Provost’s Learning Innovations Grant for Faculty

(Project Report)

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Project Title:

Improve Students’ Learning in Pervasive Computing From Both Science and Engineering Perspective

Track #2 Adaptation & Implementation

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1. Achieved Outcomes

We have implemented an undergraduate-education-oriented Pervasive Computing Lab (PCL) and developed two relevant courses. The PCL has important educational elements for both CE/CS undergraduate programs: (1) A human-friendly middleware framework that includes typical Computer Science (CS) education topics such as Data Mining and Java GUI; (2) Computer Engineering (CE) students can learn the integration of typical pervasive networks including high-speed Wireless Local Area Network (WLAN), Ad hoc Networks, and Wireless Sensor Networks (WSN) that are typical examples of Smart Spaces. (3) Security issues in pervasive environments will also be emphasized for both majors. Our PCL lab equipment selection considers the characteristics of the two components in pervasive computing systems:

(1) Equipment for learning Smart Spaces (one of the components of pervasive computing): the Crossbow classroom-oriented MICAz motes (a type of microsensors, see http://www.xbow.com) are a good choice for Smart Spaces training due to their programmable routing/MAC stack in the sensor and the reusable Java-based interfaces. To learn the design principle of sensor networks, students are asked to use Crossbow motes (see Figure 1) to design a small sensor network with required communication performance (such as delay).

(2) Equipment for learning Data Management in Mobile Platforms (the third component of pervasive computing): For this component, we also use Crossbow motes (the same as above) that can be programmed to run distributed database software. We have developed three lab assignments on the application of Cougar tool [1] to the distributed database design in wireless platforms.

Based on the above Pervasive Computing concept, we have developed two courses that (a) appear to make a cohesive sequence, (b) cover the core topics in the benchmark courses, and (c) upper-level undergraduate students in both majors can take them. These courses are listed as follows:

(1) Computer Science seminar course (developed by Dr. Ankur Teredesai): Data Management in Pervasive Computing. This course concentrates on data mining issues and distributed database management in pervasive computing environments.

(2) EECC 615 Principle of Wireless & Mobile Networks (Developed by Dr. Fei Hu and Dr. Marcin Lukowiak). This course examines the principles of current nomadic computing systems including cellular networks & CDMA, ad hoc networks, GPS and wireless LAN. The lab exercises include Physical and MAC design using OPNET.

The target audience is 3rd/4th/5th–year undergraduate students in our CE and CS programs. The above three courses are offered in separate quarters of each academic year.

To exemplify the PCL courses, we have provided our teaching topics on the course “Principle of Wireless & Mobile Networks” as shown in Figure 2. It has covered the most important wireless computing platforms such as ad hoc networks, sensor networks, Bluetooth, wireless Local Area Networks and cellular networks. Our teaching focus is the networking protocols, hardware architecture and Physical layer principles. Thus our students will be able to adapt to current wireless industry environments.
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<thead>
<tr>
<th>Time</th>
<th>Teaching topics</th>
<th>Lab Assignments</th>
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<tbody>
<tr>
<td>Week 1</td>
<td>Introduction to the course; Basic theories on radio transmission characteristics;</td>
<td>Lab 1: OPNET simulation basic wireless link model</td>
</tr>
<tr>
<td>Week 2</td>
<td>Slow fading and fast fading, path loss models; the influence of mobility on receiving radio frequency.</td>
<td></td>
</tr>
<tr>
<td>Week 3</td>
<td>Wireless modulation (BPSK, MSK, etc.), CDMA</td>
<td>Lab 2: OPNET simulation: path loss analysis</td>
</tr>
<tr>
<td>Week 4</td>
<td>Wireless LAN (I) – Architecture &amp; protocol</td>
<td>Lab 3: Cisco WLAN design – PHY/MAC layer analysis</td>
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<tr>
<td>Week 5</td>
<td>Wireless LAN (II) – IEEE 802.11 MAC</td>
<td></td>
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<tr>
<td>Week 6</td>
<td>Ad hoc Networks (1) – architecture; existing routing protocol; Mid-term exam</td>
<td>Lab 4: MANET design – routing protocols (using CAMPAQ iPAQ)</td>
</tr>
<tr>
<td>Week 7</td>
<td>Ad hoc Networks (2) – MAC design; Bluetooth</td>
<td></td>
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<tr>
<td>Week 8</td>
<td>Cellular Networks (1) – cell model, frequency reuse, interference, handoff.</td>
<td></td>
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<tr>
<td>Week 9</td>
<td>Cellular Networks (2) – 2G /3G architecture</td>
<td>Lab 5: Cellular Networks design through OPNET</td>
</tr>
<tr>
<td>Week 10</td>
<td>Satellite networks, GPS; Final Exam Review.</td>
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Figure 2. Teaching Topics of Principle of Wireless & Mobile Networks

2. EDUCATION PERFORMANCE EVALUATION

To evaluate the teaching performance on Pervasive Computing, we have invited two wireless experts from other universities (Dr. Sunil Kumar from Clarkson University and Dr. Wensheng Zhang from Iowa State University) to come to RIT. They freely commented on the following aspects:

- Is the course/lab material appropriate and relevant to the profession?
- Is the material being presented in a logical and cohesive way?
- Is the time and emphasis that is being placed on each topic appropriate?
- Are the experiments/projects/lab equipment appropriate to accomplish the aforementioned two project objectives?

They have provided some important ideas on how to integrated sensor hardware and software education for both CE and CS students. In our offered course, “Principle of Wireless & Mobile Networks”, we have adopted the multi-disciplinary education methodology, i.e. teaching both Computer Engineering and Computer Science topics for two majors. Based on our investigation on the project interests of 60 students (see Figure 3), about one-third of students (most of them coming from Computer Science Department) enjoy building different software applications for Xbow sensors such as Mica2 and Mica2Dot [2]. And 31% students (most of them coming from Computer Engineering Department) like making sensor hardware from some out-of-shelf components (such as microcontroller, memory, radio & antenna, sensor chips and power units). 21% students like OPNET software [3] labs for simulating wireless networks. OPNET is a difficult tool to use since it requires complicated Finite State Machine programming. Only 12% students like ns-2 simulation tool. The reason is that they need to use a stand-alone Unix machine to write the codes. And also ns-2 has some bugs that are not easy to fix.

We have also investigated the students’ learning outcomes in two continuous quarters: Spring 2005 and Summer 2005 in the Networking course. As shown in Figure 4, the students have higher grades in later quarter. This could come from the Pls’ teaching performance improvement since we have learned from previous experiences. Among the four groups of students, the Master Degree students have highest average score, which may be due to their solid
networking foundations during their undergraduate studies. The undergraduate students with co-op\textsuperscript{1} experiences can do the wireless networking labs better than individuals without co-op experiences. We have also used team works to carry out those labs (each team has 2 to 3 students). We have found that students can share experiences and submit better results.

![Pie chart showing student projects choice](image)

**Figure 3. Student projects choice**

![Bar chart showing students' average lab grades](image)

**Figure 4. Students’ average lab grades**

- **Pervasive Computing Lab examples:**

  In the following discussions, we will exemplify our developed multi-disciplinary pervasive computing labs that have attracted the students’ strong interest during our teaching.

**Example 1:** Sensor Network Time Synchronization Labs

Latest advancements in micro-sensor technology have led to the development of low cost and low power sensing devices with computational capabilities and wireless sensing communication capabilities. Time Synchronization is one critical aspect of such sensor networks at many layers of its design. The applications envisioned on such a network mandated collaborative execution of a distributed task amongst a large set of sensor nodes which is realized by exchanging messages that are time stamped using the local clock at the nodes. Thus Time synchronization is an indispensable piece of infrastructure in such systems.

Time Synchronization can either be (1) Sender-Receiver based (Figure 5) or (2) Receiver – Receiver based (Figure 6).

\textsuperscript{1} RIT requires students to obtain 4–5 co-ops during their 5-year undergraduate study. Those co-ops help students get hands-on experiences in their disciplines.
Some sources of clock errors include Sender uncertainty, Receiver uncertainty or Propagation delay. This project assignment is based on Sender-receiver protocol and each team will be provided with one Xbow programming board and two Mica2 wireless motes. As shown in Figure 7, this project includes 5 labs to be finished in one quarter (10 weeks). The last part of the assignment requires the use of a third mica2. This project requires extensive using of TinyOS and NesC programming language.

<table>
<thead>
<tr>
<th>Lab session</th>
<th>Grade</th>
<th>No of Weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. TinyOS Setup &amp; reading</td>
<td>10%</td>
<td>3</td>
</tr>
<tr>
<td>2. Basic Synch</td>
<td>30%</td>
<td>1</td>
</tr>
<tr>
<td>3. Estimate Offset &amp; Drift</td>
<td>60%</td>
<td>3</td>
</tr>
<tr>
<td>4. MAC Layer Time stamping</td>
<td>70%</td>
<td>1</td>
</tr>
<tr>
<td>5. Logging errors and demo</td>
<td>100%</td>
<td>2</td>
</tr>
</tbody>
</table>

This project worked very well during our Networking teaching. Many students felt that they had learned a lot of practical knowledge on wireless sensor networks besides theoretical wireless protocol details.

**Example 2:** Sensor Network Database (TinyDB)

The above example emphasizes more on Computer Engineering experiences through the using of Xbow sensors. To include some Computer Science knowledge into Engineering education (to achieve multi-disciplinary education), we have provided Database education for Engineering students. Figure 8 is our lab hardware setup. It includes a gateway (Xbow PIA board) and three Mica2 nodes (with sensor boards). The sensor can detect light, temperature, smoke and humidity. TinyDB [4] is an important research topic in sensor network database applications. We have built a lab based on TinyDB research results for undergraduate teaching. The students were asked to install Database software in some sensors to collect sensed data from environments. Figure 9 shows the window interface on the
sensor data query results. It is similar to SQL query, i.e. use SELECT language to obtain sensor data from multiple sensors.

The students enjoyed this lab very much. Please see [5] on their lab reports. The second author of this paper has developed Wireless Data Mining course that covers many important topics on sensor data management such as novelty detection from sensor data stream, classification of sensor data based on feature extraction, sensor database organization, etc. The Engineering students have improved their software skills through C/Java programming in this lab. They have also obtained some important Computer Science knowledge such as database management, TinyOS (Operating System for sensor networks), and data mining.

![Figure 8. TinyDB Lab setup](image)

3. Summary

Considering the long term, our CE program is lacking the nomadic computing and smart spaces education resources. The proposed PCL concept provides multiple types of nomadic computing / Smart Spaces platforms with integrated software exploring environment. On the other hand, currently the CS program at RIT has only a basic data communication course and its data management teaching is based on traditional central database systems. The PCL enables our CS students to learn programming methodology in an integrated hardware/software pervasive networking environment. To the best of our knowledge, our PCL is the first attempt to establish a contemporary pervasive computing lab for undergraduate CE/CS teaching. During this project we have put much effort to reproduce our PCL experience at other schools. So far, a handful of universities have shown strong interests in our PCL concepts. For example, the CE department at Clarkson University would like to establish a similar lab for undergraduate teaching.
REFERENCES