Prototyping Energy Harvesting Active Networked Tags: Phase II MICA Mote-based Devices

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ABSTRACT

With the convergence of ultra-low-power communications and energy-harvesting technologies, networking self-sustainable ubiquitous devices is becoming practical. Hence, we have been recently developing new devices referred to as *Energy Harvesting Active Networked Tags (EnHANTs)*. These small, flexible, and energetically self-reliant tags can be seen as a new class of devices in the domain between RFIDs and sensor networks. EnHANTs are made possible by the advances in ultra-low-power ultra-wideband (UWB) communications and in organic semiconductor-based energy harvesting materials. They will enable novel tracking applications, such as continuous monitoring of objects and locating misplaced items. In this demo we present Phase II EnHANT prototypes. Phase II prototypes are based on MICA2 motes integrated with an *energy sensing module* and an *energy harvesting module*. The prototypes base their communication decisions on the parameters of their energy modules, thus demonstrating *energy harvesting-adaptive communications*. A custom monitoring system is used to interactively demonstrate prototypes' adjustments to environmental energy availability conditions.

Keywords

Energy harvesting, energy adaptive networking, ultra-low-power communications, active tags, indoor light.

1. INTRODUCTION

Energy Harvesting Active Networked Tags (EnHANTs) belong to the domain between RFIDs and sensor networks [12]. Small, flexible, and energetically self-reliant, EnHANTs will be attached to objects that are traditionally not networked, such as books, furniture, walls, doors, toys, keys, produce, and clothing. In their capacity as *active tags*, EnHANTs will enable ubiquitous networking of commonplace objects, and thus will provide the infrastructure for novel tracking applications, such as locating misplaced items, continuous monitoring of objects, and determining locations of disaster survivors. Recent advances in ultra-low-power circuit design, ultra-wideband (UWB) wireless communications [7], and organic energy harvesting techniques will enable the realization of EnHANTs in the near future. Additional information about the EnHANTs project is available at [2].

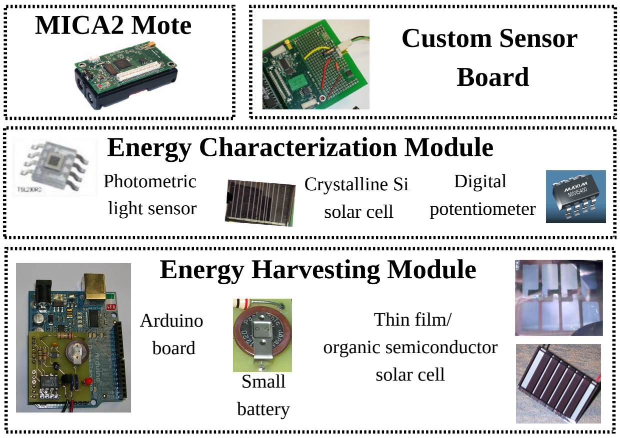

Figure 1: Components of Phase II EnHANT prototype.

One of the key enabling technologies for EnHANTs is energy harvesting, which allows perpetual operation of devices and has recently attracted attention from industry [3–5] and academia [8, 9, 14–20]. In traditional battery-based communications, the devices minimize energy spending to extend network lifetime. With energy harvesting, rather than minimizing energy consumption, the devices optimize the energy spending according to environmental conditions. The adjustments of energy spending in energy-harvesting systems can be done, for example, by varying devices' duty cycles [15, 19], activation patterns [16], or data collection rates [8, 17]. Current sensor networking research on radiant energy harvesting mostly focuses on outdoor Solar energy. Since we expect many EnHANT applications to function indoors, the EnHANT research focuses on harvesting *indoor radiant (light) energy*. As part of our research activities, we

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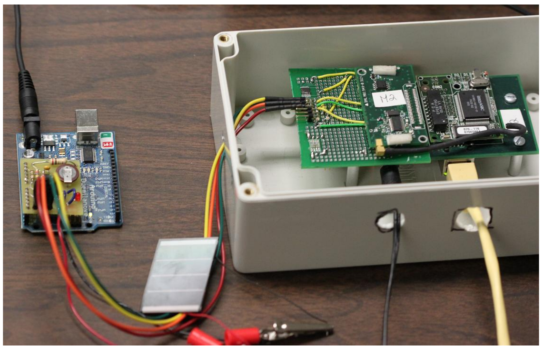

Figure 2: Phase II EnHANT prototype attached to an MIB600 programming board.

characterize and examine indoor light energy [11]. We have collected and made available an extensive set of long-term indoor radiant energy measurements [2].

In this demo we present Phase II EnHANT prototypes.[1] The hardware components of current prototypes are shown schematically in Fig. 1, and a sample prototype in shown in Fig. 2. In this demo we show how the EnHANT prototypes adapt their communication patterns to the energy they are harvesting from the environment. A particular challenge in energy harvesting-adaptive communications of ultra-low-power devices is the tight dependency between energy spending rates of the communicating devices [12]. We demonstrate EnHANT prototypes exchanging information about their energy states, and making *joint decisions* on their communication patterns based on the exchanged energy parameters.

2. SYSTEM DESCRIPTION

The Phase II prototypes presented in this demo are implemented using MICA2 (MPR400) motes [1] and custom-designed sensor boards. The prototypes rely on TinyOS operating system. A custom Fennec Fox platform, running on top of TinyOS, is used to aid in integration of novel hardware components.

Phase II prototypes are integrated with an *energy harvesting module (EHM)*. The EHM contains a *thin film solar cell*, a small battery, and an LED. The thin film solar cell in the EHM is either a commercial thin film solar cell (amorphous silicon-based), or an organic semiconductor-based solar cell developed in-house [6, 13]. The solar cells are charging the EHM's small battery. The battery is discharged by flashing an LED. When the prototype's transceiver generates and sends out a wireless message, we flash the EHM's LED, which reduces the energy level in the battery. Through the logic implemented in the EHM, the EnHANT prototypes determine the level of energy being harvested, as well as the battery energy storage level. When communicating, the prototypes exchange their identifiers and their energy harvesting-related parameters, and determine the communication rates in accordance to their energy states, demonstrating *energy harvesting adaptive communications*.

[1] Phase I prototypes were presented in [10].

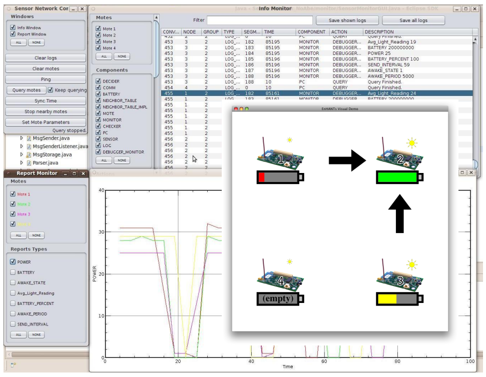

Figure 3: Sample screenshot of the monitoring system user interface.

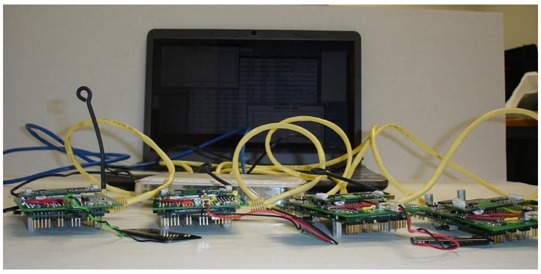

Figure 4: Four phase II EnHANT prototypes placed on programming boards connected through an Ethernet switch to a computer running the graphical monitoring system.

To easily configure the prototypes' parameters and to track their behavior, we have developed a custom monitoring and control system with a Java-based graphical user interface. This monitoring system includes a set of 'live' graphs that are used to demonstrate the changes in nodes' communication parameters and energy states. A sample screenshot of the graphical user interface is shown in Fig. 3. The monitoring system is used to track the parameters of the nodes that are placed on programming boards. Custom sensor boards we have designed allow using radiant energy-related hardware components with the prototypes in this configuration. Since the changes in the parameters of prototypes placed on programming boards can be displayed in the graphical user interface with a very short delay, this setup allows for an interactive demonstration of energy harvesting-adaptive EnHANT communications.

3. DEMONSTRATION

In this interactive demo we show several Phase II EnHANT prototypes communicating with each other. The prototypes determine how much power their solar cells are generating, and how much energy their EHM battery contains.

Based on that, the prototypes determine their communication parameters (data rates and sleep/wake cycles). In order for the demo participants to be able to quickly observe the changes in the communication parameters, the nodes are placed on MIB600 programming boards that are connected via an Ethernet switch to a computer running the monitoring system. The demo setup is show in Fig. 4.

Demo participants can change the environmental energy the devices receive by reducing or increasing the amount of light shining on the solar cells. The online monitoring system displays a set of graphs that represent the states of various prototype parameters, such as communication rates. When changing the radiant energy levels, demo participants can observe how the changes in the environmental energy availability change the power generated by the prototype's solar cell, and influence the prototype communication patterns. Demo participants can also observe how the changes in the energy available to a node influence the communication patterns of the other nodes communicating with it.

4. ACKNOWLEDGMENTS

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