Remote Experiments for Wireless Computer Networks

Executive Summary:

Introduction to Computer Networks (ECE 1150) covers various facets of wireless networks. The majority of the course is devoted to the underlying technologies used to construct wireless computer networks. Widely used wireless computer networks, such as Wi-Fi, 802.11, BlueTooth, and Radio Frequency IDentification (RFID) are examined to see how these technologies are used to achieve different networks and drive the area in general.

One of the main topics in the course is how data signals or information is actually transmitted, between computers, over the air via wireless networks. There are many methods available for over-the-air data transmission and each has pros and cons. While these issues can be presented in lecture, this may not provide students with a concrete understanding of the tradeoffs. What is needed is for students to see via a “hands-on” approach, the different data transmission techniques and to be able to compare them side-by-side using real-world test and measurement equipment.

Computer networks are composed of a number of layers, each layer performing a different task in the overall communication process. The lowest level layer, the physical layer (PHY layer) is responsible for the physical transmission over the air of the wireless data signal and special measurement devices are required to observe the physical layer operation. There are many parameters in the PHY layer that the designer has control over. These parameters involve complex concepts, which are difficult for students to grasp from a lecture. Unfortunately, the cost of the necessary equipment is very high (over $100,000 per set) and requires a trained operator to setup and run the equipment for each experiment. For a class that averages an enrolment of over 50 students this presents difficulties. Taking the class to the lab and demonstrating the experiment provides little benefit because students have only a few minutes to observe the experiment and cannot explore the results on the measurement equipment. Further, this takes away from class time and research time as trainer operators (graduate research assistants) are required to setup and operate the equipment.

A remote laboratory, which students could access over the Internet, will enable a single set of equipment to be shared by the entire class. The students will be able to start a predetermined experiment and then have access to test and measurement equipment to record the results. This enables the experiment to be setup once and used by all students at a time that fits their schedules. The remote laboratory requires a single set of equipment to setup the laboratory experiment. The RFID Center of Excellence has equipment that will be used for the laboratories in ECE 1150.

The remote laboratory could be extended to other courses, specifically Analog Communication Systems (ECE 1472) and Digital Communication Systems (ECE 1473), where the topics covered require expensive and complicated equipment to illustrate. Further, the remote laboratory does not require the student to be physically present in the lab to perform the experiments.
Project Description and Goals:

Introduction to Computer Networks (ECE 1150) covers communication using the wireless medium (e.g. Wi-Fi, RFID, cell phones). The majority of the course is devoted to the evolution of the underlying technologies used to construct wireless computer networks. Widely used wireless computer networks, such as Wi-Fi, 802.11, BlueTooth, and Radio Frequency IDentification (RFID) are examined to see how these technologies are used to achieve different networks. As the pervasiveness and capabilities of portable electronic devices such as cell phones and PDAs increases a thorough understanding of is critical for electrical and computer engineers.

This course is currently a lecture based course with no laboratory component. Many topics about wireless computer networks are difficult to explain during lecture, especially topics relating to the actual transmission of the wireless data signals. Being able to observe and generate wireless communication signals would enhance learning. While equipment exists to provide this capability, it is extremely expensive and quite complicated to setup and operate.

The cost of a set of equipment is typically around $100,000 and the complexity of the equipment requires a trained operator to setup and run the experiments. For courses with a typical enrollment of over 50 students, the cost prohibits using such equipment. ECE 1150 is a popular course and enrollment is typically well over 50 students. Purchasing the equipment alone for such a laboratory for a 50 student course would cost at least $5,000,000 and this does not include personnel for setup and maintenance of the laboratory.

What is needed is to have a one or possibly a few (two or three) sets of equipment that can be shared remotely by the entire class to perform experiments. Providing remote access to the experiments (equipment) makes it easier for commuter students to perform the experiments and simplifies maintenance and security for the equipment. The equipment can be setup in a secure (locked) lab to minimize the security risk of theft or misuse of the equipment.

The students would access the equipment remotely through a web-interface. The remote access interface enables the instructor to limit how much control students have over the equipment. This could range from simply having students press a “Start” button and record measurements reported by the equipment to giving students control over some parameters of the equipment. Limiting the control student have over the equipment makes it difficult for the settings to be inadvertently changed making current and future experiments invalid and requiring the instructor/teaching assistant/laboratory technician to setup the experiment again. Because only limited control is provided the interface can reset the equipment to a known or safe starting state when a new experiment is started. Thus, the instructor must setup the experiment only once.

The remote laboratory will enable students to observe the wireless communication using test and measurement (T&M) equipment from the RFID Center of Excellence during off hours. The RFID Center has equipment costing in excess of $100,000 and will make available the needed T&M equipment during off-hours. These experiments will allow students to visualize and see in real-life the various communication methods presented in lecture.
A remote laboratory was previously developed and used successfully in ECE 1150. The remote laboratory experiments provided the students with access to expensive equipment to run experiments illustrating concepts covered in lecture. At that time, the remote laboratory consisted of a web-camera with an associated device capable of turning on and off the equipment. The remote laboratory turned off the equipment after a specified time to conserve power. This provided for a limited set of experiments where students observed different scenarios and recorded results from measurement equipment. Please see Appendix A for pictures of the first remote laboratory. This proposal will build on the first generation of the remote laboratory to provide students with more control over the T&M equipment and experiment, and to provide enhanced data reporting and viewing to the students. One of the drawbacks of the original version of the remote interface was that it was difficult to focus the web-camera on the T&M equipment readouts while providing for a wider view of the larger experiment. Students gained valuable experience with real-world equipment and were able to see concepts taught in lecture in real-life.

Using the T&M equipment from the RFID Center of Excellence a series of experiments will be designed for ECE 1150. The RFID Center of Excellence will provide this equipment for use to students in ECE 1150 via the remote interface during off-hours. Then the remote interface that the students will use to perform the experiments will be developed. The remote interface will reset the equipment to a known and safe starting state, ensuring that all students will have a valid experiment, every time a new experiment is initiated. The automated experiment will be conducted and the interface will allow the student to observe the measured quantities of interest and will provide control over any parameters as needed by the experiment. Personnel within the RFID Center of Excellence will write a detailed procedure for setting up the equipment needed for each experiment.

For each experiment, the student will go to the course webpage containing the experiment and log in. If the equipment is in use or not available at this time the student will be informed of this and can either wait or return at another time. If the equipment is available then the student will be given the option to start the experiment along with control over any parameters enabled for this particular experiment. The student would then press a “Start Experiment” button that will initiate and run the experiment. The interface will provide results in the form of measurements and graphs to the student. The student will then record these measurements for the experiment and can take screenshots of the interface to record any graphs that are needed to complete the experiment. The following figure shows an example of the measurement display window of the RFID automated conformance test software, the ECE 1150 interface would have a similar look and feel.

The RFID Center of Excellence has developed an automated conformance test system for RFID tags and readers (conforming to the ISO 18000-7 standard). The experiment interface would have a similar look and feel to the automated conformance test system. Figure 1 illustrates communication from a reader to a tag. The software allows the user to zoom in and inspect parts of the signal as shown in Figure 2. Figure 3 illustrates the interface used to enter parameters and start a test in the RFID Center of Excellence’s RFID automated conformance test system and the ECE 1150 interface.
would have a similar look and feel. Figure 4 shows the results window from which results are recorded.

![Figure 1: Wireless communication from an RFID reader to an RFID tag captured using the equipment and software in the RFID Center of Excellence.](image)

![Figure 2: Zoomed in portion of the signal in Figure 1.](image)

![Figure 3: Parameter entry and start test panel.](image)
Past research at the RFID Center of Excellence has resulted in the development of automatic testing routines for RFID (radio frequency identification) tags and readers. This work can be extended to provide the remote functionality described here. Students in ECE 1150 would benefit from observing and experimenting with these RFID systems. The RFID Center of Excellence will provide the T&M equipment for use by the students during off-hours. The remote interface will incorporate a feature that allows the instructor to set specific time windows when the equipment is available. During those time windows students may perform the experiment, but outside of those time windows the equipment and experiment would not be available.

Development of the experiments and remote laboratory will occur during the summer of 2009 (May to Aug.). The remote laboratory and experiments will be incorporated into ECE 1150 during the fall term in 2009 (Aug. to Dec.).

List of Experiments:

The following set of experiments will be developed for use in ECE 1150.

**Experiment 1:** Passive RFID tags communicate using a method called backscatter. Some of the RFID reader’s transmitted radio frequency (RF) signal is reflected back to the reader by the tag. The tag can alter the amount of the RF signal (energy) reflected. This experiment will allow students to observe backscatter communication from a passive RFID tag.

**Experiment 2:** How data is transmitted in an RF signal is important and there are many different methods or modulation techniques. Each method has issues that must meet regulatory (FCC) guidelines. In this lab students will observe the spectral characteristics of different modulation techniques used in wireless networks e.g. ASK, FSK, PSK.
Students will take away an understanding of the benefits of each modulation method on meeting regulatory requirements.

**Experiment 3:** When transmitting a RF signal transmissions on other frequencies are generated as a side effect and this is called *noise* and regulations (FCC) must be meet with respect to noise. Limiting the amount of noise is important because the noise will interfere with other wireless systems. Gaussian FSK is a technique used to reduce the noise generated by traditional FSK modulation. In this experiment, students will observe the spectrum of traditional FSK and Gaussian FSK, and use these to compare the noise generated by both type of modulation. Students will take away an understanding of the noise generated by traditional FSK and the effect Gaussian FSK modulation has on reducing the noise.

**Experiment 4:** In Experiment 3, the noise generated by FSK modulation was observed. While Gaussian FSK reduces the amount of noise, it still produces significant noise. Phase Shift Keying (PSK) modulation is another method of wireless communication and produces significantly less noise. Students will observe and compare FSK and PSK modulation with respect to noise generated by transmission in this experiment. The students will take away a better understanding of what noise is and the effect of modulation on the generation of noise.

**Experiment 5:** Active RFID tags and readers use a communication system similar to Wi-Fi or ZigBee. Active RFID tags are concerned about conserving their battery lifetime and active RFID systems employ different methods than passive RFID systems to communicate. In this experiment, students will observe communication between a reader and tag in an active RFID system. Students will take away an understanding of how active RFID systems communicate and will compare this to communication in the passive RFID system examined in Experiments 1 and 6.

**Experiment 6:** One issue with RFID systems is to read as many tags as possible in one second. Anti-collision protocols are employed by the system to read more tags by reducing the chances of two tags responding (talking) at the same time. In this experiment, students will observe the anti-collision protocol of the Gen-2 RFID protocol and explore the effect of key parameters in the protocol on the number of tags that can be read in one second. Students will take away an understanding of the Gen-2 anti-collision protocol and this understanding can be applied to other protocols within and outside the RFID space.

In summary, this proposal will generate a remote laboratory with Internet interface enabling sharing of one set of equipment by an entire class and a set of experiments for ECE 1150. Assignment sheets and sample solutions for each experiment will be generated.

The remote laboratory could be extended to any course using laboratory equipment. Two specific courses where this work could be extended to are Analog Communication Systems (ECE 1472) and Digital Communication Systems (ECE 1473).
laboratory does not require the student to be physically present in the lab, and it would be ideal for courses taught over the Internet.
Results:

Remote Laboratory Environment:

LabView supports a Remote Panel technology that allows a server machine to publish a LabView program, termed a Virtual Instrument (VI) in LabView, over the Internet. Client machines access this VI by simply pointing their web browser to the weblink (http address) of the VI.

A server machine in the RFID Center of Excellence laboratory located in Benedum Hall room 365 hosted the VIs used by the ECE 1150 class this past fall (fall 2009). The LabView Remote Panel was used to host the VIs over the Internet. Students logged onto the system and accessed the equipment over the Internet using a web browser. Access to the VIs (instruments) was secured and limited to those taking and supporting (instructor, TAs, and personnel involved in this project) ECE 1150.

The Remote Experiments were accessed via a secure PITT VPN Tunnel (same feature used to access the University Library System from a computer outside of the Pitt network). Access to this secure tunnel was limited to students enrolled in the course, the teaching assistant (TA) for the course, the instructors, and the personnel involved in this grant. One of the Electrical and Computer Engineering laboratories (367 Benedum Hall) was given access to the tunnel as well. This ensured that students could access the experiments from their own computer or from one of the University computers.

Accessing the Remote Laboratory:

Students access the Remote Laboratory through the secure PITT VPN Tunnel. When accessing the Remote Laboratory from the lab in 367 Benedum Hall students do not have to login to the Pitt VPN Tunnel. The Pitt VPN Tunnel screen is shown below where students login using their Pitt username and password.
A special connection, **Firewall-ENGR-RDP-TestInstruments-NetworkConnect**, is setup for the Remote Laboratory which the students click to gain access. Only students or support staff for ECE 1150 have the **Firewall-ENGR-RDP-TestInstruments-NetworkConnect** option on this screen.
After this students are taken to the following screen and must press the “Start” button next to the “Network Connect” row. This will finish establishing the connection to the Remote Laboratory.

Figure 7: Screen where students click the “Start” button next to the “Network Connect” row.

Once the connection to the Remote Laboratory is established students simply open a web browser and enter the weblink for the experiment. The web browser will use the Remote Laboratory connection and will connect to the Remote Laboratory. The figure below shows the Tutorial experiment opened in the Internet Explorer web browser.
These steps are provided in a detailed step-by-step manual that is made available to the students. The student now has control of the experiment and associated equipment. Similar manuals are provided for each of the experiment control panels.

**Other Experiment Control Panels:**

The following control panel is used for Experiments 2, 3, and 4. The equipment for these experiments remained the same so the same control panel was used for all three. This reduced the number of control panels that the students had to learn to operate. This allowed them to spend more time gaining hands-on experience rather than learning new control panels.
Experiments Developed:
Experiment 1 Tutorial:

The purpose of the tutorial experiment is to let the students familiarize themselves with the experiment interface and to diagnose connection problems. The tutorial is a simple experiment accompanied with a step-by-step guide. They will use the skills they develop from the tutorial in the remainder of the experiments.

The tutorial replaced the original Experiment 1 dealing with the Gen-2 protocol. It was felt that a simple tutorial type experiment was needed to familiarize the students to the remote laboratory platform. In addition, it was felt that moving the Gen-2 experiment later in the course better fit the presentation of the course material. Experiment 1 was combined with Experiment 6 and presented later in the course where it fit better with course topics.

Experiment 2:

Experiment 2 deals with different modulation techniques and the resulting RF spectrum of each technique. Students are first exposed to the different modulation techniques in class along with their positives and negatives. In this experiment actual transmissions are generated and viewed by the students via the remote laboratory. Students see first hand each modulation type and the associated RF spectrum of each. They are required to take measurements of the noise level and power level of the signal for each type of modulation. After taking the measurements, students are asked to write a few paragraphs comparing the different types of modulation.

Experiment 3:

In Experiment 2 students investigated different modulation techniques including frequency shift keying (FSK). FSK generates a considerable amount of noise when switching between a data 0 and a data 1. This noise should be reduced because it interferes with other wireless systems. One technique to reduce the noise is Gaussian FSK. In this experiment students compare Gaussian FSK transmissions to FSK transmissions. The RF spectrum of each of the signals is measured and compared. A smaller spectrum indicates that the amount of noise is less because it is present on less frequencies. Students observe that the transition technique used for Gaussian FSK reduces the noise verses plain FSK. This experiment reinforces the lecture material on Gaussian FSK and noise.

Experiment 4:

Again, RF noise is the subject of this experiment. In this experiment, the RF noise of the phase shift keying (PSK) modulation technique is compared to that of the Gaussian FSK technique presented in Experiment 3. Students observe that PSK produces considerable less RF noise (PSK has a smaller RF spectrum) than Gaussian FSK. This experiment reinforces the lecture material on PSK and noise.
Experiment 5:

In Experiment 5 students view communication between an active tag and reader. The experiment software is based on test and measurement software developed at the University of Pittsburgh RFID Center of Excellence for ISO 18000-7 (active RFID). The ISO 18000-7 system uses FSK modulation and a more complex form of data encoding, called Manchester Encoding, when transmitting data. Using Manchester Encoding has many benefits, namely, it allows the receiver to better synchronize itself with the message, reducing receive errors. The experiment automatically identifies reader and tag messages and decodes those messages. Students are asked to identify the reader command, tag response, and the number of tags responding. To differentiate between a reader command and a tag response, students must measure the length of the Sync pulse, which indicates whether the message is from a reader or a tag.

Experiment 6:

In this experiment students observe a data exchange between an RFID reader (interrogator) and RFID tag. Then they are asked to adjust the reader parameters in order to read the tag in the shortest possible time. Students are provided with a manuscript written by Peter J. Hawrylak and Marlin H. Mickle that was used as a basis for a chapter in the book RFID and Sensor Networks describing the different parameters available in the Gen-2 protocol.

The first part of this experiment presents EPCglobal Gen-2 RFID system which is a passive RFID system operating in the UHF (ultra-high frequency) band and is one of the most common RFID systems in use today. Students control an RFID reader, developed by the University of Pittsburgh RFID Center of Excellence, to read a Gen-2 RFID tag. They are able to observe the backscatter communication method used by the tag to reply to the reader. Students are asked to identify the settings that they can read the RFID tag in the least amount of time.

Results:

The Remote Laboratory was a success. Students quickly learned to use the interface and were able to access the instruments on their own schedule. Sharing of the instruments between researchers and the ECE 1150 class was a success. Times were blocked off for researchers to have exclusive use of the instruments. For the remainder of the time, the instruments were allocated to the ECE 1150 class.

Student Feedback:

Remote Laboratory Future Plans:
The Remote Laboratory can be expanded to include new experiments to cover more topics. In this phase, the Remote Laboratory was used for a class consisting of mostly full-time students; however, the Remote Laboratory offers significant advantages to part-time students. At the graduate level most part-time students work full-time in industry and the Remote Laboratory would benefit them because they have greater flexibility as to when they can access the experiments.