
Proof-of-concept: Enhance Multi-Disciplinary Undergraduate Wireless & Mobile System Learning With Experimental Bluetooth & Sensor Kits

PIs: Dr. Fei Hu & Dr. Marcin Lukwiak (CE/KGCOE), Ankur Teredesai (CS/GCCIS)

Part I. Project outcomes:

The above PLGI project (starting from July 1, 2004) has been allocated $10K by RIT Provost’s office. It is a multidisciplinary project between Computer Engineering department (KGCOE) and Computer Science department (GCCIS). The three PIs (Drs Fei Hu, Marcin Lukwiak, and Ankur Teredesai) have successfully accomplished all the three proposed tasks as follows:

1. Developed Wireless & Mobile system labs:

In this project, we have created a series of undergraduate course labs including topics such as ad hoc routing protocols, wireless MAC layer design, data collection from sensor networks, etc. These labs cover the fundamentals of wireless and mobile systems. The department head of Computer Engineering have provided the budget to purchase networking simulation software to support those class labs, and Computer Science department have provided sensor hardware platform.

In this project, we have successfully developed and offered a professional elective course – “Wireless Networks” in Summer 2004. (Course Number: 0306-672/772). The class size was 18 (12 Undergraduate students and 6 BS/MS students). Please see Appendix 1 for course syllabus.

In this course, 6 labs were designed and assigned to 6 student groups. We adopted the following teaching mode, (we call it “Pyramid Education Mode”) (see Figure 1):

![Figure 1. New developed Education Mode in PLGI project](image-url)
In the above teaching approach, the “wireless networking” topics have been classified into four levels: (1) **PI tasks**: the faculty should have a deep understanding of advanced topics and assign them to students; (2) **PhD level topics**: the PI (Fei Hu) is currently enrolling a PhD student who will study wireless security (one of the teaching topics in this project); (3) **MS level topics**: The PhD student further decomposes a research task into a few small simulation/algorithim issues that are suitable to MS students. (4) **BS students’ labs**: the MS students then guide BS students for some course labs/projects that are related to their theses. The goal is to train BS students to understand current cutting-edge technologies.

In the developed “Wireless Networks” course, the PI (Dr. Fei Hu) asked 4 MS or BS/MS students to work with six groups of undergraduate students on the following labs (Note: all the lab reports and experiment results by the six groups can be downloaded from RIT website: [http://www.ec.rit.edu/~fxheec/2004wireless](http://www.ec.rit.edu/~fxheec/2004wireless)):

**Lab 1**: Sensor Database through Xbow ([http://www.xbow.com](http://www.xbow.com)) hardware platform. We have ordered $2,000 Mica2 motes and temperature/light sensors for students’ labs. Three students used them to build an exciting application: collecting sensor data (including both light and temperature) from the classroom (Building 9-2139) and sending them to a remote laptop that used Internet to display the sensor database, i.e. sensor data from different sensors at different times. The students learned both sensor hardware architecture and wireless protocol design.

**Lab 2**: Wireless MAC (Medium access control) layer design: a MS student (Mark Edwards) guided 3 students to use OPNET ([www.opnet.com](http://www.opnet.com)) to build the MAC protocol for wireless sensor networks. They successfully built a low-energy protocol based on the course requirements.

**Lab 3**: Wireless security: Led by Waqaas Suiddi (BS/MS student). The task was to use Java to simulate the security transmission between sensor nodes. Waqaas has used this lab to finish part of his thesis. Thus the PI has successfully found an efficient way to help graduate students with their thesis research through working with undergraduate students on class labs/projects.

**Lab 4**: Data Query in sensor networks: Led by Carter May (BS/MS student). This lab was about the design of a time synchronization protocol so that all sensors can work together to send sensor data back to the base station. Again, it was based on OPNET (a network simulation tool).

**Lab 5**: Integrate ad hoc networks and cellular networks: Led by Nidhi Verma (MS student): Nidhi’s Master thesis was about the integration of ad hoc networks and cellular networks. The PI extracted part of her thesis work for students’ lab. This group used OPNET to build an integrated scenario with both mobile ad hoc networks and cellular networks. The results had practical meaning. For example, they showed that it was possible to organize a local ad hoc network among cell phone users.

**Lab 6**: wireless routing design: Led by Tim Scotts (BS/MS student): Routing is a challenging problem in wireless sensor networks. The PI gave the students an OPNET project demo by another school and asked them to improve it from network performance viewpoint. They did it! In the last week, they demosed their revised results in the class.

The following are some comments from the students who took the wireless course in Summer 2004:

“Wireless networks are becoming more and more popular. This course provides us not only solid theory foundations but also practical wireless protocol design through Xbow hardware and OPNET software. OPNET is an advanced network simulation tool. We could use it to simulate almost any practical wireless network scenarios …”
“Wireless security is totally different from Internet security. I learned a lot from this lab. Cornell University’s JIST is a perfect tool to simulate ad hoc sensor networks.”

– Waqaas Suiddi, a BS/MS student in Computer Engineering Department, now work in Intel

“When I guided the students, I also improved my understanding of my MS thesis. This is a good course.”

– Mark Edwards, a BS/MS student in Computer Engineering Department, now work in CA

This course had 5 homework assignments and 3 tests (1 quiz, 1 mid-term and 1 final). In Week 10, all students presented their works in the class.

2. **Network Security in wireless system:**

The second task of this project is wireless security education. We have developed a 5-week course materials on *Network Security in wireless systems* for 3/4/5th year students. Those materials have been successfully used in the teaching of a course offered in Winter 2004, called 0306 672/772 “Advanced Topics in Networking”. Dr. Shanchieh Jay Yang and the PI (fei Hu) taught this course together. During the 5-week “wireless networking security”, we have taught the following new topics that have not been previously provided in Computer Engineering department:

- Security requirements in low-energy wireless sensor networks;
- Key management in large-scale sensor networks;
- Authentication from the base station to all sensors;

Especially we edited our research works to 1 week of lectures on wireless security design. We trained the students with a good research approach on how to improve current research works. The students were asked to read 5 journal papers from IEEE Transaction Journals. Then they needed to come up with new ideas on how to improve the weaknesses in those papers.

Because wireless security is so important today, it is necessary for us to further extend those 5-week materials to a 10-week course in the future projects.

We have achieved the following learning outcomes:

- Students are able to understand the security constraints and characteristics in wireless networks where the wireless signals propagate all around. *Assessment: tests and homework.*
- Understand the approach to integrating wireless security with other protocols such as routing. *Assessment: open discussions after paper readings.*
- Able to find out the problems in current research works and to propose new ideas to improve current works. *Assessment: a term paper and presentation in the final class.*

3. **Wireless-based Data Management:**

The third proposed focus in our project is on *data management* in wireless networks. For a long term, Computer Science education has focused on data management in traditional relational databases. However, with the coming of *Pervasive Computing*, more and more information is collected from large-scale, distributed, low-cost, low-memory and low-power sensor networks. We should therefore not only teach our undergraduate students the traditional topics in database management but also provide them with an exposure to the data management issues in pervasive
computing environments.

In this project, we have successfully developed a new course, Distributed Data Management, which concentrates on data query implementation/optimization, objective data collection and distributed database management in Pervasive Computing environments. Please see Appendix 2 for course syllabus.

In this 10-week course offered in Computer Science department in Spring Quarter 2004-05, we have generated the following expected learning outcomes:

- Students are able to identify the basic techniques for data management in sensor networks. Assessment: Presentation evaluation and project (in week 10)
- Students can understand the fundamentals of networking issues and prototype development in sensor networks. Assessment: Java Programming projects.
- Students are able to describe their understanding of sensor networks. Assessment: Project demonstrations.
- Demonstrate an understanding of the theoretical foundations and principles of using networking techniques in sensor networks.
- Demonstrate an understanding of software engineering principles and apply these principles to software design and rapid prototyping.
- Demonstrate an understanding of professional ethics and an understanding of the role of the profession in society.
- Demonstrate an understanding of data management issues in sensor networks.

Part II. Project Evaluations:

1. IAB (Industry Alumni Board) meeting:

In the IAB (Industry Alumni Board) meeting held this March in Computer Engineering department, we have made five questions (see Appendix 3) and solicited their comments on our PLGI project outcomes. The following are some of their evaluations:

“Wireless Networks course has been offered in many schools. Certainly it is necessary for us to develop the teaching materials for our CE students. Besides Wireless Networks course, we should also offer a Wireless Communications course since our students need to know low-layer (Physical layer) principles such as modulation, coding, etc…..”


“The labs have both hardware and software parts, which is good in terms of computer engineering training. There should be more hardware-related labs since sensors are very interesting to students……”


“I think that the students should be assigned more homework assignments. Five of them are not enough since wireless topics need immediate understanding.”


2. Students who took the developed courses in this project:

The project has developed the following materials for three courses:
• “Wireless Networks” course (Developed / offered in Summer 2004 for Computer Engineering students): we have developed 6 group-based labs; 10-week teaching materials including ad hoc networks, sensor networks, bluetooth, cellular networks, and sensor networks; 5 homework assignments; 2 quizzes; 1 mid-term; 1 final exam.
• “Advanced Networking” course (Offered in Winter 2004-05 for Computer Engineering students): the first 5 weeks are about “Wireless security” topics. We have developed 5-week teaching materials, 1 project assignment, 3 homework assignments, 1 mid-term.
• “Distributed Data Management” course (Offered in Spring 2004-05 for Computer Science students): 10-week teaching materials; projects; all tests and homework assignments.

Most students have successfully finished their labs/projects. Part of them have used what they have learned for their senior projects and Master thesis research.

All students have felt they learned a lot. About 10% of them said that we were teaching too much. That was perhaps because we gave them a little bit more research-related topics.

1. Course description: (4 credit hours)

Prerequisite: 0306 694 -Computer networks.

This course will discuss the system architecture, hardware components, smart spaces (such as sensor networks), network security and software applications in pervasive computing platforms. This course emphasizes system design such as 3G cellular networks UMTS, Bluetooth and sensor networks. The students will use pervasive computing hardware such as sensors and laptops to design ad hoc networks, and also use software such as OPNET / MATLAB to design cellular networks.

2. Textbook:

This course does not have appropriate textbooks. Handouts (papers, reports, etc.) will be distributed in the class.

3. Grading Policy:

Homework 10%
Quizzes 20%
Labs 40%
Exams (mid-term and final) 30%

4. Topics to be covered:

• DSP for wireless & mobile systems;
• Antenna design; Wireless Receiver;
• Cellular system design;
• Ad hoc Network design;
• Bluetooth system; Wireless LAN system;
• Wireless security: principle and design;
• Wireless sensor network design.

5. Learning outcomes:

• Be familiar with wireless hardware principle such as antennas, diversity receivers, etc;
• Be able to describe the system architecture of 3G cellular networks. Understand the handoff signaling procedure;
• Be able to design AODV routing protocol in ad hoc networks;
• Understand principle of wireless network security;
• Be able to design a working sensor network and run a meaningful application such as data query;
• Understand the design principle of common wireless applications based on certain protocols such as Wireless Application Protocol 9WAP).

6. Topics to be covered:
<table>
<thead>
<tr>
<th>Week</th>
<th>Topics</th>
<th>Labs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DSP for wireless communications (1) – DSP review, wireless signal transmission/receiving architecture</td>
<td>Lab 1: MATLAB simulation: wireless communication model</td>
</tr>
<tr>
<td>2</td>
<td>Hardware for wireless communications – Antenna design, diversity receiver</td>
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<tr>
<td>3</td>
<td>Mobile networks architecture (1) --cellular networks (system design)</td>
<td>Lab 2: use OPNET to design a UMTS</td>
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<tr>
<td>4</td>
<td>Mobile networks architecture (2) – Ad hoc Networks (system design)</td>
<td>Lab 3: Ad hoc network routing design (using Laptops as nodes)</td>
</tr>
<tr>
<td>5</td>
<td>Mobile networks architecture (2) – Bluetooth &amp; WLAN hardware</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Wireless security (1) – Applied cryptography, wireless security requirements</td>
<td>Lab 4: Ad hoc network routing security design (using CAMPAQ iPAQ)</td>
</tr>
<tr>
<td>7</td>
<td>Wireless security (2) – WLAN security, ad hoc network security</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Smart Spaces (1) – sensor networks architecture / protocol stack</td>
<td>Lab 5: Smart Spaces design through Crossbow sensors – MAC design</td>
</tr>
<tr>
<td>9</td>
<td>Smart Spaces (2) – sensor networks routing / MAC</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Pervasive software applications</td>
<td>No lab</td>
</tr>
</tbody>
</table>
Appendix 2 -- *Data Management in Pervasive Computing*

*(course syllabus)*

1.0 Basic information

**Credit Hours:** 4  
**Prerequisite(s):** Programming Skills in C, C++, Java or Assembly Language Or Permission of the Instructor. All enrolled students will be tested for basic programming skills during the first week of classes.  
**Co-requisite(s):** none  
**Course proposed by:** Ankur M Teredesai

2.0 Course information:

<table>
<thead>
<tr>
<th></th>
<th>Contact hours</th>
<th>Maximum students/section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classroom</td>
<td>4</td>
<td>45</td>
</tr>
<tr>
<td>Lab</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Quarter(s) offered (check)**

- Fall  
- Winter  
- X Spring  
- Summer

**Students who might elect to take the course:** Undergraduate students majoring in Computer Science, Computer Engineering, IT, Software Engineering, Physics, EE and any other student who has the requisite programming background equivalent to CS1-3 sequence.

3.0 Goals of the course:

This course will focus on the challenges of data processing and management in networks of remote, wireless, battery-powered sensing devices (sensor networks). The power-constrained, lossy, noisy, distributed, and remote nature of such networks means that traditional data management techniques often cannot be applied without significant re-tooling. Furthermore, new challenges associated with acquisition and processing of live sensor data mean that completely new networking and database techniques must also be developed. This course provides the fundamental background and knowledge that is required for undertaking an advanced study of these topics. Students will be introduced to the basic elements of sensor networks, networking issues and data management issues. The assignments and labs will demonstrate proficiency through a series of programming assignments and presentations.

4.0 Course description:
Course Description: This course will focus on the challenges of data processing and management in networks of remote, wireless, battery-powered sensing devices (sensor networks). The power-constrained, lossy, noisy, distributed, and remote nature of such networks means that traditional data management techniques often cannot be applied without significant re-tooling. Furthermore, new challenges associated with acquisition and processing of live sensor data mean that completely new networking and database techniques must also be developed. This course provides the fundamental background and knowledge that is required for undertaking an advanced study of these topics.

Students will be introduced to the basic elements of sensor networks, networking issues and data management issues. The assignments and labs will demonstrate proficiency through a series of programming assignments and presentations.

5.0 Possible resources (texts, references, computer packages, etc.)

5.1 Wireless Sensor Networks: An Information Processing Approach (Morgan Kaufmann Series in Networking) by Feng Zhao, Leonidas J. Guibas

5.2 Selected Papers from relevant conferences on Sensor Networks.

6.0 Topics (outline):

6.1 Introduction
   6.1.1 Unique Constraints and Challenges (power consumption, topology effect, bandwidth, wireless environment, security)
   6.1.2 Applications of sensor networks
   6.1.3 Collaborative processing environments
6.2 Primitive data types for Sensor Networks
6.3 Networking Issues
   6.3.1 Effect of networking issues on data collection
   6.3.2 Routing Protocols (data centric, hierarchical, location aware)
   6.3.3 Data Dissemination
   6.3.4 Quality of service and data reliability
6.4 Sensor Databases
   6.4.1 Query Processing in Sensor Networks
   6.4.2 Probabilistic Queries
   6.4.3 Query-Statistics and Optimization
6.5 Event Based Data Management
   6.5.1 Event Detection in Sensor Networks
6.6 Distributed Data Storage and Indexing
   6.6.1 Indexing Implementations
   6.6.2 Database indexing in P-2-P Networks vs. Sensor Networks
6.7 Security Issues in Sensor Networks
   6.7.1 Current viewpoints

7.0 Learning outcomes
7.1 Students will be able to identify the basic techniques for data management in sensor networks. *Assessment: Presentation evaluation and project.*

7.2 Students will understand the fundamentals of networking issues and prototype development. *Assessment: Programming projects.*

7.3 Students will be able to describe their understanding of sensor networks. *Assessment: Project demonstrations.*

7.4 Demonstrate an understanding of the theoretical foundations and principles of using networking techniques in sensor networks.

7.5 Demonstrate an understanding of software engineering principles and apply these principles to software design and rapid prototyping.

7.6 Demonstrate an understanding of professional ethics and an understanding of the role of the profession in society.

7.7 Demonstrate an understanding of data management issues in sensor networks.

### 8.0 Weekly topics

<table>
<thead>
<tr>
<th>Week</th>
<th>Teaching topics</th>
<th>Labs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction; Unique Constraints and Challenges; sensor network applications</td>
<td>Lab 1: Sensors hardware and TinyOS principle</td>
</tr>
<tr>
<td>2</td>
<td>Sensor network energy model; protocol characteristics.</td>
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<tr>
<td>3</td>
<td>Primitive data types for Sensor Networks</td>
<td>Lab 2: Build a simple sensor network application</td>
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<tr>
<td>4</td>
<td>Effect of networking issues on data collection; data dissemination</td>
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</tr>
<tr>
<td>5</td>
<td>Quality of service and data reliability; the effect of routing protocols</td>
<td>Lab 3: Cougar Data Management Tool for sensor networks</td>
</tr>
<tr>
<td>6</td>
<td>Sensor Databases &amp; data query; Query-Statistics and Optimization</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Event Based Data Management; Event detection</td>
<td>Lab 4: TinyDB application (Database for sensor networks)</td>
</tr>
<tr>
<td>8</td>
<td>Distributed Data Storage and Indexing</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Security Issues in Sensor Networks</td>
<td>Lab 5: Security protocols for sensor networks</td>
</tr>
<tr>
<td>10</td>
<td>Distributed data management in other wireless &amp; mobile systems</td>
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</tr>
</tbody>
</table>
Appendix 3:

IAB Evaluation of CE Wireless Networking Courses

Your Name:                                  From where:                                    Position:

1. From Career point of view, does the coverage of our wireless communication & networking courses meet the engineering requirements of contemporary wireless industry? Any suggestions on this?

2. Besides the topics already covered in our wireless courses, what else do you think important to our CE students if they would like to pursue wireless career?

3. From teaching point of view, do you have any suggestions on the setup of course labs (hardware/software), tests, and projects?

4. In terms of wireless security, are there any new contents you think important to our students?

5. On the two fields, i.e. “wireless communications” and “wireless networks”, do you have any suggestions in terms of teaching emphasis for each of them?