Android OS Mobile Monitoring Systems Using an Efficient Transmission Technique Over Tmote Sky WSNs

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***Abstract*— This paper proposes a new mobile monitoring system for environmental awareness toward wireless sensor networks (WSNs). This system assists Android OS mobile users to observe an environmental behavior, and then to alert for a sudden change with configured thresholds. The paper describes the instrument and component of the key design of the system. In addition, a new efficient technique to transmit environmental sensor data over WSNs is introduced by a design of flexible bit pattern to identify the type of sensor data. For performance evaluation, compared to a traditional transmission technique, analytical and practical – using Tmote Sky – results show the reduction of power consumption due to the number of aggregated bytes and transmissions.**

***Keywords*— Android OS; Efficient Transmission; Mobile Monitoring System; Tmote Sky; Wireless Sensor Networks; WSNs**

I. INTRODUCTION

For decades the advance of wireless sensor networks (WSNs) technology has been significance observing from the growth rate due to the distinctive feature, e.g., a very small size with full capabilities –sensing, processing, and transmitting– similar to a tiny computer equipped with customized operating system, i.e., TinyOS [1]. This tiny sensor mote is placed in distributing by nature leading to the decrease of overall system failure probability.

There are a number of sensor motes either fully-equipped packages, such as Tmote Sky, EYEs, Mica, and Xbow, or manually customized user-made with specific modules, i.e., CPU (MSP430, ATmega, and StrongARM) [2], Analog to Digital Convertor (ADC), Radio Signal (based on IEEE 802.15c), Sensor; and all are accessible in a market at reasonable price.

With a variety of WSNs functionalities, there are a large number of applications of which the main function is basically for monitoring/sensing purpose, such as in agriculture and environment, civil engineering (structural monitoring), military, traffic control, and health care and surgery [3–4].

With those facilities, however, WSNs come with trade-offs, especially the small battery-operated power source and ad-hoc infrastructure by nature. Therefore, a great number of researches have been conducted, practically used in real-world [5-6].

Aside from WSNs limited by a transmission range, the advance of mobile networking technology has also come to the rising stage. A number of mobile (smart) phones have drastically increased with the decrease of cost, but greater functionalities [7]. The existence of mobile technology results in user-friendly capability and ubiquitous systems with the improvement of wireless transmission speed and wide coverage.

Recently, the smart phone offers a variety of tuned up operating systems, properly used for a mobile device with unique characteristics, such as Android OS, Windows Phone 7 (WP7), Iphone IOS, Blackberry (RIM), and Bada (Samsung). All of these provide enriched features together with plenty of easy-to-develop tools, system applications, and marketing strategies. One of them, Android OS, comes with the open-platform based on Linux architecture which is actually in an increasing trend for customers' choices, i.e., 53% of the market share [8].

Note that although using Web architecture may be convenient and independent to some access systems, many customized features toward mobile applications are fruitful, such as user-friendly interface for small screen size, SMS notification services, and GPS functions.

As a result, in this paper, we explore the possibility to utilize the mobile phone (Android OS) for convenient uses as the monitoring system to acquire the environmental information toward Tmote Sky WSNs. In addition, to aid the energy-efficient transmission, we specifically designed the efficient transmission protocol to carry specific sensor data information.

This paper is organized as follows. In Section II, we briefly survey recent research/proposals regarding various techniques for monitoring schemes and sensor transmission techniques over WSNs. Then, in Section III, the overview of our architecture will be discussed. Section IV provides the detailed transmission protocol design. After that we discuss the performance analytically and practically in Section V. Finally, the conclusions are drawn in Section VI.

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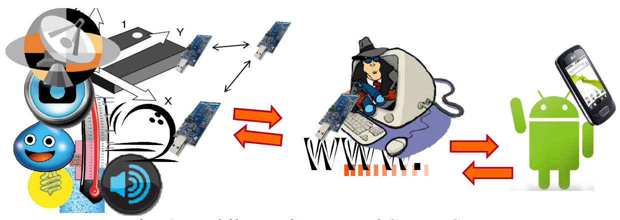


Fig. 1. Mobile Environmental Sensor Systems

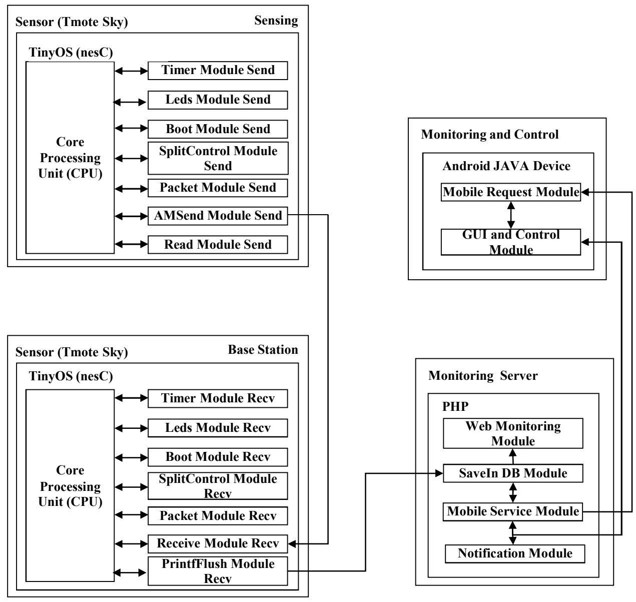


Fig. 2. System Architecture

II. RELATED WORK

There are a number of researches and applications in various areas of sensors applying WSNs for the purpose of monitoring and acquiring information, as previously mentioned, i.e., for the purpose of environment and healthcare.

Consider monitoring and management. Most of the proposals can be classified into three groups: the server-based, the web-based, and the mobile-based. The first group was investigated at the beginning of the WSNs era, basically used for retrieving the information, and then storing it in a local database for off-line analysis.

The second group is to analyze the sensing data stored from database, and then to display via web architecture. For example, Y. Yang et al. [9] proposed an on-line monitoring system based on CC2431 ship (customized mote) with TinyOS as an operating system for large electrical equipment; B. Stojkoska and D. Davcev [10] proposed a user-friendly web interface for habitat monitoring.

For the last group, there are several proposals focusing on different applications over various scenarios. For example, S. Toh et al. [11] described a robust healthcare monitoring system over WSNs and CDMA. Similarly, Y. Wu et al. [12] integrated WSNs with GSM to monitor patients with Intradialytic hypotension. N. Nasser and Y. Chen [13] proposed the middleware architecture for the personal server and the cross-layer protocol stack architecture over WSNs, and then integrated into GSM/WLAN for remote elderly monitoring.

For specific implementation, G. Virone et al. [14] proposed the system architecture for smart healthcare over WSNs using Windows Mobile OS PDA. Similarly, C.K. Harnett [15] applied a Java ME based-mobile phone for network telemetry over WSNs.

Consider Android OS-based monitoring over WSNs. There is not much investigation on this platform. However, N. Moreira et al. [16] implemented the WSNs iMote2 monitoring system. Similarly, Y. Chu et al. [17] presented the use of smartphone application-layer gateway on Openmoko Android for bio-monitoring WSNs (customized motes). Notice that those two have not much detail for performance analysis, especially for energy constraint.

In particular, to support an alert system, Y. Wu et al. [12] and S.K. Udgata et al. [18] embedded the alert/notification module in terms of SMS services following the detection of sensing alarm but again not much detail is discussed on the implementation aspect.

Consider an energy-efficient transmission over WSNs to support various sensors. A few researches focus on this issue, but routing, scheduling, and security. For instance, in [19], the design implementation defines the protocol for image transmission, which includes packet length, sender ID, packet type, image number, start block, and number of block resulting in 8 bytes header. Although this number sounds little; however, for energy constraint WSNs, optimizing this number results in longer mote life, especially once deployed in harsh condition environment.

From various techniques discussed above, noticing that there are advantages, but some useful techniques aren't considered probably due to the technology inadequacy. As a result, with the advance of current mobile phone technology, we have proposed a new system to make use of Android OS as a mobile monitoring system for environmental behavior toward WSNs. We have also discussed the alternative design of the system.

Especially, to overcome the key issue of WSNs, power consumption, an efficient transmission protocol is also proposed. The system has been implemented into a Samsung Galaxy Mini (Android SDK 2.2) and Tmote Sky for mobile networks and WSNs, respectively.

III. SYSTEM ARCHITECTURE

Fig. 1 shows an overall of the monitoring system for environmental data using a mobile phone. In general, there are four main components: sensor, base station server, monitoring server, and monitoring and control device. Fig. 2 also shows the detail of each component.

1) Sensor: this component performs as the main function to collect environmental information using Tmote Sky motes. Aside from Control Processing Unit (CPU), the main computational and interactional module, there are 7 modules based on the TinyOS functionality.

- Boot: an initialization interface.

- Timer: a timing interface to fire the scheduling time to activate the program (millisecond).

Header	ID	Address	Data
Header	0	XXXXXXX	Variable Length (1-128 bytes)

Fig. 3. Protocol Format for Image Transmission

Header	ID	Device ID	Sensor Data			
Header	1	XXXXXXX	Data1	Data2	…	Data9

Fig. 4. Protocol Format for Efficient Sensor Transmission

- Read: a read interface to retrieve the actual sensor information in split-phase either low-rate or high-latency. In addition, during the acquisition, a pre-packet transmission process is performed to identify the type of sensing data.

- Leds: an optional interface to explicitly notify users when a specific event has occurred, such as reading sensor data/transmitting/receiving the packet.

- Packet: a de/encapsulation interface for sensor data as well as specific header information. A specific bit pattern is encoded/ decoded within this component for energy-efficient transmission purpose (See also Section IV).

- AMSend: a packet transmission interface with data payload to specific addresses.

- SplitControl: a switching interface between the on and off power states.

2) Base Station Server (BSS): This component is working as the base station to receive environmental sensor data. Due to the limitation of a special hardware for base station, for our architecture, one of the Tmote Sky motes works for that purpose attached to the PC server. In other words, this component works as other sensors, but in the opposite way (receiving the information from other motes).

- Receive: this interface works in a different direction of AMSend.

- PrintFlush: unlike a traditional C programming, a *printf* interface is an external component writing in Java platform. The output of the status is redirected into a log file.

3) Monitoring Server: this component acts as the server providing the information via web architecture and mobile services. There are 4 modules.

- SaveIn DB: given the log file, web architecture using PHP-based MySQL converts that into the structured database.

- Web Monitoring: a web-based monitoring system for other Internet users.

- Mobile Service: a simple user-friendly sensor data format, generated by PHP, especially used for mobile data acquisition services.

- Notification: a user-defined configuration to send notifications/alerts via SMS services using Google SMS and Google Calendar API in case the environmental sensor data is beyond the specific threshold.

4) Monitoring and Control Device: there are 2 modules for mobile usage.

- Mobile Request: a simple transmission acquisition scheme over mobile networks using "org.apache.http.HttpResponse", "org.apache.http.client.HttpClient", "org.apache.http.client.methods.HttpGet", "org.apache.http.impl.client.DefaultHttpClient" libraries applied with a text-based PHP generated as the input from web services.

- GUI and Control: this module functions as the main human and mobile interaction system to properly display real-time sensor data from the monitoring server.

This module receives the specific environmental criteria from mobile phones, i.e., sensing interval and specific environmental levels, and then sends them back to the monitoring server to feedback the control to the actual sensor for future uses (in case some mechanical control systems are embedded with the sensor motes).

Additionally, this module supports the alert mechanism by defining the configured threshold sending back to properly adjust the environmental data variable once the sensor data is beyond the limit.

IV. BIT PATTERN FOR SENSOR DATA TRANSMISSION

In the previous section, the overall system was discussed, and here, we focus on the optimization of the transmission technique over WSNs resulting in the reduction of power consumption which is the critical issue for WSNs.

For practical uses, Tmote Sky, a well known sensor mote, was chosen for our optimization. There are 16 input/output pins resulting in up to 8 interactive sensors supported [20]. In general, there are 3 to 4 sensors embedded, i.e., temperature, humidity, and light sensors with optional Global Positioning System (GPS); however, it is probable to integrate other critical environmental sensors, such as image, sound, accelerometer, motion, pressure, magnetic field, smoke, and moisture sensors.

Normally, the sensor data aside from image (352×288 in resolution for CMUCAM [21]) and GPS (variable size depending on the length of latitude/longitude information) are fixed in length, such as 1 to 2 bytes [22]; however, it's not limited to which depends upon the efficiency of the sensor and ADC.

As a result, we design the efficient protocol to transmit probable environmental information for Tmote Sky WSNs as follows.

We use 1 data bit (IDentification bit - ID) to indicate a specific type of sensors of which the data is either fixed or varied, and possibly large, i.e., image data, as well as the support of multiple data bytes for each sensor (1st data bit = 0) spanning out over multi-frames shown in Fig. 3.

Note that the actual length of sensor data can be identified by the length field of IEEE 802.15c frame format [23].

There are two main scenarios: one is for image transmission, and the other is for sensors with variable length data which are all combined into 2^7 cases. Since as previously mentioned, there is a possibility that the data is beyond one frame, we design 2 bits for each sensor which represents the start/in-process and stop/end stage.

TABLE I
POSSIBLE BIT PATTERN SETUP WITH MAXIMAL DISTANCE

Bit Pattern	Sensor
1 010 0000	Temperature
1 000 1000	Humidity
1 000 0010	Light
1 101 0000	Sound
1 100 0100	Motion
1 100 0001	Accelerometer
1 001 0100	Moisture
1 001 0001	(For Other Usages)
1 000 0101	(For Other Usages)

For example, (0)0000001 is for in-process image transmission which is basically in a full frame (128 bytes), and (0)00000010 is for the last image transmission frame.

Note that although in fact only 4 bits is required to support both image transmission and up to 7 additional sensors, practically the actual transmission is byte-aligned, and so minimally 1 byte is for Address field (2^7-16 can be used for other purposes). Moreover, for frame-ordering, the SN field within the 802.15c frame can be used to number the frame sequence number (FSN).

In case of other environmental sensors, mostly the fixed length data, we assume that in each organizational setup, this information is known in advance, and so the system engineer can properly design. Since the number of available ports can support up to 8 devices for Tmote Sky, our alternative design is to make use of the other 7 bits excluding the identification bit. Here, the ID bit is set to 1 (Fig. 4).

In addition, we apply the maximum distance among values of 7 bits to create 9 possibilities or 9 supported devices as shown in Table I. The basic idea is to find the proper coding in which the minimum Hamming distance [24] is more than two.

Assuming the fixed sensor data known, each bit pattern represents the existence of the type of sensor data. For example, for 1010 0000, only 2 bytes (with 1 byte header) of temperature data sensor is available.

However, in case there are more than two sensor data available, the final bit pattern is computed from the mathematical function OR (| in nesc format). For example, suppose to send temperature, humidity, and light data, the final bit pattern will be 1010 0000 | 1000 1000 | 1000 0010 = 1010 1010. Here, there are 3×2 bytes (with 1 byte header).

At the receiving end, the final bit pattern will then be used to compute the existence of sensor data by performing the AND (&) operation with the predefined pattern (Table I). If the result leads to that of the predefined pattern, then that means the availability of that sensor data, e.g., for temperature, humidity, and light as follows.

```
1010 1010 & 1010 0000 = 1010 0000
1010 1010 & 1000 1000 = 1000 1000
1010 1010 & 1000 0010 = 1000 0010
```

Note that some reserved bits in the frame control field can also be applied instead of the data bits [25]; however, in case of the future use, we do not investigate this issue.

V. PERFORMANCE EVALUATION

In this section, we performed the evaluation process by dividing into three cases, first to justify the feasibility of our mobile monitoring system for sending environmental data toward WSNs, second to analytically show the performance improvement of our transmission technique, and finally to practically show the actual performance over Tmote Sky WSNs.

A. Simulation and Experimental Setup

We evaluated our proposal based on 3 main scenarios to test the feasibility and the performance as follows.

1) To illustrate the feasibility of the system, after our system design has been completed and implemented, first we show whether the system is working properly; the sensor data (temperature, humidity, and light) are sent from Tmote Sky, and then displayed on the actual Android phone. Here, we used Samsung Galaxy Mini 600 MHz 158 MB ram with Android SDK 2.2.

Similarly, mobile users can configure a proper threshold in order to make the system notify the critical event which is then sent over SMS services.

With the limitation of our testbed, the base station laptop connected with one of the Tmote Skys is on a standard configuration over Windows 7 Service Pack 1 operating system (32 bits): CPU Intel(R) Core 2 Duo 1.83 GHz (2 MB L2 Cache), 1024×2 MB DDR–SDAM, 250 MB Disk running over VMware (7.1.5) Linux Ubuntu 11.04 with PHP-MySQL and Apache web server.

For mobile and wireless networks, we used WLAN 802.11b (3Com Access Point with 10 Mbps signal strength measured from the base station) and Google Calendar SMS API as the mobile communication to connect to the Android OS phone.

In addition, since the input from sensors is in raw format, we use the equation from [22] to illustrate temperature, humidity, light intensity, e.g., -39.60 + 0.01 × (14 bits raw data) for temperature.

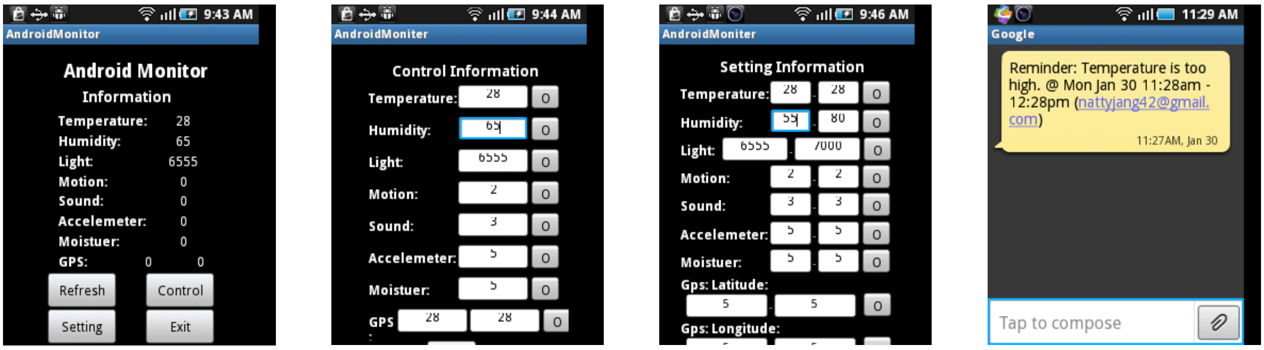
2) To show the improved performance theoretically of the novel technique to transmit the sensor data, we applied the power consumption equation regarding per transmission for data-bytes and antenna logic as follows (Joule) [26].

```
(Send) 3.54 + 0.12(#bytes)     eq. (1)
(Receive) 4.03 + 0.12(#bytes)  eq. (2)
```

Note that there are also other models applicable, such as in [27], derived by R. Vidhyapriya and R. Vanathi; however, due to the reduction of #bytes, the improved performance results will be similar in trend.

In addition, although the sensitivity of transmission interval may be altered, in general the transmission interval is in range of 0.1 to 5 seconds (0.2 second [28]); however, some other values are also applicable stated in [29]. For analytical purpose, we draw over 7 sensors.

In case of non-critical sensor data, the trade-off of small delay transmission results in a group of sensors resulting in reduction of power consumption.



(a) Monitoring Screen (b) Control Screen (c) Threshold Screen (d) SMS Service

Fig. 5. Android GUI (Mobile Monitoring System)

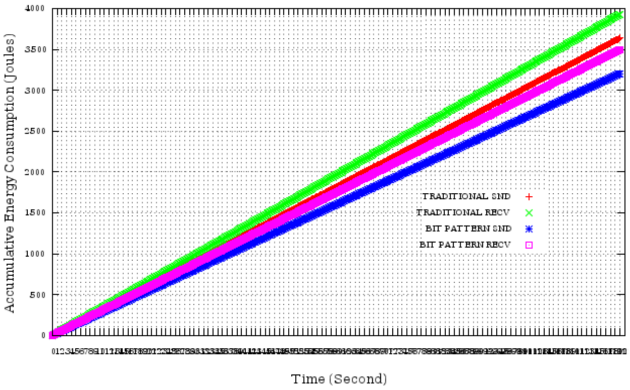


Fig. 6. Analytical Results: Battery Consumption (Joules) vs. Time (Seconds) [X axis is spanned over 120 seconds with equal distance.]

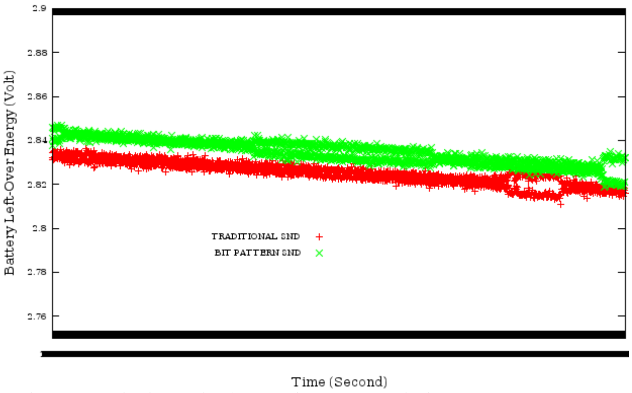


Fig. 7. Practical Results (7 vs. 9 bytes transmission - 15000 to 17000 sec.): Average Battery Left-Over (Volts) vs. Time (Seconds) [X axis is spanned over 2000 seconds with equal distance.]

Therefore, we assume each device is in 0.2 second interval. We ran over 2 mins and measured the battery power consumption (Joules) compared to a traditional transmission, i.e., with header plus data (1+2 or 3 bytes).

3) To practically show the performance improvement over Tmote Sky WSNs, we configured 3 built-in sensors to measure the environmental behavior, and then transmit the information to the base station in 1 second interval. Then, we drew the battery power left-over (Volt) over time period (5 hours) between a traditional and modified sending in comparison (Bit Pattern). With 3 sensors, the number of transmitted bytes is 1+6 and 3×3 for the modified bit pattern and traditional one, respectively. We used Panasonic R6ST battery 1.5×2 Volts. We measured 3 times and plot the average voltage. With Tmote Sky, we measured the voltage from the equation below [22].

$$V_{Battleft} = ADC_{count}/4095 \times V_{ref} \times 2 \quad \text{eq. (3)}$$

B. *Simulation and Experimental Results*

For the first scenario, Fig. 5 shows practical results in Android OS GUI (Samsung Galaxy Mini). Here, there are three sensor data toward WSNs using Tmote Sky and mobile communication using WLAN and SMS services.

Consider the performance improvement over a new transmission technique (the second scenario). Fig. 6 shows the analytical results of accumulative battery consumption over time period (2 mins). The results show that with the modified bit pattern snd/recv transmission, the power consumption increases in smaller steps (linear) compared to the traditional one over time, especially with more number of sensors transmitted simultaneously with aligned transmission intervals.

Fig. 7 shows the result of the third scenario. In our experiment, the reduction rate of voltage also depends on the brand of the battery. Also, in practice, measuring the voltage level results in fluctuation of the level; however, the results show the decreasing trend over time.

In this figure, for the sake of plotting space limitation, the period from 15000 to 17000 seconds and 2.75 to 2.90 volts were chosen; however, similar trend was applied. It took around 3600 seconds for voltage to start reduction. In this period, the average number of voltage difference is 0.01 with 0.003 as a standard deviation.

In Tmote Sky, similar to the behavior in Fig. 6, compared to the traditional transmission, the modified bit pattern consumes less power. In other words, higher battery consumption is left-over.

Note that consider measured units, we only investigated the reduction trend of battery power since the actual measured battery power may include additional functionalities not just transmission logic, and we do not focus on the accuracy of power models.

VI. Conclusion and Future Work

New mobile monitoring system for environmental behavior collection toward wireless sensor networks (WSNs) is proposed in this paper. We utilized the mobile phone - Android OS - function for an easy-to-use system for mobile users to observe the environmental data toward WSNs including an alert subsystem for a particular critical event.

In addition, an efficient transmission protocol is introduced in this paper so that the bit pattern was constructed to support various sensors over Tmote Sky motes. Especially, for simultaneous transmission, the battery power consumption is reduced with a delay trade-off.

Note that in this paper, we chose the use of Tmote Sky motes due to a well-known sensor motes for WSNs, and an open source Android OS for our system; however, other similar mote architectures and mobile phone technologies are also applicable, e.g., MicaZ and iMote; Iphone, Windows Phone 7, Blackberry, and Bada mobile devices.

In addition, although we evaluated up to three sensors for practical tests, for further investigation, similar analysis can be derived for more number of sensors, and with more sensors in practice; the power consumption will be further reduced. We are also in the progress to embed more actual sensors into Tiny OS 2.1.

Due to the time consuming (several hours) for practical tests, we do not run multiple tests for power consumption evaluation, and this is for further evaluation. Also, although the battery power saved is a small factor in a small time scale, practically, the technique will result in higher impact when used in a long time period, years, etc.

Finally, because the focus on the analysis is only for energy-efficient transmission protocol over WSNs, we only performed a simple single hop routing; however, other routing scenarios, such as AODV (Ad hoc On-Demand Distance Vector) and DSDV (Destination-Sequenced Distance-Vector) [5], are beyond the scope of this study, i.e., for future investigation.

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