the activity of the jammer added to the workspace in the second scenario, the jammer blocked the mobile device from being able to associate with the APs, resulting in the drop in global throughput. Changing the placement of the jammer would affect the results shown in the graph on the right, as the jammer would be causing signal interference with different APs than the ones affected by the jammer's placement in this particular instance. Furthermore, students were asked to reconfigure the jammer to boost its transmitter power from an initial setting of 0.05W to 0.1W to observe the effects. Figure 13 shows more marked reduction in the global wireless LAN throughput statistic after increasing the transmitter power.

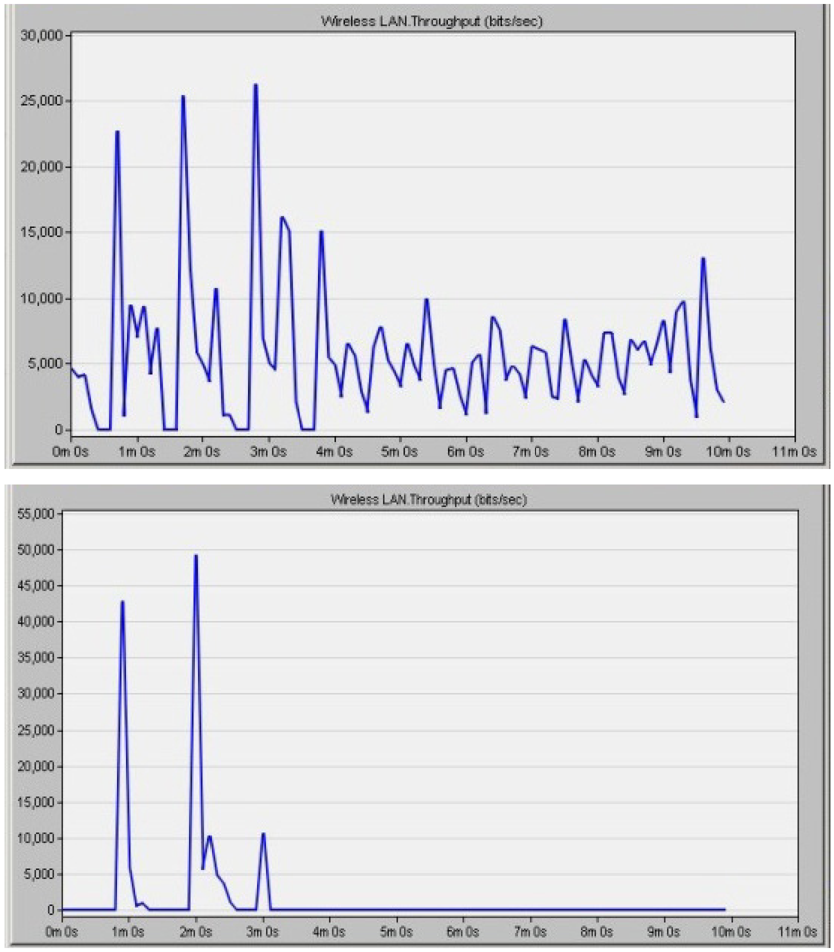

Figure 12. Global WLAN throughput without (top) and with (bottom) 0.05W transmitter power of the jammer

This lab visibly demonstrated to students that placing a jammer in the workspace clearly had an impact on wireless communications between devices, causing the complete drop in throughput as the scenario progressed. This lab helped students understand DoS attacks could cause damage to a network and countermeasures should be implememnted to prevent such attacks and interference.

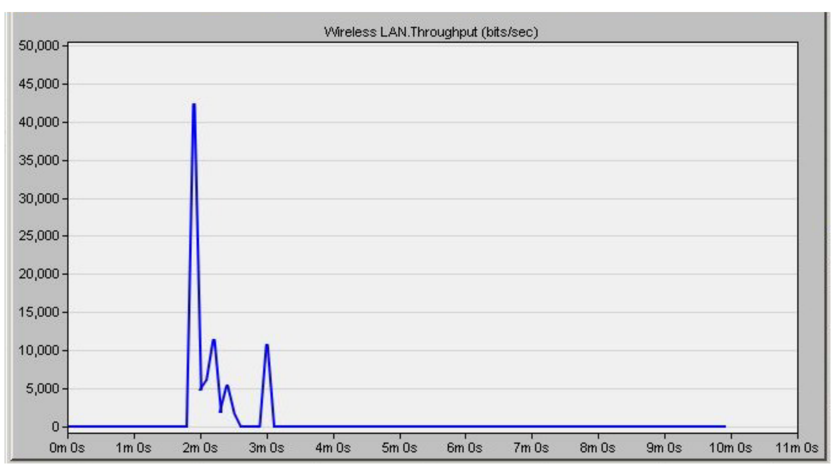

Figure 13. Global WLAN throughput with 0.1W transmitter power jammer

Wireless Ad-Hoc Network Lab

A BSS network contains one or more central management APs but an IBSS network contains no APs. It is a type of ad-hoc network in which wireless devices communicate with each other in a peer-to-peer fashion. Devices can also act as routers to forward data from one network node to another. In this lab, a wireless mobile ad-hoc network (MANET) was implemented in a 100 meters by 100 meters office as shown in Figure 14. It included a set of mobile wireless devices which were connected wirelessly to a Gateway using the IEEE802.11n standard at 65Mbps.

Each device was configured to move freely and independently in any physical direction. In addition, each device was capable of reconfiguring its link and forwarding traffic to its neighbors.

An IP Cloud was included to simulate data flow over a Wide Area Network (WAN). A Point-to-Point (PPP) Server hosts three applications: video conferencing (high resolution), ftp (high load), and http (heavy browsing). The Gateway communicated over the IP Cloud to the PPP Server via PPP T1 duplex links. In order to help students understand the opertations of wireless routing protocols, five protocols were included: Optimized Link State Routing Protocol (OLSR), Dynamic Source Routing (DSR), Ad Hoc On-Demand Distance Vector Routing (AODV), Temporally-Ordered Routing Algorithm (TORA), and Gateway Routing Protocol (GRP). Students were asked to simulate them and compare their various characteristics. The learning objectives of this lab were to (1) Learn to implement a MANET using IEEE 802.11 standard and (2) Evaluate and analyze the performance of different wireless routing algorithms.

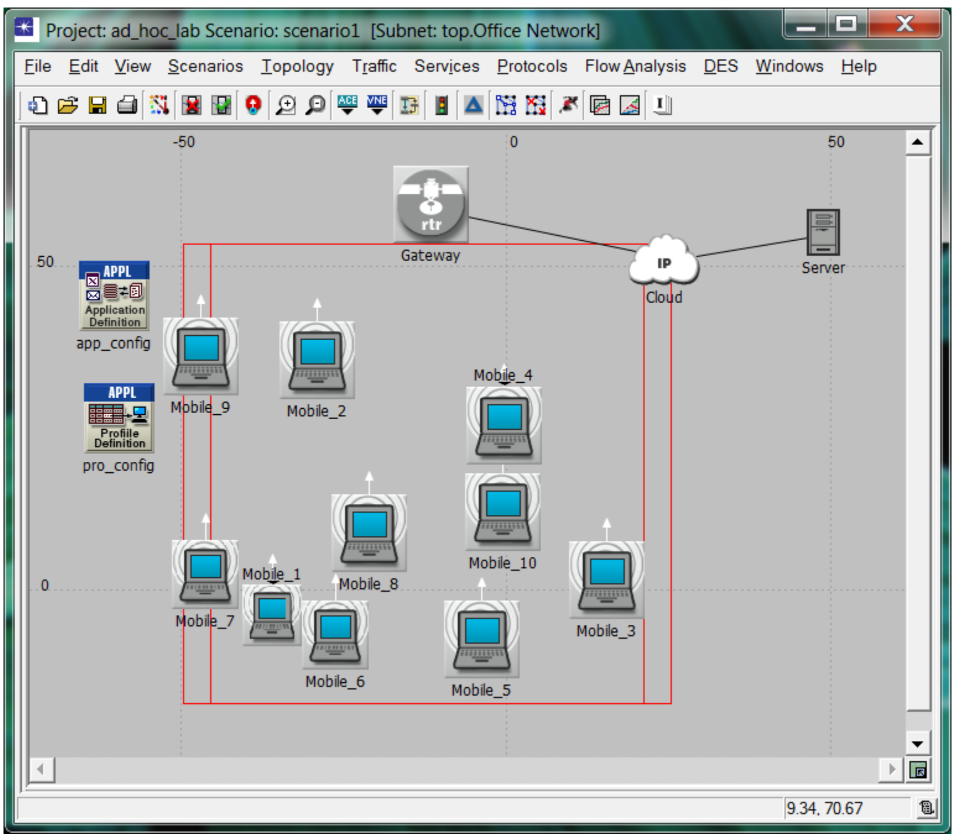

Figure 14. Network architecture of the wireless mobile ad-hoc network lab

This lab presented a unique opportunity to simulate a MANET and saw the impact of various routing protocols in action. With the simulation results, students were able to see the impacts of various routing protocols on network performance in terms of delay, data drop, and throughput. For example, Figure 15 shows the comparison of throughput of those five routing protocols. It indicated that AODV protocol displayed the highest throughput. Students also learned that OLSR provided the second highest overall throughput. TORA and DSR offered values comparable to one another, although they did not reach the same throughput values seen in AODV. GRP presented the lowest throughput values. In addition, Students were asked to compare the number of hops per route and route discovery time between AODV and DSR, as shown in Figures 16 and 17. Both demostrated that AODV outperformed DSR, which had a lower number of hops per route and a shorter route discovery time.

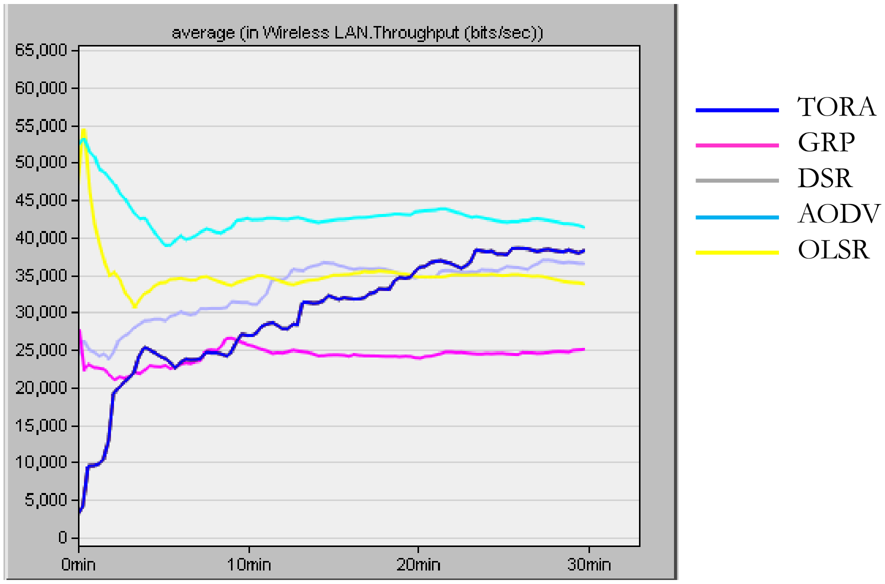

Figure 15. Throughput of five routing protocols

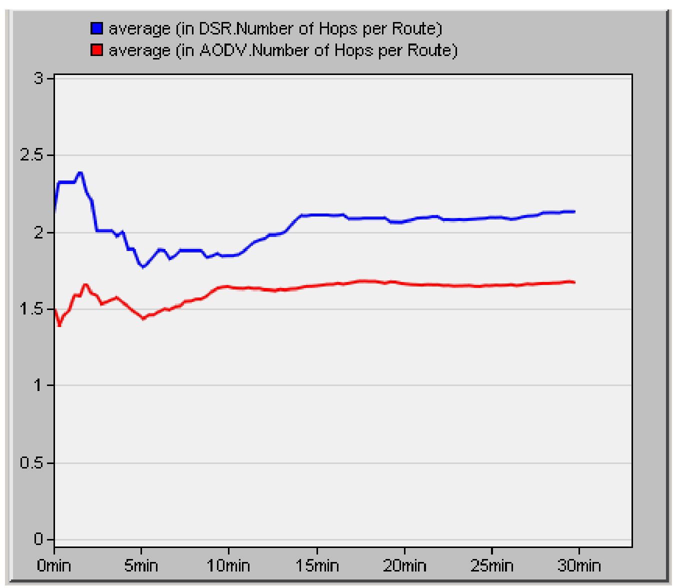

Figure 16. The number of hops per route of AODV and DSR

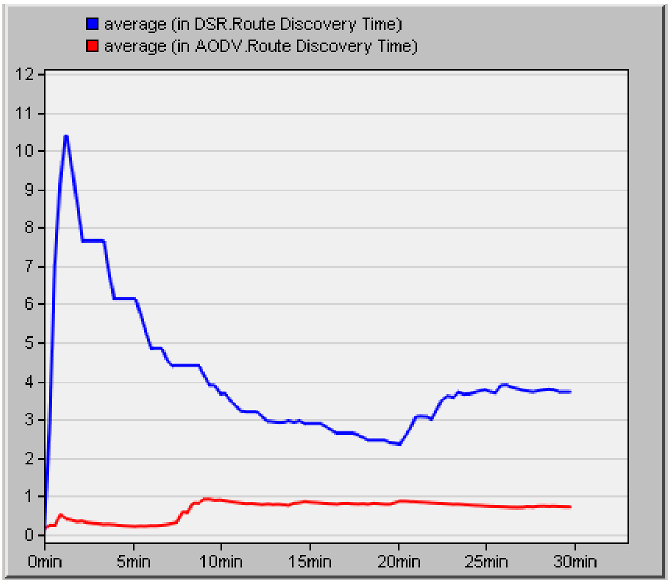

Figure 17. Route discovery time of AODV and DSR

EVALUATION

The study was undertaken during the fall semesters of 2013 and 2014 academic years. The objective of the study was to evaluate whether the labs' were effective to students' learning as well as to find the weaknesses of the lab instructional manual in order to improve its quality in future classes. The analysis presented here comprises 37 surveys collected from 12 on-campus and 25 DE students. The survey questions were divided into five categories with a total of 17 questions. Table 1 shows the questions. The question type was Likert response scale. Available responses were: strongly disagree, disagree, neutral, agree, and strongly agree. Tables 2 and 3 summarize the results. Figures 18 and 19 show the results from a question category perspective. In order to investigate attitudes of the respondents toward each question, we coded the responses accordingly: strongly disagree = 1, disagree = 2, neutral = 3, agree = 4, and strongly agree = 5.

Table 1. Survey questions

Category 1 Lab Environment	Q1.1. I have no difficulties logging into the lab environment to conduct the lab activities. Q1.2. This VMWare View provides a simulated realistic network environment.
Category 2 Lab Manual	Q2.1. The steps shown in the instructional lab manuals are clear and easy to follow. Q2.2. The lab manual provides all of the necessary information in order to conduct lab activities. Q2.3. The learning objectives of labs are clearly described.
Category 3 Analysis	Q3.1. I understand how to select statistics parameters (e.g. load, delay, and throughput) in order to generate simulation diagrams. Q3.2. I know how to configure required network attributes (e.g. application definition and supported profile) for simulating a wireless network. Q3.3. I understand how to extract useful information by analyzing the simulation diagrams.

Category 4 Overall Evaluation	Q4.1. I feel the learning objectives of labs are achieved. Q4.2. I feel the final project outcome met my initial expectations. Q4.3. I would rate the overall quality of the project as high. Q4.4. I am satisfied with the overall outcome of the project. Q4.5. I would rate the technical difficulty of the labs as difficult. Q4.6. I spent excessive time working on the labs.
Category 5 Wireless Network Technologies	Q5.1. I have a better understanding of different wireless network technologies after finishing the labs. Q5.2. It's a good strategy to imitate wireless networks by using a simulation tool, instead of using physical wireless devices. Q5.3. I believe I am able to apply the knowledge of wireless communications technologies to my future career.

Table 2. Survey result of on-campus class

Question	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Mean	Variance	Standard Deviation
Q1.1	1		1		10	4.50	1.55	1.24
Q1.2			1	3	8	4.58	0.45	0.67
Q2.1	1			6	5	4.17	1.24	1.11
Q2.2				5	7	4.58	0.27	0.51
Q2.3		1	1	5	5	4.17	0.88	0.94
Q3.1				5	7	4.58	0.27	0.51
Q3.2			2	2	8	4.50	0.64	0.80
Q3.3				7	5	4.42	0.27	0.51
Q4.1			2	6	4	4.17	0.52	0.72
Q4.2			3	6	3	4.00	0.55	0.74
Q4.3			2	5	5	4.25	0.57	0.75
Q4.4				9	3	4.25	0.20	0.45
Q4.5	1	3	5	2	1	2.92	1.17	1.08
Q4.6	1	3	5	2	1	2.92	1.17	1.08
Q5.1			2	8	2	4.00	0.36	0.60
Q5.2			3	2	7	4.33	0.79	0.89
Q5.3			1	7	4	4.25	0.39	0.62

Table 3. Survey result of DE class

Question	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Mean	Variance	Standard Deviation
Q1.1	1			5	19	4.64	0.74	0.86
Q1.2				7	18	4.72	0.21	0.46
Q2.1			1	12	12	4.44	0.34	0.58
Q2.2		1	1	10	13	4.40	0.58	0.76
Q2.3		1	2	6	16	4.48	0.68	0.82
Q3.1		1		13	11	4.36	0.49	0.70
Q3.2		1	1	12	11	4.32	0.56	0.75
Q3.3		1	3	9	12	4.28	0.71	0.84
Q4.1			3	8	13	4.44	0.51	0.71
Q4.2		1	5	10	9	4.08	0.74	0.86
Q4.3		1	3	10	11	4.24	0.69	0.83
Q4.4		2	4	7	12	4.16	0.97	0.99
Q4.5	2	8	5	7	3	3.04	1.46	1.21
Q4.6	2	4	8	6	5	3.32	1.48	1.22
Q5.1			3	7	15	4.48	0.51	0.71
Q5.2		1	2	13	9	4.20	0.58	0.76
Q5.3		1	3	11	10	4.20	0.67	0.82

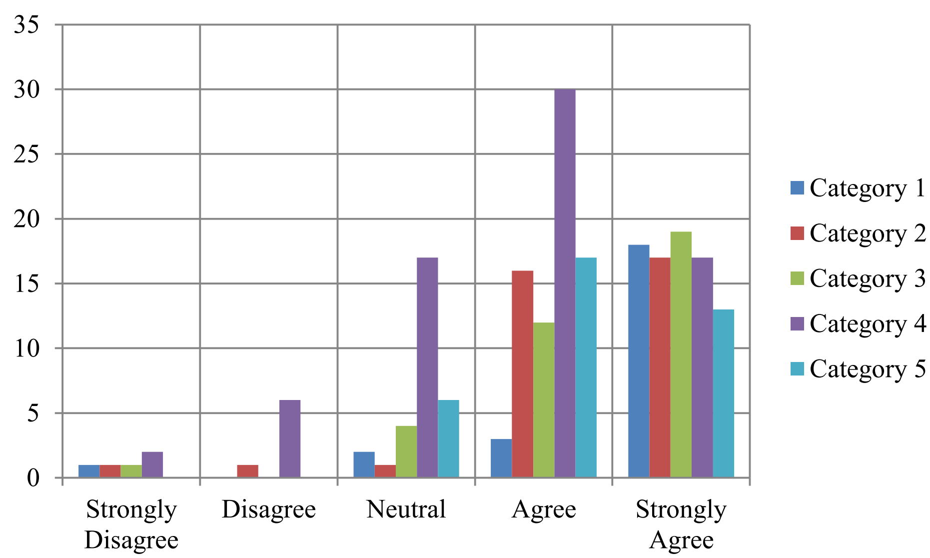

Figure 18. Survey result of on-campus class

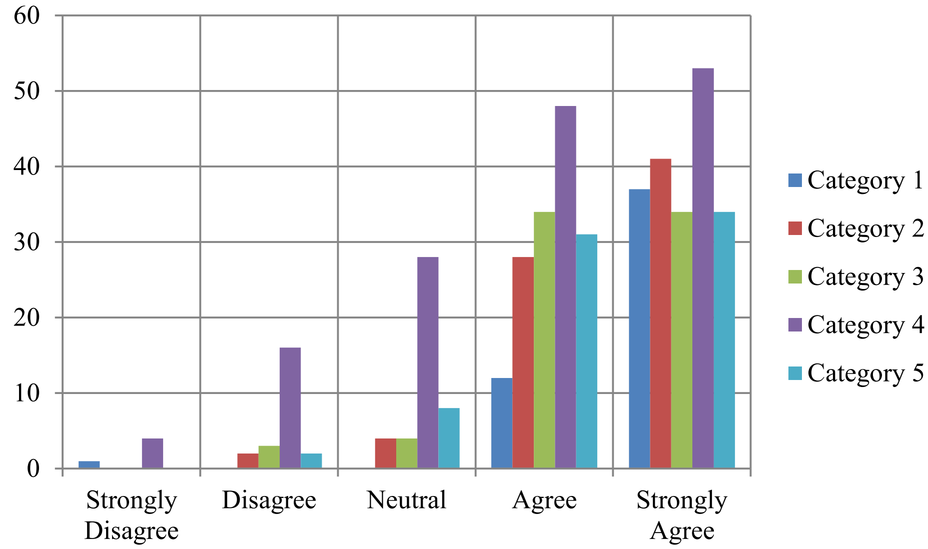

Figure 19. Survey result of DE class

For both the on-campus and DE classes, frequent responses for all five categories fell into the strongly agree and agree categories. Overall, respondents had very positive attitudes toward the lab exercises and the learning objectives of the project. The mean values of all the questions were above 4, except for questions Q4.5 and Q4.6, in which respondents believed the labs were not difficult enough and did not spend much time to finish them. We were confident that these results were due to the fact that the instructions in the lab manuals were reasonably clear. Therefore, respondents did not encounter technical difficulties while conducting lab activities.

On the subject of Category 1, respondents expressed that they neither had issues logging in, nor did they experience slow connections. They agreed that Riverbed Modeler running in the VMware View environment provided a detailed and realistic experimental environment. On the subject of Category 2, 95% of respondents indicated that the lab manuals were complete, easy to follow, and provided all of the necessary information in order to conduct lab activities. After finishing the Riverbed Modeler project, respondents said that they had become acquainted with the process of creating wireless network topologies, understood the setup of the required parameters, and understood how to analyze the simulation results from the result of the subject of Category 3. On the subjects of Categories 4 and 5, they agreed that the labs provided useful information pertaining to wireless network technologies. One-hundred percent of respondents agreed that they have a better understanding of different wireless network technologies after completing the labs, and that this information would benefit them should they decide to pursue a career in wireless network design or implementation.

In addition to the 17 questions, students were asked to provide an example in which this project added to their existing knowledge of wireless network simulations. Most of the responses were very positive. The following shows some of the responses:

- "I really enjoyed doing this lab and learning about the different routing technologies and then comparing their results. I think I would use this tool for testing in a similar scenario before buy equipment and implementing this type environment."
- "I think the labs are well made and the simulation program is great."
- "Everything that I used in the Riverbed labs added to my knowledge! This was an interesting tool that showed me a lot about how jammers and other devices affect performance between device communications. It was also interesting to be able to see how different routing protocols affect network throughput and network delays."

- "I learned some of the key methods to transmitting data across MANET networks, and setting up access points on WLAN networks."
- "Not coming from a networking background, especially a wireless networking background, I knew nothing of ad-hoc beyond hearing the name and had no concept of the different protocols. I do now." and
- "I learned how to use the Riverbed Modelling software, which I thought was a very useful tool for setting up test networks."

CONCLUSIONS AND FUTURE WORK

In order to equip students with a solid understanding of both theoretical and practical knowledge of wireless communications and networking, five learning techniques (lectures, exams, assignments, labs, and readings) were implemented in a course of wireless communications. While lectures performed as a teacher-centered teaching strategy, labs, assignments, exams, and readings served as student-centered learning. All of the five learning techniques played important roles to help students learn the subjects of wireless communications and networking.

A set of wireless networking labs was developed, and Riverbed Modeler was used as the simulator and the software was installed in a number of virtual desktops within VMware View for students conducting lab activities. Students were instructed to create different types of network topologies and the behavior of the networks and individual wireless devices were inspected. The complete procedure not only helped students understand the abstract technical terms in a meaningful way, but it also provided them with hands-on learning experience in terms of wireless network configuration, implementation, and evaluation.

A survey of the labs was conducted. The results showed that students were satisfied with the learning outcome and that they had a better understanding of different wireless network technologies after completing the labs. With the help of the simulator, students believed that the labs have successfully enhanced their practical skills and that it would benefit them should they decide to pursue a career in wireless network design or implementation.

Continuous revision of the labs and instructional lab manuals will be made according to the feedback from students. Based on the experience, more wireless networking labs (e.g., WiMax and Zigbee) and network issues (e.g., channel interface and the hidden node problem) could be studied in the future.

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BIOGRAPHIES

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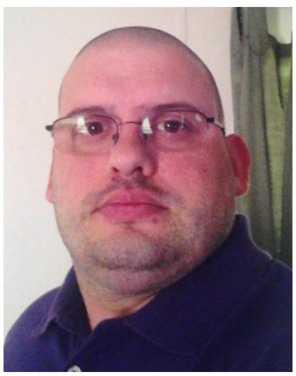

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