The Design and Implementation of Smart Sensor-based Home Networks

Changsu Suh, Young-Bae Ko† , Cheul-Hee Lee and Hyung-Joon Kim

R & D Departments, Hanback Electronics Company, Daejeon, Republic of Korea
† College of Information & Communication, Ajou University, Suwon, Republic of Korea
{scs, chlee, hanhyul}@hanback.co.kr and youngko@ajou.ac.kr†

Abstract. Recently, advancements of the wireless communication and micro electronic technologies enable the inter-connection between devices and automatic operations within the home areas. Additionally, sensing physical information based on the wireless sensor device helps more intelligent services to incorporate the ubiquitous paradigm into the home networks. In this paper, we address the new smart device with the various sensing ability as well as the wireless communication in order to implement the real ubiquitous house. Moreover, we suggest the new intelligent home scenarios based on the new devices and embedded systems. To show the realistic of our works, we develop a small model house by using our smart devices, RFID and embedded devices. Our works can be contributed the developing of the ubiquitous computing and the real implementations for home networks.

Keywords. Ubiquitous House, Intelligent Home Services, Wireless Sensor Networks, Embedded System

1 Introduction

With the advancements of MEMS (Micro Electro Mechanical Systems) technology, the ubiquitous paradigm [1] can be incorporated to home networks and it is becoming the attractive research issues in the industry areas. To provide more intelligent services, home networks need the new smart devices which have processing and wireless networking abilities. The smart devises are operated with general home equipments, and this collaboration has lead to a new trend to close the ubiquitous systems beyond the wired home networks.

In order to provide more intelligent home services, the physical environments sensing information is demanded. Recently, as the part of ubiquitous networks, wireless sensor networks is populated and issued to perceive physical sensing information [2]. The wireless sensor networks is the collection of smart sensors or RFID, which can self-organize and co-ordinate among each other to gather and transmit sensed data such as temperature, pressure, humidity and photo etc. This technology can be combined into home network areas for making the home services more advances. For example, light sensing information can help to develop the automatic movement of

† This research was in part supported by Ubiquitous Autonomic Computing and Network Project, IT Foreign Specialist Inviting Program.

curtain according to amount of light in the home. Temperature and humidity sensor can provide the intelligent air condition system and helps the development of the smart music players [3].

In this paper, we introduce the new smart sensor devices with processing and networking as well as various sensing abilities for the ubiquitous home networks. The sensor nodes establish the wireless networks and can be controlled by remote embedded systems. By using these devices, we implement a real ubiquitous model house where the intelligent services are operated based on the wireless sensor networks. The main purposes of the model house are:

- The wireless home network is established by the smart devices that are equipped to electronic households.
- These equipments are centrally controlled by the remote embedded system
- The control system is easily used by inhabitant
- Defining control packet formats between control system and smart sensors.
- Providing intelligent house operations based on the wireless sensor networks
  - Movement detecting sensor manages the door-lock systems.
  - Gas sensor prevents the explosion.
  - Actuator sensors control the TV, refrigerator and electronic lamp.
  - Weather information affects the curtain movements.
  - Magnetic sensor detects the window's open/close states.
  - RFID system is combined into home networks

Our paper addresses not only the new smart sensor device and additional modules but also the intelligent home operation. The contributions of our works are as follows: First, we suggest the new paradigm as the ubiquitous house based on wireless sensor networks. Second, we show various intelligent home services with physical sensing information. Third, we implement the new smart device, a real ubiquitous house models and easy home controller system.

The rest of paper is organized four sections. In the section 2, we show the recent researches about home network related our works. Section 3 introduces the new wireless sensor devices and additional sensing modules. Section 4 presents intelligent home services and the implementation of a real house models. Finally, we conclude this paper and describe our future works in section 5.

2 Related Works

There are many projects and researches proposed for the intelligent environments of the ubiquitous home networks. In this section, we briefly survey them.

The MavHome Project [4, 5] is focused on the research of intelligent agents in the smart home environments. The project suggests the role of prediction algorithms based on the inhabitant actions in order to automatically perform repetitive tasks for the inhabitant. The MavHome architecture is designed with modular components and has four cooperating layers: The decision layer, information layer, communication and physical layer. The role of perception is processed from bottom to up layer. The Georgia Tech Aware Home project [6, 7] focuses on the location services of inhabitant and activity recognition within an actual house. The project is developing the multi-camera tracking, audio/video sensors and automated separation of sound sources etc. The AIRE project [8] at the MIT AI Lab studies the pervasive computing designs and people centric applications. The project has constructed "AIRE spaces" such as an intelligent conference rooms, smart workspaces and offices. The Neural Network House [9] applies concepts of a neural network to control heating, lighting, ventilation, and water temperature for minimizing operating cost in the home. Edwards et al. [10] suggests seven challenges from the technical, social, and pragmatic domains for the ubiquitous environment.

We address the home network researches mainly based on the physical sensing information. Sival et al. [11] utilizes the pressure-based floor sensors for achieving more efficient retrieval and summarization of video and audio data. Pressure floor sensor detects the person's movement, and the information is analyzed to index the video and audio. It shows the efficient multimedia processing as a movement pattern of human. Mori et al. [12] suggests the ubiquitous sensing room equipped with cameras, various sensors and RFID to measure natural daily human behavior. Considering the distributed sensor management, it divides sensor modules into three types and constructs four-layer architectures. Yamazaki [13] has built the ubiquitous home as a real-life testbed. It is equipped with several cameras, microphones, RFID and various type sensors. Moreover, he has suggested a new database system and communication middleware for management of the ubiquitous home. Stankovic et al. [14] proposes the new wireless sensor network architecture and challenge issues for providing the healthcare application in the home environments.

Comparing with previous researches, our home network architecture is unique. In our ubiquitous house, home services and electronic equipments are controlled by smart sensor devices. It makes home networks configuration and management more convenient and comfortable. In our architecture, various ubiquitous scenarios and operations can be easily developed and controlled on the wireless sensor networks.

3 ZigbeX: A New Smart Sensor Device

In this chapter, we introduce the new smart sensor device which has sensing, processing and networking capabilities. Since it is operated with a battery (AA) for the portability, we carefully design to consider low power consumptions. It can basically sense the physical photo (light), temperature and humidity. However, we think these sensing abilities are not sufficient for the ubiquitous house environments. So, we develop the additional sensing boards have the air pressure sensor, acceleration sensor, gas sensor and motion detection sensor. Moreover, to control the general electronic householders, we design actuator board as an electronic switch. The additional boards are equipped and controlled by our smart sensor devices. In the following subsections, we describe the detail hardware architectures and characteristics of new smart devices and additional boards.

3.1 Basic Features of Zigbex

We develop the new smart sensor device for ubiquitous home networks. We call the smart sensor as ZigbeX [17]. It is equipped with a low power microprocessor (Atmega 128 [18]) and narrow-band RF device (CC2420 radio transceiver [19]) which can support a physical ability of IEEE 802.15.4 standard [24]. Its size is 40mm x 70mm and its power is supplied by two 1.5V AA batteries. To extend additional hardware, the ZigbeX has the 50 pin connector which is directly matched to the atmega 128 microprocessor. Communication with a host computer or laptop is possible through a serial cable or parallel cable. The ZigbeX sensor node utilizes TinyOS [20] as the operating system. TinyOS was developed at U.C. Berkeley and can be optimized to wireless sensor embedded systems. Numerous applications and programs such as TinyDB [25], B-MAC [26], S-MAC [27] and Surge are developed on the TinyOS, and most of them can be operated on our smart devices. Fig. 1 shows the picture of ZigbeX sensor node and its block diagram.

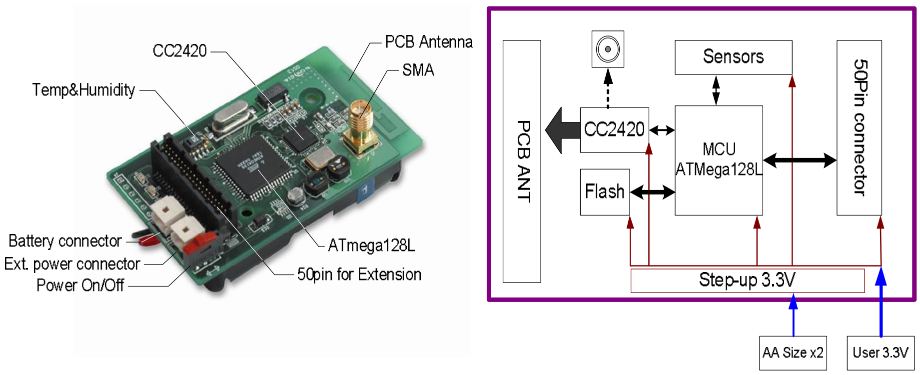

Fig. 1. Picture of the ZigbeX sensor node and its block diagram

Atmega 128 CPU used in ZigbeX is low power AVR 8 bit Micro controller. It can support the maximum 8MHz clock and have 133 command and 32 registers. The CPU includes 128K bytes ISP flash memory and 4K bytes EEPROM. To communicate with other computer, atmega 128 provides the JTAG and UART interfaces.

CC2420 of Chipcon Inc is the RF radio transceiver of the ZigbeX sensor node. CC2420 is operated from 2.4 ~ 2.483 GHz frequency and has 16 different channels. Its modulation scheme is DSSS and maximum data rate is 250 kbps. Inverted F-type PCB antenna is used for CC2420 and its range is 75 ~ 100m in outdoor and 20 ~ 30 m in door respectively. ZigbeX's power supply is the MAX1678 converter [21]. Power level should be from 2.7V to 3.6 V which is supplied by AA size batteries.

In the ZigbeX, three type sensors are basically included: The photo (light) sensor, temperature and humidity sensor. The CdS [22] is the photo sensor of the ZigbeX. Since its resistance value is changed by amount of light, we can detect the light information as the change of regular voltage which runs through the photo sensor. The output analog signal of CdS is transmitted to ADC port of CPU and it is changed to the digital signal. It is operated between -30 ~ 70 C and its response time is 20 ~ 30 ms. We select the SHT11 of Sensirion Ins [23] as temperature & humidity sensor. SHT11 can simultaneously sense these two types of physical information and it can change the output analog signal to digital signal itself. SHT11 is connected with CPU by 2-wire serial interface and it transmits the 14 bits-digital sensing values to CPU. Table 1 shows the platform summary of ZigbeX.

Table 1. The platform summary of ZigbeX sensor node.

Type	Device	Description
CPU	Atmega128L	8 Mhz
RF Transceiver	CC2420	250 Kbps
Antenna	PCB antenna	20 ~ 100m
Flash Memory	AT45DB041B	512 Kbytes
Power	AAx2	3.3 V
Basic Sensor	CdS	Photo (light) sensor
	SHT11	Temp. & humi. sensor

3.2 Additional Features of ZigeX

To perceive more various physical information, we develop the additional sensor boards equipped with the ZigbeX node. They are connected to 50 pin connector of ZigbeX and are directly controlled by the Atmega 128 microprocessor. There are three type additional boards: The first is weather board for sensing more detail atmosphere conditions within a house. The second is motion detecting boards for tracking the person movements. The last is actuator board which can control electronic devices. These additional sensor boards are managed by ZigbeX sensor nodes, and their program libraries have been developed on the TinyOS.

The weather board can sense five types physical information: temperature & humidity, air press, infrared light and acceleration. The temperature & humidity sensor is same as the basic sensor of ZigbeX, but it can increase the sensitivity of atmosphere condition. Our air pressure sensor has the range from 10 mbar to 1100 mbar and its accuracy is affected by temperature. It has functions of analog signal to digital signal convector (ADC). Infrared sensor can sense an ambient infrared and light which is used to compensate the infrared value. It also has the ADC function. Accelerometer can detect a vibration of the sensor node. It has the X/Y axis and its output is analog signal.

The home board supports the motion detection function. It is activated when a person walks or moves. It can be applied to the automatic service based person movements or home security systems, and its output is analog signal.

The actuator board has no sensing ability, but it can operate as switch for control electronic householders. In this board, two relay switches are equipped. This board can help to manage various operations and services in the ubiquitous house. By this actuator board, the role of sensor devices can be changed from just physical information detector to electronic device controller.

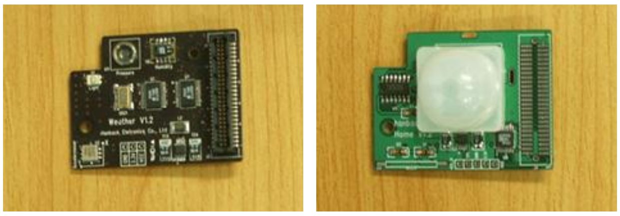

Fig. 2. Additional weather and home boards

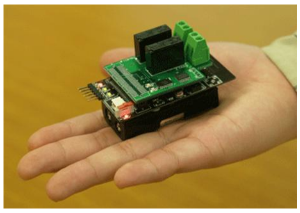

Fig. 3. Additional actuator board on the ZigbeX

Fig. 2 and 3 show three type additional sensor boards. In order to reduce energy consumption, each sensor's power is enabled by the analog power switch when CPU wants to get the physical information from sensor. Three additional boards are controlled by the I2C, DATA line or signal pulse of CPU.

4 A Design of ZigbeX based Ubiquitous Home Network

One of the goals in this paper is to propose the new ubiquitous home services which make inhabitants more comfortable and house environments more intelligent. These home operations are designed based on the wireless sensor networks and are managed by the home control system. In this section, we present the ZigbeX based ubiquitous home network. First, we discuss the wireless home network system and smart sensor based intelligent home scenarios. Then, we describe the implementation of a small model house and control system.

4.1 ZigbeX based Home Network System

Our notion of home networks is operated based on the wireless sensor networks. Sensor nodes are equipped to several electronic devices and can control their operation. Therefore, in our home architecture, we can say that the wireless network between sensor nodes influences whole home devices and can represent as the ubiquitous home network. There have been proposed many researches related to sensor network managements [15, 16]. These networks technologies can be applied to our home network architecture because our system utilizes the wireless sensor devices as home network devices. Optimizing the wireless sensor technology to the home networks is our future works, but since we develop the ZigbeX sensor nodes on the TinyOS, many protocols included in the TinyOS can be directly utilized to our home network system.

The smart sensor nodes can be automatically operated in the home areas. Nevertheless, there need a centric controller system to manage the whole home operations. The system may have a good processing ability, large memory space, wired power supply and internet connection. We develop the home control embedded system can communicate with ZigbeX sensor nodes and manage our whole home networks. In order to easily control the system by inhabitants, we equipped the touch screen panel. More detail specification of the control system will be described in the 4.3 subsection. For communications between home network and control system, command packet and its format should be defined. We designed 12 command packets according to the ZigbeX sensor types. The command packets are distinguished into three types: action command, get data command and event command. The action command instructs some specific actions to the sensors. The get data command is used to perceive the physical information on the specific sensors. The event command is utilized to inform some specific events such as detecting person or detecting gas. All packets include sensor node ID and packet sequence number to identify the packet.

4.2 Intelligent operation scenario with the proposed system

In this subsection, we introduce several intelligent operations based on the ZigbeX sensor nodes for the ubiquitous home networks. These operations are following

- The door-lock systems: Movement detecting sensor is deployed in front of the door. When it detects the some person's movement, the sensor node transmits the event command packet to the home control system by using its RF transceiver. In order to confirm the person's identification, control system transmits the get data command to image camera device and RFID reader which are located near the door. After receiving data from two devices, the control system decides whether door opens or not. Upon deciding an open action, it transmits the action command to actuator sensor nodes equipped to the door.
- Gas detecting system: To prevent the gas explosion, gas sensor periodically checks the amount of gas in the atmosphere and reports the values to home control system. If detecting a large amount of gas, the gas sensor immediately turns off a gas valve without the action command from home control system. In this situation, since it is no wait time to communicate with control system, gas sensor decides its operation itself and confirms the situation to the control system
- Control TV, refrigerator and outlet: If a smart sensor node can be equipped to any device, the home network can really become the ubiquitous system. However, it is very difficult to equip sensor to all home devices. So, we select the TV, refrigerator and outlet as representative electronic devices. By using actua-

tor board, home control system can manage these devices according to the ubiquitous scenarios.

- The curtain movements: Weather information affects the curtain movements. For example, if it is cold or light is less in the home, the weather sensor node decides that close curtain is better to inhabitants. At that case, the sensor node transmits the action command to the actuator board for closing the curtain. When receiving the command, the actuator board moves the curtain.
- The detection of window states: If a magnetic is equipped in the boundary of window, magnetic sensor can detect the window states. When window is suddenly opened by some invader, the sensor node informs the situation to home control systems.
- Applying RFID into home networks: RFID is one of the important systems in the ubiquitous sensor networks. In order to apply RFID system to our home networks, we equip the 13.5MHz RFID reader to ZigbeX sensor nodes. Tag ID and data detected by the RFID reader are transmitted to ZigbeX sensor node through a serial line and ZigbeX transmits the information to home control system by using its RF transceiver.

4.3 Ubi-House: Implementation of ZigbeX based Ubiquitous Home Networks

In order to prove the realistic of our works, we constructed a small model house named Ubi-House where intelligent operations are implemented. Under Fig. 4 illustrates the model house. There are deployed 12 ZigebX sensor nodes to control door-lock, detecting gas, electronic devises, curtain movement and window states. They are connected by smart sensors and are managed by home control systems.

Movement detecting sensor, image camera and RFID reader are deployed at the side of door in the Ubi-House. The home control system manages the door lock based on the information which is generated by them. Image camera uses USB interface and is connected to home control system by the wired line. RFID reader can be connected to ZigbeX sensor nodes and controlled by action command. To prevent the gas explosion, we deploy two ZigbeX sensor nodes into the Ubi-House: Gas detecting sensor and actuator sensor. Two sensors are located at the side of gas valve to immediately detect gas and turn off the valve. Since the operation to detect gas consumes high energy, gas sensing is periodically performed. The periodic value is set by home control system. We deploy three small electronic device models (TV, air conditioner and refrigerator) and two outlets. To confirm the operation of electronic devices, we insert LED which is controlled by the actuator board into the electronic device models and connect electronic lamps to the outlets. By action commands from ZigbeX sensor nodes and control system, the LED and lamp are turned on/off. Mini curtain in the Ubi-House is connected to the two small motors which are controlled by the actuator board. Since the movement of curtain is influenced by weather information, the actuator board may receive the action command packet from a weather sensor node or home control system. Suddenly opening the window is immediately detected by magnetic sensor and the situation is also reported to control system.

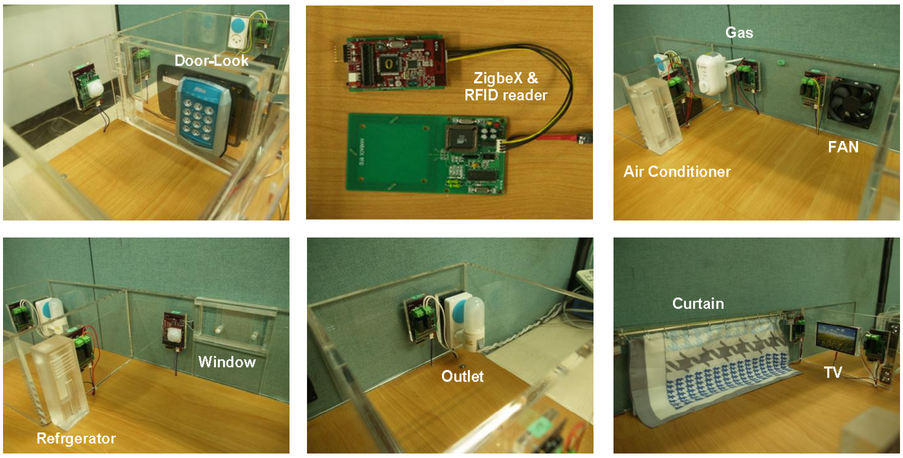

Fig. 4. Pictures of the small model house

We utilize EMPOSII [17] as the home control systems. EMPOSII uses the Intel Xscale PAX255 as processor and has various connectors to support Ethernet, Bluetooth, USB, serial and wireless sensor communication. Its operating system is the embedded linux (kernel 2.4.19). In order to provide the easy control to inhabitants, we insert the touch screen panel system to EMPOSII. We design this home control system to have enough resources for managing the whole home equipments. Moreover, since this system can be connected to the internet and other wireless technologies such as Bluetooth and WLANs, it can provide various ubiquitous services.

5 Conclusion and Future Works

For the more intelligent home network, we develop the new smart sensor devices, additional boards and home control system. By using these systems, we suggest the new home network paradigm as "the smart sensor devices based ubiquitous home networks." Our proposed systems make the ubiquitous home networks more intelligent and automatic. To show the realistic of our work, we implement the small model house based on our smart sensors and embedded systems. These works contribute on the developing of the ubiquitous home network implementation areas.

We have two future works to extend this paper. First, we will develop the position system for exactly detecting the human location by using an ultrasonic. This system will be also operated on the ZigbeX sensor node. Second, we will design the new sensor MAC and Routing protocols. Many sensor network protocols have been proposed, but they are not optimized to the home network environments. We will develop the new communication protocols adjusted to the home networks.

References

1. M. Weiser, "The Computer for the 21th Centry," *in IEEE Pervasive Computing Magazine*, Jan. - Mar. 2002.
2. I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, "Wireless Sensor Networks: A Survey," *in Elsevier Computer Networks*, 2002.
3. C.-ho Cha, J.-H. Kim and Y.-B. Ko, "Smart Media Player: The Intelligent Media Player Based on Context-Aware Middleware and Ubi-Sensor," *in IMSA' 05*, Aug. 2005.
4. MavHome project, http://mavhome.uta.edu/
5. D. J. Cook, M. Youngblood, E. Heierman, K. Gopalratnam, S. Rao, A. Litvin and F. Khawaja, "MavHome: An Agent-Based Smart Home," *in IEEE PerCom' 03*, 2003.
6. Aware Home project, http://www.awarehome.gatech.edu/projects/
7. C. D. Kidd, R. Orr, G. D. Abowd, C. G. Atkeson, I. A. Essa, B. MacIntyre, E. Mynatt, T. E. Starner and W. Newstetter, "The Aware Home: A Living Laboratory for Ubiquitous Computing Research," *in the International Workshop on Cooperative Buildings*, 1999.
8. AIRE project, http://aire.csail.mit.edu/
9. M. Mozer. "The neural network house: An environment that adapts to its inhabitants," *in the AAAI Spring Symposium on Intelligent Environments*, 1998.
10. W. Keith Edwards and R. E. Grinter, "At Home with Ubiquitous Computing: Seven Challenges," *in UbiComp' 03*, 2003.
11. G. C. de Silva, B. Oh, T. Yamasaki and K. Aizawa, "Experience Retrieval in a Ubiquitous Home," *in ACM CARPE' 05*, Nov. 11, 2005
12. T. Mori, H. Noguchi, A. Takada and T.Sato, "Sensing Room: Distributed Sensor Environment for Measurement of Human Daily Behavior," *in INSS' 04*, 2004.
13. Tatsuya Yamazaki, "Ubiquitous Home: Real-life Testbed for Home Context-Aware Service," *in IEEE TRIDENTCOM' 05*, 2005
14. J. Stankovic, Q. Cao, T. Doan, L. Fang, Z. He, R. Kiran, S. Lin, S. Son, R. Stoleru and A. Wood, "Wireless Sensor Networks for In-Home Healthcare: Potential and Challenges," *in HCMDSS*, June 2005.
15. J. N. AL-KARAKI and A. E. KAMAL, "Routing Techniques in Wireless Sensor Networks: a Survey," *in the IEEE Communication Magazine*, Dec. 2004
16. I. Demirkol, C. Ersoy and F. Alagoz, "MAC Protocols for Wireless Sensor Networks: a Survey," *in the IEEE Communications Magazine*, 2005.
17. ZigbeX Sensor Node and EMPOSII, http://hanback.com
18. Atmega 128, http://www.atmel.com/.
19. Chipcon Corporation, CC2240 Low Power FSK Transceiver.
20. TinyOS, http://webs.cs.berkeley.edu/tos/
21. MAX1678 converter, http://www.amp.com
22. CdS photo sensor, http://www.keweidi.com/pro-e1.htm
23. SHT11 sensor, http://www.sensirion.com
24. IEEE Computer Society, MAC and PHY Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs), IEEE 802.15.4 TM-2003.
25. S. Madden, M. J. Franklin, J. M. Hellerstein, and W. Hong. "TinyDB: an Acquisitional Query Processing System for Sensor Networks," *in ACM Transactions on Database Systems*, March 2005
26. J. Polastre, J. Hill, and D. Culler, "Versatile Low Power Media Access for Wireless Sensor Networks," *in ACM SenSys' 04*, Nov. 2004.
27. W. Ye, J. Heidemann, and D. Estrin "Medium access control with coordinated, adaptive sleeping for wireless sensor networks," *in IEEE Transactions on Networking*, June 2004.