1. Applicant:

Name: Mohammad Mostafizur Rahman Mozumdar

Title/Rank: Ph.D. candidate—Expected in December 2009

Department/School: Department of Electronics, Politecnico di Torino

University Address: Corso Duca degli Abruzzi 24, 10129 Torino, Italy.

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2. Title of Proposal: “Development of a framework for monitoring and controlling energy consumption of smart buildings”

3. Amount Requested: $ 55,000 (50,000 + 5,000 for medical insurance) per year for 3 years.

Applicant Agreement:

I agree to abide by the conditions and reporting requirements of ISSNAF

(Mohammad Mostafizur Rahman Mozumdar) 02/09/2009

Applicant’s Signature Date
Development of a framework for monitoring and controlling energy consumption of smart buildings

Summary:
The global energy crisis and green house effects are forcing us to rethink about our energy consumption even in our daily life. Recent studies show that building operation (lighting, heating, ventilation, air-conditioning, etc.) represents a major portion of the total energy consumption in highly developed countries. Controlling these operations effectively can reduce energy consumption from 30% to 50%. In this process, we need to be also concerned about safety, security, privacy, health and comfort constraints of the occupants, in order to maximize operational productivity. In this context, we propose to develop a complete framework to design Wireless Sensor Networks (WSNs) and the supporting IT systems, aimed at effectively monitoring and controlling energy consumption of the buildings. The framework is aimed at filling the gap between the architects and civil engineers who design buildings with their supporting functionalities (lighting, heating, ventilation, air conditioning) and the electronics engineers who design the sensing and actuating infrastructure. It will communicate design intent between these two groups, and provide fast feedback about design decisions to the first group. Prof. Alberto L. Sangiovanni-Vincentelli is one of the leading figures at UC Berkeley and has made multifaceted contributions as a scientist, engineer, entrepreneur and an inspiring teacher. His outstanding research spans different fields (electronic systems, EDA tools, etc.) over several decades. In the last decade, he has been actively working on energy efficient wireless sensor networks systems which are the main focus of my current research activities. That motivates me highly to work under his supervision at UCB. Our proposed framework will be a milestone for reducing building energy consumptions and hence will greatly enrich my knowledge and experience.

Fellowship Applicant:
• Mohammad Mostafizur Rahman Mozumdar, PhD expected December 2009

Research Advisor at University of California, Berkeley
• Prof. Alberto L. Sangiovanni-Vincentelli

Research Advisor at Politecnico di Torino, Italy
• Prof. Luciano Lavagno
Biographical Sketch: Mohammad Mostafizur Rahman Mozumdar

<table>
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<tr>
<th>Nationality:</th>
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<tbody>
<tr>
<td>Date of Birth:</td>
<td>18-02-1978</td>
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<td>Marital Status:</td>
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Research Interests

My research interests are in the domain of embedded system, mainly in wireless sensor networks, including modeling and automated code generation techniques.

Education

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<th>Institution</th>
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<tr>
<td>Politecnico di Torino, Italy</td>
<td>Ph.D. in Electronics and Communications Engineering (expected completion: December 2009)</td>
<td>2009</td>
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<tr>
<td>Aachen Technical University (RWTH), Germany</td>
<td>M.Sc. in Computer Science</td>
<td>2004</td>
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<td>(Grade: Very good/ Sehr gut)</td>
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<tr>
<td>Bangladesh University of Engineering and Technology (BUET), Bangladesh</td>
<td>B.Sc. in Computer Science and Engineering (Grade: 3.49/4.0)</td>
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Doctor of Philosophy

Advisor: Prof. Luciano Lavagno

Showing functional correctness by simulation before implementation, and preserving it by automated code generation, is extremely useful to reduce the development time for an embedded application. This is even more true for wireless sensor networks, since their nodes often provide very rudimentary debugging facilities, and sufficiently large networks for realistic analysis may be expensive to deploy. While model-based design is becoming quite standard for several domains that have similar constraints as wireless sensor networks, such as automotive electronics, there is a lack of tools for this purpose in the WSN world. In order to fill this gap, my thesis describes a framework in which a developer can create sensor network components (both at the application and at the protocol level) that can be used as building blocks to model, simulate and automatically generate code for different underlying platforms and operating systems.
Experiences


**Activities:** Modeling, code generation and hardware-in-the-loop simulation for wireless sensor networks. The activity focuses on a complete design flow, based on Mathworks tools, for model-based design of WSN applications. The goal is fast design of those applications by people who are not necessarily familiar with the intricacies of radio transmission, protocol optimization, and embedded processor programming.


**Activities:** Implementation of a body sensor network framework on the ZigBee platform.

October 2005 – December 2006: *Assistant Professor*, Department of Computer Science, American International University Bangladesh (AIUB), Dhaka, Bangladesh.

**Activities:** Teaching courses at under graduate level, supervising theses and counseling students.

June 2005 – August 2005: *Senior Lecturer*, Department of Computer Science and Engineering, United International University, Dhaka, Bangladesh.

**Activities:** Teaching courses at under graduate level, supervising theses and counseling students.


**Activities:** Development of graphical user interface and library for scientific software which enables FE-based tooth contact analysis of cylindrical gears for automobiles.

December 2001 – August 2002: *Senior Software Engineer*, Bangladesh Japan Information Technology (BJIT), Dhaka, Bangladesh.

**Activities:** Worked on different phases of software development, such as requirement analysis, system design, coding and afterwards as a team leader.
Research Publications

Book Chapter:


Articles:


Conference Publications:

1) “Platform Independent Modeling for Hardware In the Loop Simulation and Automatic Code Generation of ZigBee and TinyOS Application” (on submission)
2) “Multi-modal simulation and code generation framework for WSN applications development” (on submission)
4) M.M.R. Mozumdar, F. Gregoretti, L. Lavagno, L. Vanzago, "Porting application between wireless sensor network software platforms: TinyOS, MANTIS and...


**Poster/Demonstration/talk:**

- Demo/Poster: M.M.R. Mozumdar, A. Al-Khateeb, L. Lavagno, L. Vanzago ,"Modeling, hardware in the loop simulation and code generation for wireless sensor networks based on ZigBee and TinyOS platforms" at DATE 2009, Nice, France, April, 2009

- Talk: "Behavior Simulation and Functional Verification of WSN Application" in ARTIST Workshop on Tool Platforms for Embedded systems, Berlin, Germany, July, 2007

Invited Speaker


Teaching Experience

- Embedded System, Politecnico di Torino, Italy (with Prof. Luciano Lavagno)
- Lab on Micro-electronics, Politecnico di Torino, Italy (with Prof. Luciano Lavagno)
- Theory of Computation, American International University, Dhaka, Bangladesh
- System Programming (with Lab), American International University, Dhaka, Bangladesh
- Object Oriented Programming (with Lab), American International University, Dhaka, Bangladesh
- Programming Language – C (with Lab), American International University, Dhaka, Bangladesh
- Internet Security, American International University, Dhaka, Bangladesh
- Data Structure, United International University, Dhaka, Bangladesh
- Client Server Technology, United International University, Dhaka, Bangladesh

Professional Service

Reviewer:

- ACM Transactions in Embedded Computing Systems (ACM TECS)
- ACM Transactions on Sensor Networks (ACM TOSN)
- The Fourth International Conference on Systems and Networks Communications (ICSNC 2009)

Technical Program Committee:

- The Fourth International Conference on Systems and Networks Communications (ICSNC 2009)
Memberships:

- IEEE

Organizational skills:

- Elected as PhD student representative (2009) for doctorate school of Politecnico di Torino, Italy

Computer skills and Competences

Operating Systems:

- Linux, Windows

Programming Languages:

- TinyOS, MANTIS, ZigBee (Ember), C, C++, Matlab, Java, Visual Basic, Pascal, Assembly programming

Other language & Tools:

- Simulink, Stateflow, Real Time Workshop (Embedded Coder), TLC script, C-Shell scripts, LaTeX, Drawing tools i.e. Visio and Microsoft office tools, UML, XML, LISA processor design tool, etc.

References

1. Prof. Luciano Lavagno (Advisor), Politecnico di Torino, Italy. Email: luciano.lavagno@polito.it
2. Laura Vanzago (Advisor), STMicroelectronics, Milan, Italy Email: laura.vanzago@st.com
3. Prof. Francesco Gregoretti, Politecnico di Torino, Italy, Email: francesco.gregoretti@polito.it
Research Plan

Specific Aims:

This research project focuses on minimizing building energy usage and lifecycle costs within strict safety, security, privacy, health and comfort constraints, while maximizing operational productivity, i.e., the engineering of adaptively optimal buildings.

To achieve the goals of the project, information technology coupled with Wireless Sensor Network technology will provide an effective and robust solution for designing future smart buildings. Recent breakthroughs in wireless sensor network and MEMS technology will permit highly flexible location of sensors and actuators, including an increased density and variety of sensor types, informing more comprehensive control systems. The framework will have at least three major aspects:

- **A GUI for designing sensor networks for smart buildings:** It will facilitate the users to deploy sensors using standard 2D/3D (floor/whole building) architectural models, in order to cover the desired locations of the buildings and form an effective and economical sensor network.

- **Modeling, simulation and code generation tools:** This tool will allow users to develop sensor network applications that will run on virtual nodes (deployed using the above mentioned GUI) and then automatically generate code for the target sensor platforms.

- **IT system to monitor/control the energy consumption units:** A control loop IT system will involve scheduling of activation of energy consumption, as well as of energy sources (e.g. solar panels on roof), in cooperation with energy providers. The system will provide information, based on the data collected from the sensors, smart meters, about energy consumptions of the buildings and ultimately allow the users to control the energy consumption using this infrastructure.

Background and Significance:

Two-thirds of primary energy use in the US is electrical and about two-thirds of all electric power is used in buildings [Inter-laboratory Working Group, 2000]. In commercial buildings, heating, ventilation, and air-conditioning (HVAC) consumes approximately 28% of the total energy, followed by interior lighting at 25%. In residential buildings, space heating and cooling have the highest energy consumption at 43%, followed by miscellaneous use at 16%, and water heating at 14%. Reducing energy use in buildings has become a problem of great importance.

The major objectives of a building control system are to minimize energy use and to maintain occupant comfort. The state-of-the-art in building control has greatly advanced in recent years. For example, pneumatic controls are being replaced by digital ones, and energy management and control systems (EMCS) now are increasingly used to monitor and manage HVAC systems in large commercial buildings. The form of building controls
has been changed, but the control functions are still rudimentary, with on/off, proportional, integral, and derivative (PID) feedback control methods still being dominant. Occupants’ comfort is not directly considered in building operation, although occupant complaints reduce work productivity and increase maintenance costs. Hence researchers are now focusing on sensor networks in order to design energy efficient smart buildings (Byoung-Kug 2008, O'Flynn 2008, Vincent 2006, Michael 2005).

In the last decade, the landscape of wireless sensor network (WSN) applications has been extending rapidly in many fields such as factory and building automation, environmental monitoring, security systems and in a wide variety of commercial and military areas. Advancements in microelectro-mechanical systems and wireless communication have motivated the development of small and low power sensors, actuators and radio equipped modules which are now replacing traditional wired sensor systems. These tiny modules usually called “motes” can communicate with each other by radio and act like as neurons to collect information from the environment.

Wireless sensors nodes can reduce energy consumption of the building by collecting data about different energy consuming components or environmental parameters (light, temperature, humidity and so on) and then calibrating them either autonomously or by using feedback from the occupants. Moreover, since the network is based on wireless communication, no wiring is required and the nodes can be both deployed and (if needed) relocated with dramatically reduced costs.

**Preliminary Studies:**

Large sensor networks with hundreds to thousands of nodes may need to be employed for commercial buildings. In a densely covered sensor network, local variation of the measured data among nodes is often low, thus its individual transmitting would lead to a significant waste of energy. Using a clustering topology (L. Necchi et al. 2007, A. Bonivento et al. 2005, H. Cam et al. 2003) is a popular approach, in which the sensor network is partitioned into several clusters to collect data. In clustered topologies, one or more nodes collect data from all the rest (called data aggregation) and then perform same computations (e.g. average, standard deviation, gradient) based on the collected data, prepare a single packet and send it to the network sink. Instead of routing each data packet from the nodes, a single summarized data packet is transmitted for the cluster, thus reducing network traffic load and ultimately saving energy.

We proposed a robust and efficient data aggregation algorithm (M.M.R. Mozumdar et al. 2008(a), 2010) to select a cluster leader that will perform data aggregation in a partially connected sensor network. The algorithm reduces the traffic flow inside the network by also adaptively selecting the shortest route for packet routing to the cluster leader.

Application development for WSNs is quite challenging, because in principle it would require detailed knowledge both of the application area and of the available hardware and software platforms. Moreover, design aids, in the form of functional simulation, power
and performance analysis and on-target debugging are still very rudimentary. Many hardware and software platforms include only LEDs as a debugging aid.

In order to solve these problems, we proposed and developed a framework by which application developers can model WSN application by using high level abstractions, and simulate them using configurable and realistic topologies of the network. Then we used this high level abstraction to automatically generate code for several target operating systems (TinyOS, MANTIS and ZigBee). This framework for modeling, simulation and automatic code generation of WSN applications is based on MathWorks tools and has been described in (M.M.R. Mozumdar et al. 2008 (b, c), 2009 (a, b, c)). To the best of our knowledge, this is the first time that a framework of this sort has been developed and tested for the WSN application domain.

Research Design and Methods:

To achieve the objectives of this project, we propose several steps that need to be followed and several tools and IT systems that need to be developed. The steps are shortly described in the following.

Step 1: Designing sensor networks for smart buildings

![Figure 1: A graphical user interface to design sensor networks of smart building (being developed at Politecnico di Torino)](image)

The first tool that is needed to facilitate fast design of sensor networks for energy efficient buildings is a graphical user interface (GUI) with which the designer, who will most likely not be an electronics engineer but rather an architect or a civil engineer, will be able to place sensors at different locations of the building and then check several Quality of Service and cost parameters, without physically creating the network. This tool will take a floor plan as an input (in one of the civil engineering standard formats). Then the user will need to specify some simple parameters for the radio/channel model (such as...
TX/RX power and gain, SYS loss, loss of wall dB/cm, etc), which have a direct impact on the cost of each node. Figure 1 shows a simple demonstration of a precursor to such a GUI (which is under development at Politecnico di Torino).

**Step 2: Designed sensor networks simulation for application development**

After placing sensors to cover the desired areas of the building, the next step is to develop the applications that will run on the nodes. Functional verification of these applications is challenging, because most of the available sensor nodes on the market (such as MicaZ, TelosB, Tmote Sky, etc.) provide very limited debug aids. This makes code development on the actual platform virtually impossible. Even if better debugging aids were provided (similar to those provided by a state-of-the-art in-circuit emulator), there would still be the need of a simulator to model networks with many nodes.

![Diagram](image)

**Figure 2: A high level view of the modeling, simulation and multi-platforms code generation**

The available functional analysis packages, such as TOSSIM for debugging of TinyOS application, OmNet and NS, fall into two main categories. One is very platform- and OS-specific (such as TOSSIM), and provides essentially a binary API to model the OS and the motes, with limited facilities for re-using existing channel models, tracing, collecting statistics and so on. The other are generic network simulators (such as OmNet, NS, etc.), sometimes enhanced with models tailored to the radios and channels used by WSNs. Both have significant drawbacks when it comes to complex application development. The first group makes it virtually impossible to port an application to a different platform. The second group still leaves a lot of detailed platform-dependent code to be developed and debugged. Integrated use of a network simulator followed by a platform simulator is the most commonly used path, but still requires one to port code between a number of environments. Moreover, in case a bug is found at the end, one has to resort to led-based debugging, which is extremely time-consuming.
In order to solve these problems, we propose to build a design framework for smart building sensing applications development. Users will be able to model the application using high level abstractions, and simulate it using configurable and realistic topologies for the network itself. Then the users will be able to automatically generate code for several WSN target operating systems. A high level view of the whole framework is depicted in figure 2.

**Step 3: Deployment of sensors**

After modeling and simulating sensor applications by using the proposed framework, we can now automatically generate code for the target platform (node HW, protocol stack and operating system). After loading the binaries into the sensor nodes, now the deployment engineer can use the layout print for each floor and place the sensor nodes at the specified locations.

**Step 4: IT system to monitor/control the energy consumption units**

![Figure 3: A schematic view of the initial IT framework for energy efficient smart building](image)

This system will provide advanced control of different energy consuming operations, implementing a standard protocol such as BACNet (Building Automation and Control Networks) to communicate between different entities. This system will be designed with the capabilities to discover the best power pricing and time to activate various services, as well as interact with the building users to ensure comfort and so on. The system must have automated diagnostic features to detect problems (for example related to HVAC or lighting) and report them to the concerned entities. As the first step, a simplified system (shown in the figure 3) can be built, including a data logging server that collects data from the sensor network and provides web services by which occupants or administrators can monitor the energy consumption remotely and can provide direct feedback to control building operation.
Bibliography:

Inter-laboratory Working Group. “Scenarios for a Clean Energy Future (Oak Ridge, TN; Oak Ridge National Laboratory and Berkeley, CA; Lawrence Berkeley National Laboratory)”; ORNL/CON-476 and LBNL-44029, November, Chapter 4., 2000


M.M.R. Mozumdar, F. Gregoretti, L. Lavagno, L. Vanzago, “An algorithm for selecting the cluster leader in a partially connected sensor network” The Third International Conference on Systems and Networks Communications, Sliema, Malta on October 26-31, 2008 (a)


M.M.R. Mozumdar, F. Gregoretti, L. Lavagno, L. Vanzago, "Porting application between wireless sensor network software platforms: TinyOS, MANTIS and ZigBee" at 13th IEEE International Conference on Emerging Technologies and Factory Automation, Hamburg, Germany, September 15-18, 2008 (c)


