

# An Integrated Laboratory Course in “Wireless and Mobile Systems Design” Motivation, Objectives, and Approach<sup>1</sup>

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## 1. Opportunities for Innovation

We have identified three opportunities for innovation that address key deficiencies in Virginia Tech’s curriculum with respect to wireless and mobile systems design.

- *We need to offer students an integrated approach to the design and characterization of wireless and mobile systems.* While we cannot make every student an expert in all topics from the wireless channel to mobile application design, we can provide students with a critical understanding of the context for their work in different aspects of wireless systems.
- *We need to prepare students for multidisciplinary teamwork.* We believe that the ability to function in a multidisciplinary environment is especially critical in wireless and mobile systems design where there is interplay with application, operating system, protocol, hardware, and communications issues.
- *We need to couple laboratory projects and case studies to create a student-centered, discovery-based course.* This hands-on laboratory course for upper-division undergraduate students and graduate students can provide valuable and unique design and experimental experiences. We believe that this approach is more effective than traditional approaches in developing students’ knowledge and understanding and in retention of learning objectives.

### 1.1. An Integrated Approach to Wireless and Mobile Systems Design

Wireless networking, as a topic in engineering and computer science curricula and as an engineering practice, presents unique challenges. In particular, traditional layered protocol models, such as the seven-layer Open Systems Interconnection (OSI) model, lack the richness and complexity needed to architect and design effective wireless and mobile systems. Traditional networking courses separate the treatment of functionality at the different layers. For example, routing protocols are considered without regard to characteristics of the underlying physical links and transport layer performance is studied in isolation of the physical layer, which may exhibit high bit error rates. Mobility and the effects of the wireless channel necessitate an integrated treatment of multiple layers.

Our own courses in wireless communications and networking tend to promulgate the disconnection between layers. We have a strong wireless curriculum in ECE with a large number of undergraduate and graduate courses. Some of these courses have excellent laboratory components that consider issues such as the realization of communications algorithms using digital signal processors and the design of radio frequency hardware. However, these courses reflect the traditional strengths of our faculty in the communications area and focus almost

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exclusively on the physical layer. We also have a strong graduate networking curriculum in CS and ECE. However, these courses tend to focus on issues strictly above the physical layer and, for the most part, provide only limited coverage of wireless networks. An exception is an advanced graduate course on Wireless Networks and Mobile Computing. However, this course has little engineering design content and is not accessible to undergraduates. Our networking offerings at the undergraduate level are somewhat deficient. ECE currently offers courses in Telecommunications Networks (covering telephony, access networks and interconnect technology, and integrated network technology) and Network Application Design (covering applications built on TCP and UDP using sockets). CS currently offers a course in Network Architecture and Programming (covering the fundamentals of TCP/IP and socket programming).

This course takes quite a different approach from existing courses. As illustrated in Figure 1, our philosophy is to cover an appropriately selected vertical slice of topics that span mobile applications, middleware, mobile networking, and wireless networks and links. This is in contrast to the traditional approach of covering a broad horizontal slice (e.g., as in courses on local area networks or physical layer communications). We believe that this more integrated view of wireless and mobile systems is critical to the success of computer scientists and engineers designing and researching *any* aspect of such systems. Given the realities of prior background, the relative inflexibility of hardware as a design medium, and the time constraints of a three-credit hour class, we take a somewhat uneven slice across the topics. The course emphasizes characterization of the lower layers of wireless and mobile systems to understand the properties of and design constraints presented by wireless networks and wireless links. The course emphasizes design at the upper layers, specifically building applications using middleware and modifying core protocols to examine protocol architectures and to characterize the performance of alternative designs.

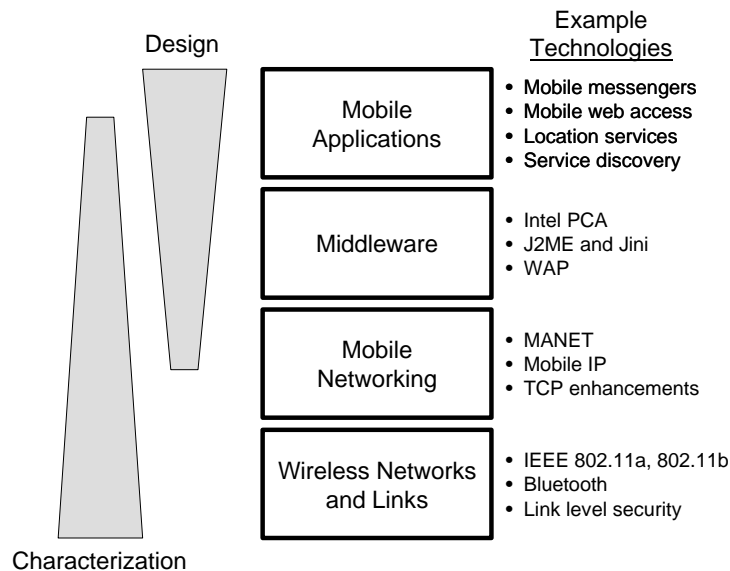


Figure 1. An integrated approach to wireless and mobile systems design.

### 1.2. Incorporating Multidisciplinary Teamwork

The need for engineering and CS students to learn to work in multidisciplinary teams is widely recognized by both industry and academia. For example, multidisciplinary courses and

multidisciplinary student teams have been features of numerous projects funded through the NSF Engineering Education Coalitions program. This is one of the key goals of SUCCEED, a coalition of engineering schools in the southeast, including Virginia Tech. We believe that wireless, in particular, requires the ability for engineers and computer scientists from diverse backgrounds to work together to realize systems. Further, the subject matter of wireless and mobile systems provides an excellent opportunity to provide students with multidisciplinary design and teamwork experiences that can be of value regardless of the students' final career paths.

We seize this opportunity in this course. Students complete case studies and laboratory projects in multidisciplinary teams of two to four students. Teaching the class itself is an experiment in multidisciplinary collaboration. A multidisciplinary team of CS and ECE faculty and students has developed the course material and taught the course.

### *1.3. Student-Centered, Discovery-Based Learning*

It is well known that people learn better by actually using concepts to construct and manipulate physical systems than by just listening to lectures, reading a book, or solving problem sets. Physical science, engineering, and computer science educators have long used laboratories and programming assignments to provide such experiential learning. Students are able to discover new knowledge and reinforce knowledge gained from lectures and reading. Over the past 20 years, business schools have increasingly used the case method to present problems and issues. Case studies allow groups of students to cooperatively investigate and analyze an issue, make recommendations, and present results.

We integrate three pedagogical components in the class:

- hands-on laboratory projects where students design, implement, and test system and application software or measure and analyze system attributes, with results presented in a laboratory notebook;
- case-based studies of system architectures, specific technologies, and development methods and tools resulting in student presentations; and
- lectures to provide a foundation for case studies and laboratory projects.

While case studies and laboratory projects are highly beneficial, they are costly to implement due to development time, laboratory support, and equipment.

### *1.4. Uniqueness of the Course*

While a few other universities do a good job of providing hands-on experiences in networking and presenting an integrated view of wireless and mobile systems, we believe that our proposed course offers significant differences that are worthy of implementation and study. Several universities offer hands-on courses in wireline networking. Most of these courses consider the design and configuration of networks (e.g., planning addressing architectures and configuring routers). However, we know of only a few (with a notable example being Georgia Tech) where undergraduates get “under the hood” of TCP/IP and modify networking protocols for wireline systems. Our course follows a similar approach, but considers wireless and mobile systems.

A number of integrated courses in wireless networking and mobile computing are emerging. These courses tend to be taught at the graduate or advanced graduate level and most do not

include hands-on project work. Some courses are notable in their inclusion of design-oriented projects using handheld devices (such as courses at Maryland, Rutgers, and Florida). Our course is innovative in that we incorporate a more focused and structured laboratory component to enable the course to be taken successfully by upper-division undergraduate students.

## 2. Course and Laboratory Design

The course consists of five modules, with one module corresponding to each of the four topic areas identified in Figure 1 shown previously and one additional module as a preface to provide necessary background in networking and wireless. The five modules, lecture topics, and example themes for associated case studies and laboratory projects are listed in Table 1.

Table 1. Course Modules and Example Associated Components

<i>Module</i>	<i>Lectures</i>	<i>Case Studies</i>	<i>Laboratory Projects</i>
Networking and Wireless Fundamentals	<ul style="list-style-type: none"> <li>• Introduction to TCP/IP</li> <li>• Wireless and mobility challenges</li> <li>• Mobile devices</li> <li>• Security issues</li> </ul>	<ul style="list-style-type: none"> <li>• Handheld mobile devices and cellular phones</li> <li>• Protocol stack for mobile Internet</li> <li>• Security architectures</li> </ul>	<ul style="list-style-type: none"> <li>• IP trace route</li> <li>• Packet dumps for TCP and UDP sessions</li> <li>• IP performance measurement</li> </ul>
Wireless Networks	<ul style="list-style-type: none"> <li>• Multiple access networks</li> <li>• IEEE 802.11 PHY and MAC</li> <li>• Overview of Bluetooth</li> </ul>	<ul style="list-style-type: none"> <li>• Operation of IEEE 802.11a and 802.11b</li> <li>• Bluetooth operation</li> </ul>	<ul style="list-style-type: none"> <li>• Characterization of IEEE 802.11b performance</li> <li>• Characterization of Bluetooth performance</li> </ul>
Mobile Networks	<ul style="list-style-type: none"> <li>• IP routing issues</li> <li>• Overview of Mobile IP</li> <li>• Overview of MANETs</li> <li>• TCP Performance</li> </ul>	<ul style="list-style-type: none"> <li>• Operation of OLSR</li> <li>• Networking solutions for Mobile Internet access</li> </ul>	<ul style="list-style-type: none"> <li>• MANET configuration</li> <li>• OLSR performance modification</li> </ul>
Middleware	<ul style="list-style-type: none"> <li>• Role of middleware</li> <li>• Socket API</li> <li>• Intel's Personal Internet Client Architecture</li> </ul>	<ul style="list-style-type: none"> <li>• Middleware solutions for Mobile Internet</li> <li>• WAP versus iMode versus J2ME</li> </ul>	<ul style="list-style-type: none"> <li>• SDK and middleware familiarization</li> <li>• Development process</li> </ul>
Mobile Applications	<ul style="list-style-type: none"> <li>• Application example</li> </ul>	<ul style="list-style-type: none"> <li>• Mobile application design</li> </ul>	<ul style="list-style-type: none"> <li>• Prototype application development</li> </ul>

A traditional 3-credit course typically consists of 150 minutes of lecture per week, with students spending an additional 6 to 9 hours per week doing reading, homework, and projects. To accommodate a more student-centered, discovery-based approach, a typical week in this course consists of:

- 50 to 75 minutes of lecture to introduce key concepts and to provide a foundation for case studies and laboratory projects;
- 25 to 50 minutes of case study presentations by students and discussion of relevant issues; and
- 50 minutes of laboratory meetings for instructors and graduate assistants to demonstrate tools and discuss assignments and for students to report on the status and outcome of projects.

We offer the class both in Blacksburg and in northern Virginia. To leverage human resources and to ensure a multidisciplinary approach to lectures, we share lectures between the two sites. Virginia Tech has a well-developed interactive videoconferencing system for distance learning

with equipment in Blacksburg, at the Northern Virginia Center (NVC), and at the Alexandria Research Institute (ARI). Laboratory sessions are local.

We have developed two instructional “laboratories,” one in Blacksburg and one at the ARI and NVC. We leverage mobile devices and networks to create a laboratory environment that is more flexible and portable than a traditional laboratory. This eliminates the need for continuous dedicated laboratory space (a traditional laboratory consumes space even if the course is not being taught) and permits us to take the laboratory “on the road” for teaching workshops and short courses. We organize the laboratory equipment into “kits” consisting of a notebook computer, a handheld personal digital assistant (PDA), wireless networking equipment (IEEE 802.11a, IEEE 802.11b, and Bluetooth), and software. A single kit supports software development and a set of two kits enables testing with two or four mobile devices. A kit is assigned to every two students. Teams cooperate to perform large-scale testing. Shared resources are available for file sharing (to retrieve software, share files within a team, and submit code), network access, protocol and application testing (for packet capture and protocol analysis), and display for laboratory demonstrations.

The kits allow students to characterize wireless networks, experiment with and modify mobile networking software, develop code using middleware, and develop and test mobile applications. The following examples illustrate the theme and scope of laboratory projects.

- Measure the throughput of a wireless network technology (IEEE 802.11b or Bluetooth). Determine the effect of contention by 1 to 4 hosts transmitting at different rates. Determine the throughput of a handheld PDA versus a notebook. Experiment with factors that may affect throughput such as distance between nodes and building materials.
- Measure the overhead of a mobile ad hoc network (MANET) routing protocol (e.g., the Optimized Link State Routing, or OLSR, protocol). Determine the effect of varying levels of application traffic and mobility.
- Modify OLSR running in Linux to serve as a gateway between a Bluetooth piconet and an IEEE 802.11b wireless local area network.
- Implement a simple scheme to realize a split-connection approach to improving TCP performance over a wireless link.
- Implement a mobile client (on a PDA) that accesses a server (on a notebook) to retrieve live or archived audio or video content. Use Intel’s Personal Internet Client Architecture (PCA) to implement this client-server application.
- Using PCA, implement a peer-to-peer, multiplayer game using two or more PDAs.

### **3. Impact**

We envision significant impacts on wireless workforce availability, the quality of education and preparedness for individual students, curriculum improvement at other universities, and the level of collaboration at Virginia Tech.

We are expanding the available wireless workforce by introducing a significant number of traditional and non-traditional ECE and CS students to the field of wireless and mobile systems. We teach 50 students per year in for-credit courses. This includes traditional undergraduate and graduate students at Virginia Tech’s Blacksburg campus and working professionals enrolled in

part-time graduate study at the university's Alexandria Research Institute and Northern Virginia Center in the metropolitan Washington, DC region. Regardless of the exact specialization, e.g., wireless communications or mobile applications designer, these students will be better prepared to work in the demanding multidisciplinary field of wireless and mobile systems. We also plan to adapt the material and projects into an intensive three-day non-credit short course. We estimate that 15 to 30 people will take the short course each offering.

We hope to impact individual students in significant ways. This course is one of the premier instructional experiences for many students. The course creates excitement and enthusiasm for wireless and, we believe, motivates more students to take jobs or pursue graduate study in the wireless or associated industries. Further, regardless of career choices, we believe that this course improves the student's ability to do multidisciplinary design, work in teams, and communicate.

As the developers of the course and as experimenters with the pedagogical approach used in the proposed class, we see the need to share our ideas and experiences. All lecture material, case study assignments, and project assignments are available on a public web site. A discussion list is available for other instructors to ask questions and/or discuss related issues. The site provides links to other web resources.