Graduate Real-Time and Embedded Systems

Fall 2009

Syllabus and Organization

1. Course Objectives

The primary objectives of this course are to:

- obtain a broad understanding of the technologies and applications for the emerging and exciting domain of real-time systems and embedded wireless networks,
- get in-depth hands-on experience in designing and developing a real operational embedded network system, and
- design and develop foundational systems software, sensor-actuator-controller algorithms and network protocols.

2. Course Overview

The use of distributed wireless sensor networks has surged in popularity in recent years with applications ranging from environmental monitoring, to people- and object-tracking in both cooperative and hostile environments. This course is targeted at understanding and obtaining hands-on experience with the state of the art in such wireless sensor networks which are often composed using relatively inexpensive sensor nodes that have low power consumption, low processing power and bandwidth. The course will span a variety of topics ranging from radio communications, network stack, systems infrastructure including QoS support and energy management, programming paradigms, distributed algorithms and example applications. Some guest lectures may be given.

Each discussion-oriented lecture will be preceded by the reading of 1-2 papers, resulting in a rich collection of papers by the end of the semester. Early in the semester, hands-on exercises will be used to teach the programming of FireFly sensor nodes by using the 'nano-RK' power-aware sensor real-time operating system (RTOS) and using 802.15.4 radio communications. Then, project groups of no more than 3 students will define, design, implement and test an embedded network project. Final in-class project presentations will be supplemented by a written report. A final exam may be conducted to evaluate the students' understanding of the materials covered. Grading criteria will include classroom participation, course project content and report, quizzes and a final exam.

Prior hands-on experience with network programming, operating systems and assembly language are essential. Exceptions can be made only with the explicit permission of the instructor.

Prerequisites: Programming in C/C++, ESE 350 or equivalent, one course on computer networks and senior or graduate standing.

3. Instructor

Prof. Rahul Mangharam, Assistant Professor of Electrical and Systems Engineering

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4. Classes

- *Days*: Tuesdays and Thursdays
- *Time*: 1:30pm - 3:00pm
- *Place*: 317 Moore

5. Lecture Content

Wireless Embedded Networks
- Introduction
- Applications

Component Technologies
- Sensors
- Physical Layer
- Sensor Platforms
- Link and Routing Protocols

System Infrastructure and Development
- Clock Synchronization
- Power Management
- Security
- Topology Control
- Programming Abstractions
- Storage

Scheduling Theory and Algorithms
- Real-Time Operating Systems
- Fixed Priority and Dynamic Scheduling
- Aperiodic and Sporadic Task Scheduling
- Priority Inversion and Task Synchronization

Applications
- Localization
- Data Dissemination
- Mobility
- Distributed Control

Future Directions

Tentative Lecture Schedule

The tentative lecture schedule is given below. There may be changes due to instructor travel constraints, particularly during the last week of classes.

Week #	Seq #	Lecture #	Date	Topic	Notes
1	1	1	09/10	Course Description	
	2	2	09/15	WSN and Applications	
2			09/17	The FireFly platform	
	3	3	09/22	Projects and Labs Description	Lab #1 Out
3	4	4	09/24	FireFly Platform and nano-RK OS	
	5	5	09/29	Sensor Platforms and Tools	Lab #1 Due; Lab #2 Out
4	6	6	10/01	Sensors	
	7	7	10/06	Physical Layer-1	Lab #2 Due; Lab #3 Out
5	8	8	10/08	Physical Layer-2	Quiz #1
	9	9	10/13	Medium Access Control	
6	10	10	10/15	Routing	Lab #3 Due
	11	11	10/20	Clock Synchronization	
7	12	12	10/22	Power Management	Quiz #2
	13	13	10/27	Sensor Operating Systems	
8	14		10/29	Project Goals & Design – 1	
	15		11/03	Project Goals & Design – 2	Mid-Semester Break Fri
9	16	14	11/05	Fixed Priority Scheduling	
	17	15	11/10	Dynamic Task Scheduling	
10	18	16	11/12	Aperiodic/Sporadic Scheduling	Quiz #3
	19	17	11/17	Task Synchronization	
11	20	18	11/19	Real-Time Operating Systems	
	21	19	11/24	Rea-Time Network Control	
			11/25	* *Thanksgiving Break* *	Enjoy Thanksgiving!
			11/30	* *Thanksgiving Break* *	
12	22	20	12/01	Mobility and Distributed Control	Quiz #4
	23	21	12/03	Sensor Network Applications - Localization	
13	24	22	12/08	Sensor Network Applications – Data Dissemination and Aggregation	
14	25	23	12/10	Sensor Network Simulation	
	26		12/11	Final Project Presentations – 1	
15	27		12/12	Final Project Presentations – 2	
	28	24	12/15		Final Reports Due

6. Reference Books and Materials

Papers and copies of chapters will be made available for required and recommended readings. Expect a big compilation of papers, ranging from 1 to 3 per lecture, by the end of the semester.

Recommended references include:

1. Edgar H. Callaway Jr. and Edgar H. Callaway, "Wireless Sensor Networks: Architectures and

Protocols", Auerbach, ISBN 0849318238, 360 pages, 2003.
2. Jose A. Gutierrez, Edgar H. Callaway and Raymond Barrett, "IEEE 802.15.4 Low-Rate Wireless Personal Area Networks: Enabling Wireless Sensor Networks", IEEE, ISBN 0738135577, 155 pages, 2003.
3. Holger Karl and Andreas Willig, "Protocols and Architectures for Wireless Sensor Networks", John Wiley & Sons, ISBN 0470095105, 526 pages, 2005.
4. Cauligi S. Raghavendra, Krishna M. Sivalingam and Taieb Znati (editors), "Wireless Sensor Networks", Springer, ISBN 1402078838, 442 pages, 2005.
5. Ian Sinclair, "Sensors and Transducers", 3rd Edition, Newnes, ISBN 0750649321, 306 pages, 2001.
6. Jon S. Wilson, "Sensor Technology Handbook", Newnes, ISBN 0750677295, 704 pages, 2004.
7. Feng Zhao and Leonidas Guibas, "Wireless Sensor Networks: An Information Processing Approach", The Morgan Kaufmann Series in Networking, Morgan Kaufmann, ISBN 1558609148, 376 pages, 2004.

7. Grading Criteria

Your final grade for this course will be based on your performance in the course project, class participation, quizzes, assignments and the final exam. The breakup will be as follows:

- Project: 60%
- Lab Assignments: 15%
- Quizzes: 20%
- Lecture Presentation: 0%
- Classroom Participation: 5%

Final grades will be assigned based on the following rules:

- If you score more than 92%, you get an 'A' grade guaranteed.
- If you score more than 82%, you are guaranteed to get at least a 'B' grade.
- If you score more than 72%, you are guaranteed to get at least a 'C' grade.
- If you score less than 72%, you are guaranteed to get some grade, not necessarily good!
- A curve will be fit by discretion of the instructor if a sufficient number of students do not meet the above criteria.

7.1. Project

The **project** will be a group effort with 2-3 members. More information will be provided in the next sections.

7.2. Lab Assignments

There will be **3 lab assignments** in the early part of the semester to help you familiarize yourself with the sensor nodes you will be using for the project. You need to understand how to program them, how to enable communications among them, how to save energy, and how to build applications.

7.3. Quizzes

Quizzes will be in-class and closed-book. Expect 4 quizzes for the semester. The quizzes will be scheduled and are intended to ensure that you have gone through all assigned readings.

8. Course Project

Each project will be done by a team of 2-3 students. Exceptions are available only with the explicit permission of the instructor.

8.1. Goals of Project

The following skills will be learnt during the course of the project:

- Hands-on experience with a wireless sensor network.
- Ability to understand and formulate a design problem in the context of a wireless sensor network.

- Design skills obtained by coming with an implementable design to address the chosen problem.
- Implementation and demonstration of a working solution.
- Evaluation and benchmarking of the performance of the system.
- Documentation and presentation of the problem, design and implementation.

8.2. Project Report

A written team report on the project is expected at the end of the semester along with an online copy of the source code as well. At the end of the semester, each project will be required to make a presentation either in class or in a separate day set explicitly aside for the purpose.

8.3. Project Description

A list of projects to choose from will be made available during the third lecture of the semester. Follow the class bboard for any global announcements or changes on the project. Form a group and pick a project from the list. No project from the list can be picked by more than two groups (i.e. ideally, each group works on a different project).

8.4. Project Groups

As mentioned above, the course project will constitute a significant portion of your course grade. The course project will be performed in groups of 4 students. Any exceptions have to be approved by the instructor. We anticipate that each project group will be given 6 sensor nodes and a sensor node programmer for its use through all project activities. It is the responsibility of each project group to take good care of each sensor node (for example, you need to make sure that pins are not bent out of shape) and return them at the end of the semester.

Note: All members of a project group are *not* guaranteed the same project grade. So, if you have a project member who is not contributing, talk to him/her first. If the situation does not improve, bring it to the attention of your TA and/or the instructor.

9. Laboratory Usage

A portion of **the graduate computer cluster** will be available for use by students taking the course. We hope to make this section of the lab available 24 hours a day. However, since the lab space is shared with one or more other courses, you can expect a significant amount of crowding, particularly near the end of the semester and when assignments/projects are due.

We expect to be able to set aside three 3-hour slots per week during which the graduate computer cluster will be set aside exclusively for use by ESE-680 students. Each group will have access to one Linux workstation. A group may use more than one workstation only if nobody from the other group(s) is present. A reasonable-person principle will be applied at all times.

10. Computer Accounts

The projects will involve programming in C in the graduate computer cluster, or at a place of your convenience. All editing, coding and compiling will be done in the Linux programming environment. (Windows XP is usable but not stable for the needs of the lab. Specifically, you can work with it, but if for some reason, the Windows XP box stops communicating with a sensor node, XP needs to be rebooted). You must have an ESE course account for this course – one will be created if you do not have an ESE account.

11. Announcements

Announcements will be made on https://courseweb.library.upenn.edu. The instructor and the TAs will post announcements regarding the class on this bboard. Check this bboard regularly for clarifications, corrections, and all course-related announcements. If Penn is shutdown due to snow, there will certainly

be no class. Otherwise, it is still possible that your instructor and others are unable to commute to school in the foul weather. Please check the Penn and class bboards in case of more than about 4 inches of snow for class status.

12. Policy on Computer Failures

Computer failures (e.g. server failures, network failures, power outages, etc.) are a fact of life. Plan your project to be able to cope with this degree of uncertainty. Short failures will be considered to be part of the normal course of events. In the case of catastrophic failures (which last more than 12 hours), notify your friendly teaching assistant.

13. Policy on Cheating

I expect that this section on cheating is the only reference to the topic we will have throughout the course. I expect that the students taking the course have the integrity not to cheat. However, to be fair to the vast majority of honest and hard-working students, the University and SEAS's policies on cheating will be rigorously enforced. Simply put, any and all materials that you submit for grading must be your own. For projects, the students *within* a project group are strongly encouraged to interact, discuss and collaborate with each other. There should not be any collaboration on any take-home exams that are given (even within project teams). The goal of this course is for you to obtain hands-on experience in a domain which is still evolving and is generating a lot of excitement in the computer industry, communications industry and the consumer/entertainment world. Hence, discuss the course material with your friends, the TAs and the instructor. Such discussions can be extremely valuable and I encourage it in all aspects of this course other than exams and related team projects. Course Project

Learn a lot and have fun doing it!