Information Systems 48 (2015) 320–326

Contents lists available at ScienceDirect

Information Systems

journal homepage: www.elsevier.com/locate/infosys

Hybrid wireless sensor network for building energy management systems based on the 2.4 GHz and 400 MHz bands

Ayeon Kim, Jaejun Han, Taeyoon Yu, Dong Sik Kim*

Department of Electronics Engineering, Hankuk University of Foreign Studies, Yongin-si, Gyunggi-do 449-791, Republic of Korea

ARTICLE INFO

Available online 14 July 2014

Keywords:
2.4 GHz ISM band
Building energy management system
Sub-1 GHz band
Wireless sensor network

ABSTRACT

In this paper, a hybrid wireless sensor network (WSN) system is considered and implemented for the building energy management systems. Characteristics of the radios, which are based on the 2.4 GHz and 400 MHz bands, respectively, are analyzed for the building environments. For battery-operated portable sensors, narrow-bandwidth radios of the 400 MHz band are employed in a star connection between their parent nodes. Between the parent nodes, a mesh network is constructed for an efficient and fast data transmission based on the wide-bandwidth radios of the 2.4 GHz band. The hybrid WSN system is implemented and tested for a building environment and provides a reliable wireless communication link for gathering sensing data.

1. Introduction

The wireless sensor network (WSN) technology, which is based IEEE 802.15.4 with the 2.4 GHz ISM (industry science and medical) band, supports low prices and long battery lifespans with moderate rates, simple structures, and simple data connectivity. Such a technology is appropriate for the areas, in which a short-range wireless communication is required [1], and has been growing because of its simple regulation and worldwide availability [2]. When we implement WSNs for the building energy management systems; however, the wireless link margin of the 2.4 GHz-based WSN is quite low especially for building environments, of which spaces are separated by various types of partitions and are occupied by obstacles, such as furniture. In order to increase the link margin as well as the data transmission range within the framework of the 2.4 GHz-based WSN, we should increase the transmission power or the number of nodes. Increasing transmission power will obviously decrease the battery lifespan, and placing lots of sensor nodes in the building environments will seriously increase the implementation complexity.

In order to increase the wireless communication distance while maintaining reliable communications in the building environments with low power consumption and low implementation complexity, narrow-bandwidth radios should be considered. Recently, sub-1 GHz radios have been employed in wireless communication networks, such as the smart utility network (SUN). Based on very low rates of 1.2–50 kbps with narrow-bandwidths in the sub-1 GHz band, radios can provide longer communication distances than the 2.4 GHz case with the increased receiver sensitivity [3,4]. Regardless of the increased communication distances in the narrow-bandwidth radios, the reduced data rates may not be enough to gather the sensing data that are accumulated by many sensors. In this paper, we propose a hybrid WSN system, which is suitable for the building environments and possesses both

* Corresponding author.
E-mail addresses: aykim1208@hufs.ac.kr (A. Kim), jjhan@hufs.ac.kr (J. Han), kris85@hufs.ac.kr (T. Yu), dskim@hufs.ac.kr (D.S. Kim).

http://dx.doi.org/10.1016/j.is.2014.06.005
0306-4379/

communication-distance and data-rate advantages of radios in 400 MHz and 2.4 GHz bands, respectively. We also introduce an implementation of the proposed hybrid WSN system.

This paper is organized in the following way. In Section 2, a hybrid WSN architecture is proposed for the building environment with a comparison between the radios of 2.4 GHz and 400 MHz bands. In Section 3, an implementation of the hybrid WSN architecture is introduced. Several experimental results on the radios for the build environment are introduced in Section 4. The conclusion is stated in the last section.

2. Hybrid wireless sensor network

In this section, we first observe and compare the characteristics of the wireless links that are based on the 2.4 GHz and 400 MHz band radios. We then construct a hybrid WSN system, in which both types of radios are employed.

2.1. Wireless communications based on the 2.4 GHz and 400 MHz band radios

The electro-magnetic wave of the 2.4 GHz band tends to reflect and to be interfered by obstacles compared to the 400 MHz case. The wireless communications can be interrupted by the fading problem due to the reflected and then interfered electro-magnetic waves through multi paths. Hence, for the 2.4 GHz radios, constructing a long-distance communication system is not appropriate especially for the building environment. The electro-magnetic wave of the 400 MHz band shows a better diffraction property than the case of higher frequencies, such as 2.4 GHz. Hence, using the 400 MHz band is suitable for wireless communications in the building environments, in which a better diffraction property than the 2.4 GHz case can be successively exploited [5]. Even for the subway station environment, which has a moving population with various obstacles, the wireless communication range in the 400 MHz band is wider than the 2.4 GHz case [6]. Increasing the wireless communication range is of importance since a WSN can be constructed by using less number of sensor nodes.

In order to further enlarge the communication range of the 400 MHz radios, a narrow-bandwidth communication scheme is employed for increasing the receiver sensitivity while decreasing the data rate. For the sensor nodes, which measure simple values, such as temperature, the data amount is quite small. Hence, relatively low data rate with high receiver sensitivity is appropriate for the 400 MHz radios. Due to the low power consumption property and the enough wireless link margin of the lower frequency radio of 400 MHz, we can design a battery-operated small sensor node, which can be placed at any places of building to measure useful information.

A node based on a star connection can collect the measured data in the sensor nodes. The node then transmits or relays the collected data to a server though RF links or Ethernet. In this case, the data rate should be higher than the sensor node case of the 400 MHz radios because of the collected data from many sensor nodes. In the 2.4 GHz band radios, more amounts of data can be transmitted due to the relatively high rates of wide-bandwidth receivers compared to the narrow-bandwidth receivers of the 400 MHz band. For example, the data rate of the 2.4 GHz band in IEEE 802.15.4 is 250 kbps, which is much faster than 1.2 kbps of the narrow-bandwidth radios in the 400 MHz band. Hence, using the 2.4 GHz band is more appropriate for transmitting an amount of data in terms of the data rate. However, the wide-bandwidth receivers accept further signals including noises compared to the narrow-bandwidth case, and thus the accumulated noise deteriorates the receiver sensitivity [7]. Hence, using the 2.4 GHz radios with relatively high data rates is appropriate for collection of the sensing data at a fixed position with supplied power to secure a reliable wireless links.

2.2. Hybrid wireless sensor network architecture

In this section, we introduce a hybrid WSN system that has both advantages of the 2.4 GHz and 400 MHz bands. This system consists of (1) CoAP (constrained application protocol) Wireless Sensor, (2) Simple Sensor Device, and (3) CoAP Gateway as shown in Fig. 1. CoAP Wireless Sensor plays a role of the parent node for multiple Simple Sensor Devices. One CoAP Wireless Sensor gathers sensing data from many Simple Sensor Nodes by constructing a star connection. In order to cover a wide range of wireless communication between CoAP Wireless Sensor and multiple Simple Sensor Nodes, we use a narrow-bandwidth radio of the 400 MHz band because of its longer distance than the 2.4 GHz band case. Since Simple Sensor Node can be moved or placed at any position in the rooms of building, Simple Sensor Device should be operated based on batteries and should have a simple circuit only for sensing and transmitting the sensing data.

Fig. 2 illustrates the star wireless connection between a CoAP Wireless Sensor and multiple Simple Sensor Devices. The sensing data, which are measured in Simple Sensor Devices, are forwarded to the CoAP Wireless Sensor that is corresponding to their parent node. Depending on the structure of the target building, in order to enlarge the sensing area, we can also add many star connections with multiple CoAP Wireless Sensors and their Simple Sensor Devices. For an efficient data communication, the CoAP Wireless Sensors can then form a mesh network between

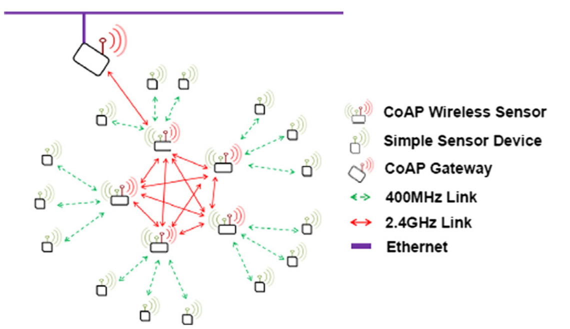

Fig. 1. Hybrid wireless sensor network for the building environment.