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An Experiential Course in Wireless Networks and Mobile Systems

Scott F. Midkiff

EDITOR'S INTRODUCTION

In this column, I describe an innovative, senior- and graduate-level course on wireless networks and mobile systems taught by Ing-Ray Chen, Luiz DaSilva, and myself at Virginia Tech. Please let me know your comments and suggestions for future columns. —*Scott Midkiff*

In spring 2005, for the third time, the electrical and computer engineering faculty and computer science faculty at Virginia Tech are teaching the course Wireless Networks and Mobile Systems, ECE/CS 4570. This course has some particularly interesting features. It offers integrated coverage of a broad set of topics that you would normally find in separate courses, often in different departments. It gives undergraduate students access to cutting-edge topics usually reserved for graduate courses. It also departs from the traditional lecture format to combine lectures with moderated laboratory sessions and at-home exercises and design projects. Here, I discuss the course's history and guiding principles that my colleagues and I employed in its implementation, the laboratory exercises and design projects, and outcomes, including dissemination activities.

HISTORY AND GUIDING PRINCIPLES

The course originated in the summer of 2002 when Ing-Ray Chen (CS), Luiz DaSilva (ECE), and I (also in ECE) responded to a request from Intel for "wireless curriculum development" proposals. We'd previously discussed the need for a laboratory-oriented, undergraduate networking course and had also collaborated on multidisciplinary research in wireless networking, primarily through a National Science Foundation-funded Integrative Graduate Education and Research Training (IGERT) grant. We decided to respond with a proposal that addressed our need in the form of a multidisciplinary, cross-listed course in wireless networks and mobile systems (see the "Quick Facts" sidebar).

Because we were primarily targeting upper-division undergraduate students, we took a "broad brush" approach to introduce topics ranging from wireless network technology—such as IEEE 802.11 wireless local area networks—to mobile applications and pervasive computing (see the "Course Topics" sidebar). Although some graduate students do take the course, we felt this emphasis on breadth better met our goals than the more focused, in-depth approach you typically find in graduate courses. We also wanted to avoid teaching a survey course that only superficially covered many topics. For each topic, we selected example technologies to illustrate key concepts and to introduce students to practical systems and standards. We also devoted substantial effort—and class time—to promoting experiential learning. Although lectures are necessary to introduce concepts and terminology, we wanted students to learn the topics through first-hand experiences with the selected technologies.

Fortunately, Intel selected our proposal (along with others from Carnegie Mellon University, the Indian Institute of Technology in Madras, Rutgers University, and the University of California, Los Angeles for funding. Intel provided equipment and support for graduate students to assist in developing the

QUICK FACTS

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Departments: Computer Science and Electrical and Computer Engineering
Institution: Virginia Tech
Instructors: Ing-Ray Chen, Luiz A. DaSilva, and Scott F. Midkiff
Level: Upper-division undergraduate and graduate
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course. Because this type of hands-on course on cutting-edge topics requires a tremendous amount of development effort and testing, this support was crucial to our success. We developed most of the course during fall 2002 and offered it, for the first time, in spring 2003. In that semester and in subsequent offerings in spring 2004 and spring 2005, we taught the course at both Virginia Tech's main campus in Blacksburg (to a mix of full-time undergraduate and graduate students) and at the university's Northern Virginia Center in Falls Church (to full-time and part-time graduate students). We shared lectures between the two locations using two-way, interactive videoconferencing equipment (see Figure 1). Separate laboratory sessions were held at each location.

During the first offering, all three faculty members—Chen, DaSilva, and myself—taught the course as a team. This was essential as no one of us was comfortable teaching all of the topics. However, we learned all of the material to some degree during the first offering. In spring 2004, DaSilva and I taught the course, and Chen and I are teaching the course in the current (spring 2005) semester. About 50 students have enrolled each semester.

Figure 1. Ing-Ray Chen lectures from the Northern Virginia Center.

COURSE TOPICS

The Wireless Networks and Mobile Systems course covers a broad range of topics. We organize topics, each covered in one week, into five major modules:

Fundamentals of wireless and mobile systems

- Technology overview
- Wireless environment, IEEE 802.11, and Bluetooth

Middleware for mobile systems

- Role of middleware and application program interfaces
- Client-server computing
- Peer-to-peer and ad hoc computing, service discovery

Wireless networks

- IEEE 802.11 medium-access control and Bluetooth
- Mobility in wireless LANs

Mobile networks

- IP-routing overview, mobile ad hoc network routing algorithms
- IP addressing, IP routing, Mobile IP
- Nomadic services, Dynamic Host Configuration Protocol, network address translation, and virtual private networks
- Security in wireless local area networks and mobile networks

Mobile applications

- Database services in mobile networks
- Location and context-aware pervasive computing

COURSE STRUCTURE

We teach the course in an unusual format, which usually requires some explaining to those who have to schedule class times and classrooms. Each week during the semester, students attend a 75-minute lecture and a 75-minute in-class laboratory session. The lectures introduce concepts and terminology for a topic, while students gain direct hands-on experience for that topic in the laboratory sessions. During most weeks, students also work on either an at-home exercise—for example, an experiment to investigate the effect of interference from a microwave oven on IEEE 802.11b performance—or a design project. Students organize themselves into groups of two for the in-class laboratory sessions, at-home exercises, and design projects. We issue each group a set of equipment (see the “Equipment Kit” sidebar) that suffices for individual group assignments and that we aggregate for some of the in-class laboratory sessions.

For example, when we discuss *mobile ad hoc networks*, the lecture covers basic MANET concepts, the principles of reactive and proactive routing protocols, and details of the Optimized Link State Routing protocol.[1] During the week’s in-class laboratory session, students use the INRIA (l’Institut National de Recherche en Informatique et en Automatique) OLSR implementation with Naval Research Laboratory modifications to form different MANET topologies with and without multiple-hop routing (see Figure 2). By having all of the groups collaborate, we form ad hoc networks with 10 to 15 nodes. Students measure throughput and control overhead and monitor routing information using tools, including Iperf and Ethereal. Students analyze results and answer more detailed questions about operation and performance in the week’s at-home exercise.

Students must be able to keep up with the course’s fast pace, even though some topic will push almost every student outside the comfort zone. For prerequisite knowledge, we expect students to have solid programming skills in a contemporary object-oriented programming language and some basic networking knowledge. We expect undergraduates to have had Computer Network Architecture and Programming (CS 4254) or Network Application Design (ECE 4564). Graduate students will typically have one of these courses or will have taken the first graduate networking course, Network Architectures and Protocols I (ECE/CS 5565) and have programming experience using C++, C#, or Java.

Grading in the course reflects the emphasis on experiential learning. We based semester grades on the following allocations:

- In-class laboratory exercises: 10%
- At-home exercises: 45% (5% for each of nine at-home exercises)
- Design projects: 20% (10% for each of two design projects)
- Midterm exam: 10%
- Final exam: 15%

We based the grade for the in-class laboratory exercises mainly on participation. The in-class laboratory exercises prepare students for the at-home exercises and design projects, which we grade for correctness.

Figure 2. Students collaborate to measure the performance of a MANET routing protocol.

HANDS-ON ASSIGNMENTS

We intend for the in-class laboratory sessions, at-home assignments, and design projects to be the most valuable learning experiences in the course. In selecting assignment topics, we chose specific technologies that illustrate key concepts. In many cases, we wanted students to work with more than one technology or system—for example, a reactive and a proactive MANET routing protocol or more than one mobile middleware system—but we had to make difficult choices to cover the desired range of topics in a one-semester, three-credit-hour course. One of our most difficult choices centered on using middleware packages and programming languages. The first time we taught the course, students did assignments using both Java 2 Micro Edition and Microsoft Embedded Visual C++. Students struggled with learning both systems in a short amount of time, and using J2ME was a bit clumsy in the PocketPC environment. So, in the second and third offerings, we used only .NET CF and C#, which let us assign more challenging exercises and design projects, albeit at the expense of generality.

In selecting specific assignments, we emphasized analysis at the lower layers of the protocol stack and design at the higher layers. For example, students do experiments to study the performance of IEEE 802.11a versus IEEE 802.b wireless networks while they design and implement new mobile applications. Practical considerations drive this approach; implementing a modified, medium-access control protocol in a real system is infeasible within the constraints of an academic course, and modifying an ad hoc routing protocol

THE EQUIPMENT KIT

We loan the following equipment to groups of two students:

- One Dell Latitude C640 notebook computer with Windows XP Professional, Linux Red Hat and other software installed
- One Compaq iPAQ 3850 with Microsoft PocketPC 2002 and a dual-card sleeve
- One Intel IEEE 802.11b wireless gateway
- Two Xircom IEEE 802.11b network interface cards
- One Intel IEEE 802.11a network interface card
- One Xircom Bluetooth network interface card

Additionally, we use an Intel IEEE 802.11a/b dual-access point and an Intel Ethernet switch for in-class laboratory sessions and project validation.

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or Mobile IP would tend to require more time than we have in our schedule. But, it's perfectly reasonable to ask students to design and implement a Universal Plug-and-Play (UPnP) device or controller at the application layer.

We use the in-class laboratory sessions for experiments that require multiple sets of equipment and to provide guided tutorials. The following list shows topics for the in-class laboratories for the spring 2005 semester; we used similar laboratory topics in the previous two offerings:

- Establishing wireless connections and observing IEEE 802.11 traffic
- Configuring IEEE 802.11a and 802.11b, configuring an ad hoc network, measuring IEEE 802.11a throughput, and using Ethereal
- Using .NET CF to develop a standalone PocketPC application
- Developing a Web service client using .NET CF
- Configuring UPnP and observing service discovery, service control, and file synchronization
- Configuring Bluetooth piconets and measuring the effects of Bluetooth and IEEE 802.11b interference
- Measuring the effect of request-to-send (RTS) and clear-to-send (CTS) on throughput in IEEE 802.11b
- Measuring delay, throughput, connectivity, and overhead in MANET routing protocols
- Measuring delay, throughput, addressing, and overhead in Mobile IP
- Tracing network address translation (NAT), configuring and tracing operation of the Dynamic Host Configuration Protocol (DHCP), and configuring and monitoring virtual private networks
- Analyzing IEEE 802.11 security and observing security vulnerabilities
- Analyzing on-demand data access versus broadcast-based data access
- Observing a context-aware PocketTV application running on PocketPC using IEEE 802.11b

We couple most in-class laboratory sessions with an at-home exercise that analyzes results from the in-class laboratory or requires students to perform a more time-consuming task than is possible in the 75-minute laboratory session. Here are the spring 2005 at-home exercises, which resemble those in previous semesters:

- Experimenting with network measurement and monitoring utilities
- Measuring IEEE 802.11b throughput and the effect of encryption, range, and interference
- Using Microsoft .NET CF for mobile application development
- Developing a .NET CF Web service for wireless access
- Analyzing 802.11b and Bluetooth interference data
- Analyzing RTS and CTS throughput data
- Analyzing results for the OLSR MANET routing protocol and investigating reactive and proactive MANET routing algorithms
- Investigating Wi-Fi Protected Access (WPA) and IEEE 802.11i versus Wired Equivalent Privacy (WEP)
- Analyzing the performance of flat versus broadcast disk organizations

We assign two challenging design projects. In all three offerings to date, one project required students to develop part of a UPnP system—the device, the controller, or both—and the other project required students to design, configure, and implement a wireless "hot spot" service, including a customized authentication application, firewall functions, DHCP, and NAT. Students have uniformly given high marks to the hot spot project. Students like the fact that they develop an essentially complete system that has the feel of a commercial wireless hot-spot service.

Although students like the UPnP project, it's been more difficult to achieve the right level of complexity for the UPnP project. In the first semester, students developed a system where an iPAQ could control a PowerPoint presentation on the notebook computer using UPnP. To simplify the project, we gave the students some code. As it turned out, we provided too much code, which left the students with too few design choices. In the second offering, we used a different UPnP application, but some practical issues forced the device and the controller to both run on the notebook, which kept students from seeing a truly networked application. This semester we're returning to the PowerPoint application. We're giving students the iPAQ-based control application but are requiring them to develop almost all of the control application that will run on the notebook computer.

OUTCOMES

The course has been extremely popular with students and has been rewarding, although challenging, for both the faculty and graduate student developers.

Survey results from the spring 2003 semester were consistently positive—84 percent of students rated the in-class exercises effective or very effective; 69 percent of students expressed the same opinion about the at-home exercises. Sixty-eight percent of students found the lectures to be effective or very effective. The two design projects received the highest ratings—82 percent of students considered the UPnP design project effective or very effective, and 94 percent of the students rated the hot-spot project effective or very effective. Confirming our motivation to develop a hands-on course, students cited the opportunity for hands-on experience as the course's most valuable aspect. We received similar survey results for the spring 2004 offering. Students also "vote with their feet." In Blacksburg, for each of the three semesters, we've had far more requests for the class than we can accommodate.

Although developing and executing the course's hands-on aspects required considerable efforts by the team of faculty and graduate assistants, it's been rewarding and enlightening. While we expected the graduate students that assisted with the course to contribute knowledge from their research to the course, we found that several of the students also applied knowledge gained from the course to their research or have adjusted their research topics on the basis of their experiences in developing assignments.

The instructors have also worked to disseminate their teaching experiences and course materials. In addition to the public course Web site (www.irean.vt.edu/courses/ececs4570), which includes lecture slides, assignments, and other information from the course, the instructors have given workshop presentations and tutorials related to the course. In March 2004, we made a presentation at the Workshop on Pervasive Computing Education.[2] In October 2004, DaSilva and I were the featured presenters at the Curriculum Development Workshop for Wireless Networks held at National Chiao Tung University in Hsinchu, Taiwan, sponsored by Intel and the Taiwan Ministry of Education (see Figure 3). About 100 faculty members, graduate students, and researchers from throughout Taiwan attended the workshop. DaSilva and I also offered a hands-on tutorial based on selected topics from the course at the 2004 Wireless Communications and Networking Conference, and DaSilva plans to present a similar short course at WCNC in 2005.

Figure 3. Luiz DaSilva at a curriculum development workshop in Taiwan (courtesy of Intel).

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