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Comparison of the Frequency Bands for the Wireless Sensor Networks in the Building Environment

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Abstract

In this paper, for the pratical building envoronments, the propagation properties of the electromagnetic waves of the sub-1GHz bands, including the 447MHz, 868MHz, and 715MHz, and the 2.4GHz band are experimentally observed in therms of the received signal strength indicator (RSSI) value. The compasion of the frequency bands can be utilized to efficiently construct the wireless sensor networks (WSN) for the building automation control. In order to measure the RSSI values in the building, an RSSI measurement system is first designed, in which the master part can transmit data packets and measure the corresponding RSSI values, and the slave part can respond the received data packets. Using the measurement system, the RSSI values are then experimentally measured at four types of building enviroments. From the experimental result analysis, we could notice that the sub-1GHz, especially the 447MHz band, showd a good communication performance for the building environment and could provide an efficient WSN construction when the data rate is relatively low.

Keywords: *2.4GHz band, received signal strength indicator, sub-1GHz bands, wireless sensor network.*

1. Introduction

In the residential or commercial areas of buildings, for an efficient implementation of the building energy management system (BEMS), monitoring the indoor air quality from the measured room temperature, humidity, CO2 gas, etc., is essential for controlling the indoor environment condition by systems, such as the building automation system (BAS). Exploiting the wireless sensor network (WSN) technology can provide further efficient and flexible gathering approaches [1],[2]. For example, we can easily construct the WSN of the building using the 2.4GHz-based ZigBee radio through the industrial, science, and medical (ISM) band.

For the building environments, because of the complicate obstacles, such as the concrete or gypsum wall, furniture, and partition walls, the direction of the 2.4GHz wave propagation can be blocked. The diffraction property of the wave enables the electromagnetic wave to reach areas over the obstacles. However, the diffraction property of the 2.4GHz band is usually poorer than those of the sub-1GHz frequency bands, such

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as the 447MHz and 917MHz bands. In other words, for the 2.4GHz-based RF communication, the line-of-sight communication environment is not secured in the building environment and thus a reliable wireless link cannot be achieved. On the other hand, the sub-1GHz bands can provide a reliable wireless link for the building environment because of the better diffraction property [3]. However, the data rates of the sub-1GHz radios are lower than that of the 2.4GHz radios. Hence, a hybrid WSN can be employed to supplement the low data rates of the sub-1GHz radios partially using the 2.4GHz radios [4].

In this paper, the propagation properties of the electromagnetic waves for the real building environment are experimentally investigated and compared based on the radios of the 2.4GHz and sub-1GHz bands. From the experimental investigations, we can verify the good diffraction properties of the sub-1GHz radios and notice that the hybrid WSN can efficiently gather the environmental data for the building environment.

This paper is organized in the following way. In Section 2, we introduce the design of the RSSI measurement system. In Section 2, we introduce the experimental environment for comparing the propagation properties of different RF waves with various frequencies. In Section 4, the RSSI values are experimentally measured for analyzing and comparing the propagation properties. The conclusion is given in the last section.

2. Design of the RSSI Measurement System

In this section, the design of the RSSI measurement system for the comparison of the frequency bands in the building environment is introduced.

Figures 1 and 2 show the RSSI measurement systems for the sub-1GHz and 2.4GHz bands, respectively. The measurement system has two types of wireless transceivers; the master part transmits data packets and displays the RSSI and the packet error rate (PER) values, and the slave part transmits the corresponding acknowledge signal. Here, the two types of wireless transceiver parts have the same structure. The master part is designed to be able to transmit data to and receive instruction data from a PC though the RS232 interface. The connected PC can also display the measured RSSI and PER values.

Each transceiver part is composed of an MCU (micro controller unit) and an RFIC (radio frequency integrated circuit). The employed MCU chips are MSP430F1611 and MSP430G2553 of Texas Instrument (TI). For the 2.4GHz-band ZigBee physical layer, the RFIC of MG2450 (Radiopulse) is used. For the sub-1GHz frequency band tests, the RFIC of CC1120 (TI) and Si4463 (Silicon Labs) are used. Figures 1(b) and (c), and Figures 2(b) and (c) show the wireless modules of the sub-1GHz and 2.4GHz bands, respectively. The power of the transceiver part is supplied from two "AA" lithium batteries with the operating voltage of 3.0V. The RF parameters can be programmed by the attached MCU via SPI for setting the channel frequency, transmission rate/power, modulation type, packet format, etc. For the RSSI test in the paper, the RF parameters are set as in Table 1.

Table 1. RFIC parameters for the Sub-1 GHz and 2.4 GHz bands

Frequency band	Sub-1GHz	2.4GHz
Modulation type	2-GFSK	O-QPSK
Transfer rate	1.2kbps	250kbps
Transmission power	8dBm	8dBm

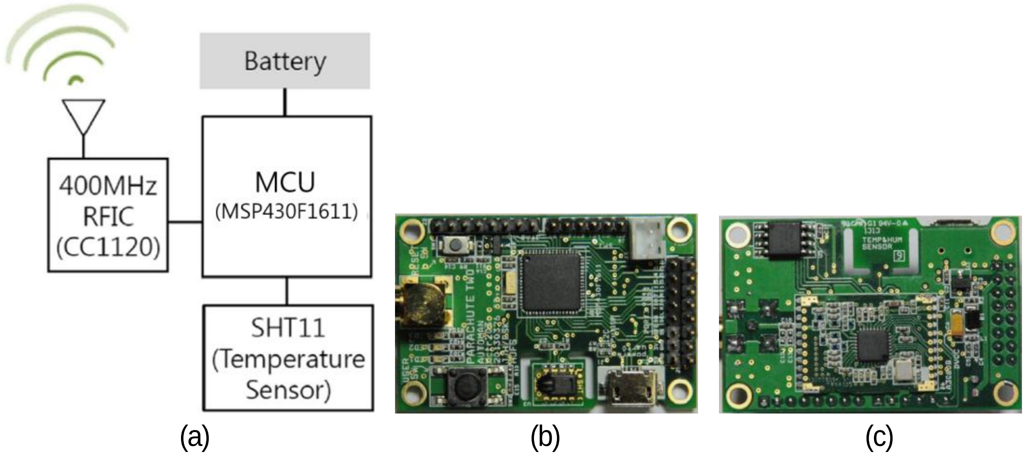


Figure 1. Sub-1GHz RSSI measurement system. (a) Block diagram of the RSSI measurement system. (b) The top of the transceiver part. (c) The bottom of the transceiver part.

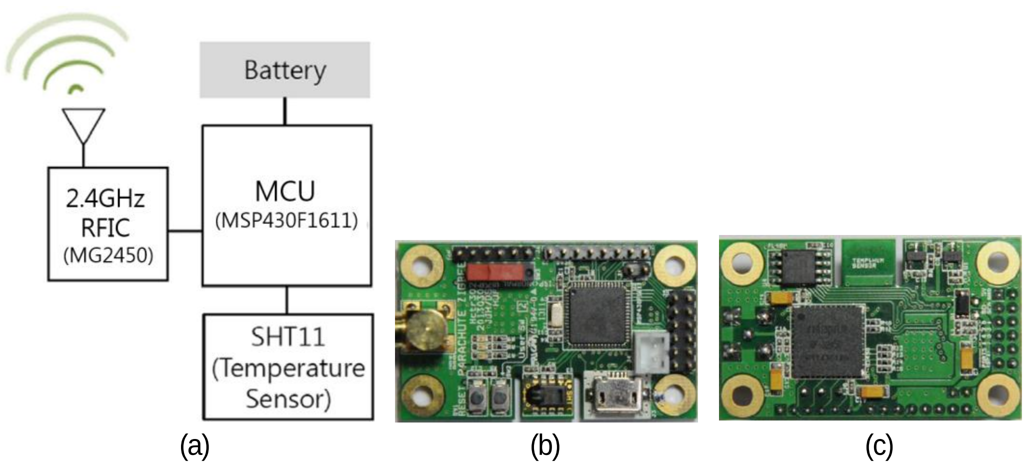


Figure 2. 2.4GHz RSSI measurement system. (a) Block diagram of the RSSI measurement system. (b) The top of the transceiver part. (c) The bottom of the transceiver part.

3. Experimental Conditions for Comparing the Propagation Properties

In this section, different types of experimental conditions, which can represent practical types of building environments, are introduced. The electromagnetic wave from a wireless module radially proceeds through an antenna is propagated in manners of the reflection, transmission, and diffraction in the obstacle environments of buildings [5]. However, the propagation properties especially near obstacles are unpredictable. Hence, in order to obtain a stable comparison, the transceiver parts are placed as far as possible from the obstacles, such as the walls, floors, ceilings, and furniture at appropriate heights. For the 2.4GHz-band test, we choose a channel, in which the RF wave interference from WiFi or Bluetooth can be alleviated.

3.1 RSSI Measurements for Rooms with Walls

In the first experimental condition, the experiments are carried out in a space having three consecutive rooms as shown in Figure 3, in which four walls separate the space. The two concrete walls separate the three rooms with the thickness of 130mm~150mm, whereas the outer two concrete walls have the thickness of 220mm. In order to experimentally measure the RSSI values for this condition, the master part is placed at 'Start' in Figure 3 alleviating any possible influences due to the surrounding obstacles, such as walls and pillars, and the slave part is moved following the arrow of Figure 3 to measure the RSSI values at intervals of 1m.

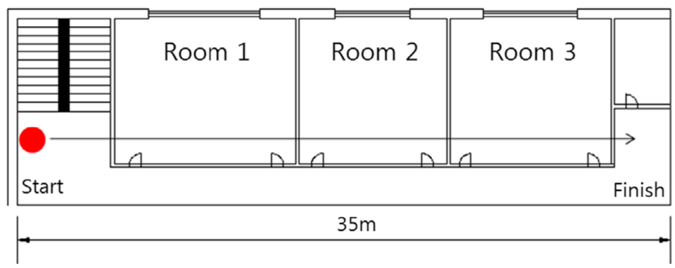


Figure 3. Experimental condition for rooms with four walls.

3.2 RSSI Measurements on the Same Floor

In the second experimental condition, the experiments are performed on the same floor of a building as shown in Figure 4. In Figure 4, we can see three elevators designated as 'X' and the emergency stairs, which have the ferroconcrete structures. The exterior glass walls are placed on the left and right sides of the space and the concrete walls are placed on the other sides of the space. Thin gypsum board walls rather than the concrete ones are placed to separate the office rooms. In the experiment, the master part is placed at the left bottom of the corridor marked as 'TX'. The slave part is moved along the corridor and the office rooms for measuring the RSSI values. Several meaningful locations are marked as Sections A, B, C, and D as shown in Figure 4 to characterize the propagation properties of the RF waves.

Sections A and B are blocked area from the start point marked as 'TX' and can be used to check the diffraction property of the RF wave. Here, the diffraction point can be corners of the ferroconcrete structures, such as the point marked as 'SPOT' in Figure 4. Section C can be used to compare the transmission characteristics depending on the frequency bands. On the other hand, Section D is a line-of-sight area and can be used to check any fading problems from the reflected waves.

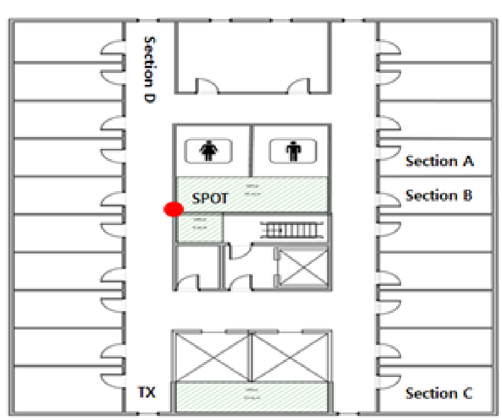


Figure 4. Experimental condition for the same building floor.

3.3 RSSI Measurements for Multiple Floors of the Building

In this experimental condition, the experiments are carried out for multiple floors in a building. In order to conduct the experiment, the master part is located in the middle of the 8th floor of the building and the slave part is moved to lower stories to measure the RSSI values while the received RSSI values are available.

3.4 RSSI Measurements for Various Obstacle Materials

The transmission properties of the RF waves can be observed for the obstacles that are made of different materials. In the building environment, the ferroconcrete wall and the steel door can significantly deteriorate the transmission energy of the RF wave. Thus, a comparison of the RSSI values obtained from the transmitted RF waves after various obstacles is necessary. In the experiments, the RSSI values for the passed waves are measured after two obstacles, the ferroconcrete wall and the steel door.

4. Experimental Results

In this section, the RSSI values were experimentally measured for the four types of conditions that are introduced in the previous section. The measured results were then analyzed and discussed.

4.1 Experiments for Rooms with Walls

Figure 5 shows the RSSI measurement results with the sub-1GHz bands for rooms with walls. Here, the RSSI values are measured from the master part using three frequency bands of 447MHz, 868MHz, and 915MHz, respectively, while the slave part was moving from Wall 1 through Wall 4 as shown in Figure 3. For the range of 0m through 25m, the 447MHz band showed a better transmission property than the cases of the 868MHz and 915MHz band. However, for the range of 25m through 35m, the 915MHz band showed the best result. Since the RF wave of the 447MHz band has a longer wavelength as 67cm than the 915MHz case of 32.8cm, the diffraction property of the 447MHz band can be better than the 915MHz case. Hence, even though there were several walls in the experiment of Figures 3 and 5, the 447MHz band can have a larger transmission range than the 915MHz case especially for the range of 0m through 25m. However, for the sub-1GHz bands including 447MHz, 868MHz, and 915MHz, we can observe that the propagation properties are quite similar to each other and are not seriously interfered by the walls due to their diffraction properties for the building environment.

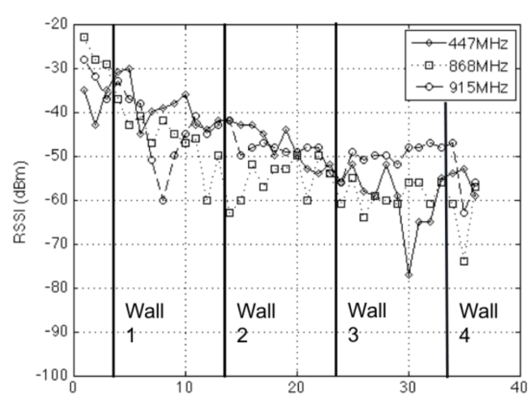


Figure 5. Experiments in rooms with walls for the sub-1GHz bands including the 447MHz, 868MHz, and 915MHz bands.

4.2 Experiments on the Same Floor

Figure 6 shows the RSSI values measured for the three frequency bands of 447MHz, 915MHz and 2.4GHz, where the RSSI values are represented as the gray levels according to the gray bar; the darker the gray levels are, the lower the RSSI values. For the line-of-sight cases, such as Section D, the RSSI values were similar for the three frequency bands. However, for the blocked sections of Sections A, B, and C showed different RSSI values depending on the diffraction properties of the frequency bands. When the radio waves reach the corners of concrete walls, they are diffracted at the corners and can propagate to the other sides over the obstacles. Since the 447MHz band has the best diffraction property, its RSSI values at Sections B and C shows the highest values as shown in Figure 6(a) compared to the 915MHz and 2.4GHz cases of Figures 6(b) and (c), respectively. Here, the 915MHz band also shows a higher RSSI values than the 2.4GHz case since the 915MHz band has a better diffraction property. For Section C, we can observe the transmission property through the ferroconcrete structure. From Figure 6, the transmission properties of the three frequency bands are similar to each other. For the 2.4GHz band, we could observe an interesting result that the RSSI values under the WiFi routers were deteriorated as shown in the corridor of Figure 6(c).

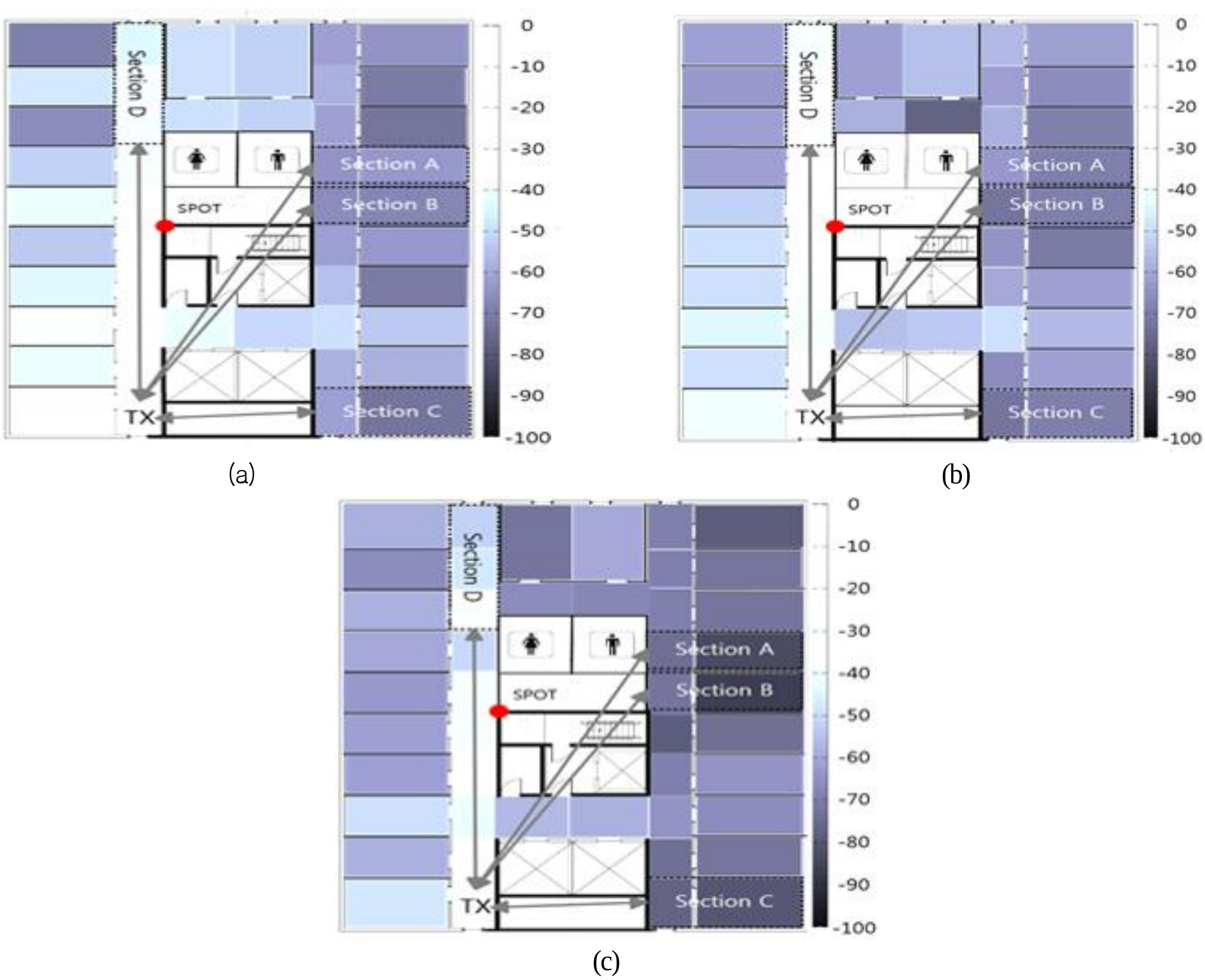


Figure 6. Experiments for the same floor in the building. (a) The result of the 447MHz Band. (b) The result of the 915MHz band. (c) The result of the 2.4GHz band.

4.3 Experiments for Multiple Floors of the Building

In Figure 7, the experimental results of the 447MHz and 915MHz bands are illustrated for multiple floors of the building. The master part of the RSSI measurement system was located on the 8th floor and the slave part was moving down. The transmission powers of the radio modules were set to 15dBm for both 447MHz and 915MHz bands. As the slave part went to the down floors, the measured RSSI values for the 447MHz case were better than the 917MHz case. Hence, when transmitting data through multiple floors in the building environment is considered, using lower frequency bands, such as 447MHz band, is better than the 917MHz band.

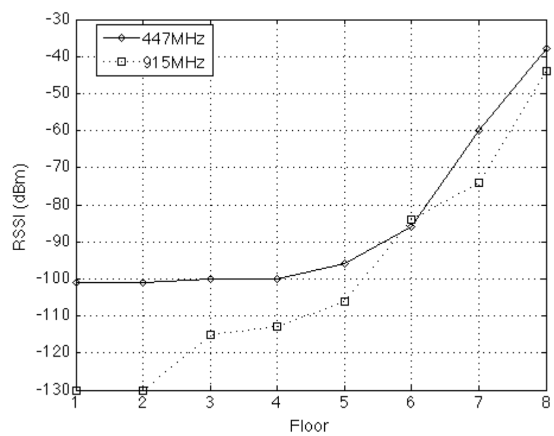
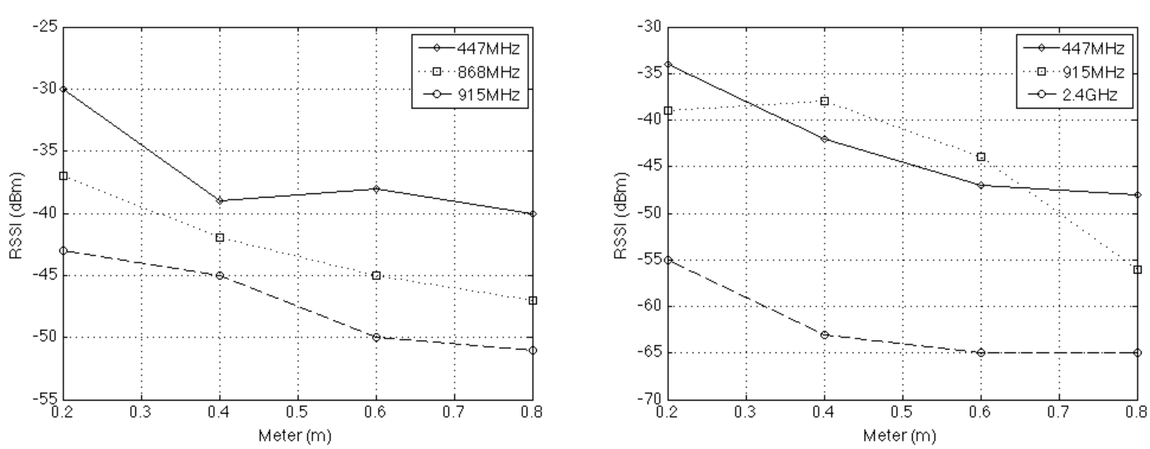


Figure 7. Experiments for multiple floors of the building

4.4 Experiments for Various Obstacle Materials

Figure 8 shows the RSSI measurement results for the 447MHz, 915MHz, and 2.4GHz bands depending to the type of the obstacle materials, the ferroconcrete wall and the steel door. From Figure 8, we can observe that the radio wave propagation properties of 447MHz and 915MHz were superior to that of 2.4GHz for both materials. The results for the building environment were also came from the better diffraction properties of the 447MHz and 915MHz bands.



(a) (b)

Figure 8. Experimental results for various obstacle materials. (a) Ferroconcrete wall. (b) Steel door.

5. Conclusion

In this paper, we first design the RSSI measurement systems operating in the sub-1GHz bands including 447MHz, 868MHz, and 915MHz, and the 2.4GHz band. In order to compare the propagation property of the RF electromagnetic waves, we then experimentally measured the RSSI values for different types of experimental conditions in the practical building environment. For the building environment, we can conclude that the sub-1GHz bands are more appropriate than the 2.4GHz case in constructing the wireless sensor network because of the better diffraction properties of the sub-1GHz bands.

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