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Performance Analysis of Xbee-Based WSN in Various Indoor Environments

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ABSTRACT

This paper presents the development and the performance analysis of Xbee based Wireless Sensor Network (WSN) in various indoor environments. The main objective is focus on the effect of absorption from different types of wall, different levels of a multilevel building, humidity level and the presence of other wireless device in such area. The test is performed by deploying two sets of hardware which consist of Xbee Pro module, Xbee Sheild and Arduino board with microcontroller chip. Results indicate a substantial effect of the various indoor scenarios to the value of Received Signal Strength Indicator (RSSI) and the rate of successful received packets. Furthermore, this paper also proposes standard procedures in the planning and deployment of Xbee based WSN in indoor environment which have similar characteristics with the tested area. Extended studies can be done in order to optimize the performance of Xbee based WSN.
KEYWORDS: Arduino, RSSI, WiFi, 2.4GHz, Zigbee.

INTRODUCTION

Wireless Sensor Network (WSN) is a trend since the last few years due to the advances made in the wireless communication, information technologies and electronic field [1]. With the rapid development of this technology, there has always been an urge for ways to extend that technology and integrate it into every aspect of daily life. The low-cost, low powered development of multifunctional sensors and controller have received increasing attention from various industries. Moreover, it is poised to become a very significant enabling technology in many sectors, since it is now widely used in military, health, environment, commercial areas and even at home [2, 4].

In analyzing the performance or quality of Xbee based WSN, the key properties of radio for practical applications are the range, which is the area that can be covered, and the bandwidth. In order to identify the most important properties, several parameters are proposed to be tested including received packet ratio and Received Signal Strength Indicator (RSSI) [3, 4]. In term of structure, indoor environments have dominated the multi-path effect, where the reflections from obstacles cause multiple receptions at the receiver end. The effect can be positive or negative depending on how the reflections interfere. Range has played a very important part in the performance of WSN. The location between two communicating nodes can give an impact to its RSSI level [5, 6]. Close-door environment lead to worse localization accuracy because building walls cause significant wireless signal attenuations. Zigbee devices are also likely to be interfered by WiFi devices since both communication protocols share the same Industrial, Scientific and Medical (ISM) radio bands between 2.4GHz and 2.485GHz [7].

In order to provide a test-bed for the research, two sets of hardware which consists of Xbee Pro module, Xbee Sheild and an Arduino board were used. Xbee brand Zigbee radios were used to provide communication between both sets of embedded devices. Although the both sets of hardware were not optimized by any specific application, but the deployments of the hardware were efficient enough in analyzing the performance of Xbee based WSN in various indoor environment [6]. Common performance indicators such as RSSI and rate of successful packet received were analyzed in order to characterize the network link behaviour in indoor environment. The effect of other 2.4GHz sources such as WiFi was also taken into account. These insights may be useful for future deployment of WSN devices in such area.

METHODOLOGY

Figure 1 represents the whole process of the research. Three major processes include the development of hardware, software and various scenarios test in order to analyze the performance of Xbee based WSN in various indoor environment.

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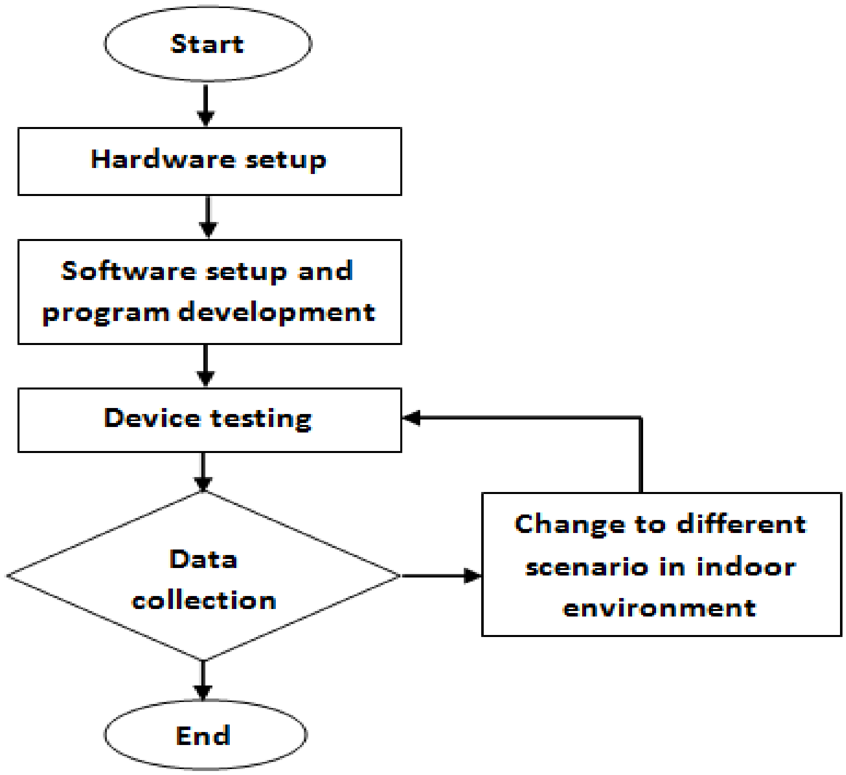

Figure 1: Flow chart of research implementation

Hardware Development

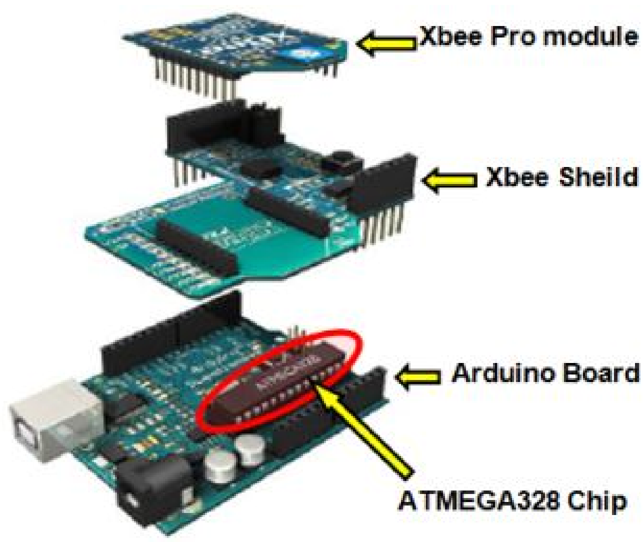

Figure 2: Hardware setup for base and remote nodes

An Arduino board which is embedded with Xbee Shield and Xbee Pro as its communication module is used as a base and remote node as illustrated in Figure 2. An Arduino board which employs ATMEGA328 chip as a processor is used at the base node [2, 8]. As for the remote node, no chip is required since the board is not loaded with any program. The remote node is setup for loopback process as illustrated in Figure 3. Base node is then connected to a laptop via a USB cable during data collection process as shown in Figure 4.

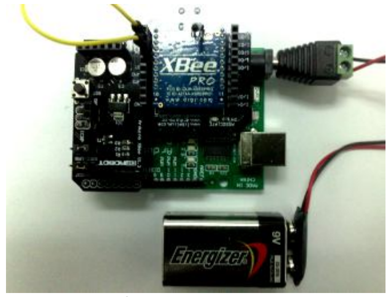

Figure 3: Loopback setup for remote node powered by a 9V battery

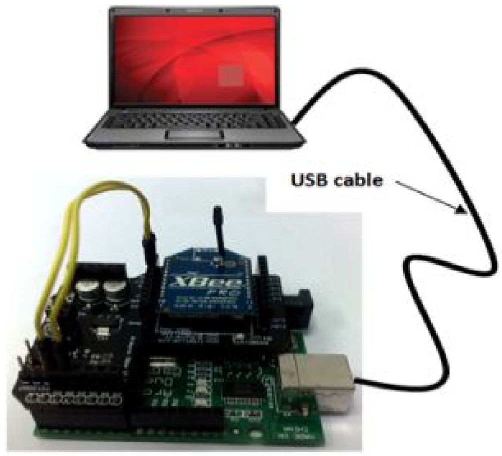

Figure 4: Hardware setup for base node and connected to a laptop via USB cable

Software Setup

Digi International's X-CTU is a software tool which is used for configuring Xbee Pro modules [2]. The setting includes its destination address, node address, sampling rate and also for energy scanning purpose of every channel available at the tested area [11]. Arduino IDE software is used as a code editor and a compiler. Arduino IDE is also use to monitor the packet transmission process during the test.

Scenario Test

The scenario test is carried out with point to point communication setup between base node and remote node as shown in Figure 5. The packets are transmitted regularly over a given time period and the corresponding data is saved [3].

Figure 5: Point to point communication between base node and remote node

Data were collected at different indoor locations and scenarios. The first scenario setup was between two classrooms which are separated by a wall as shown in Figure 6.

Figure 6: Base and remote nodes is separated by a wall

There are three types of wall that were tested for these experiments which are concrete, wooden and Glass-fire Reinforced Cement (GRC) board wall. The distance of both nodes from the wall was synchronized throughout the experiment which is at 1.5m.

Next, test was conducted in a four levels building which is the highest building in UiTM Dungun Terengganu. Base node was placed at the bottom level and remote node was placed at the second level as illustrated in Figure 7. The remote node was then moved to the third and finally to the fourth level.

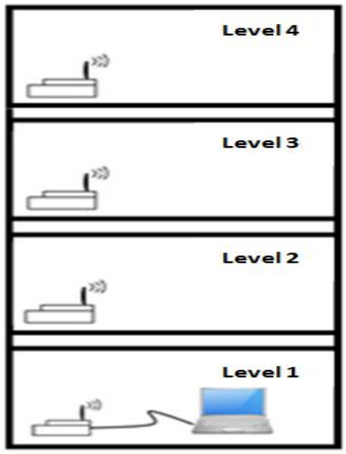

Figure 7: Nodes positioning for performance test in a multilevel building

As illustrated in Figure 8, the experiment setup was to measure the performance of the tested device between two different environments regarding to the difference in temperature and humidity.

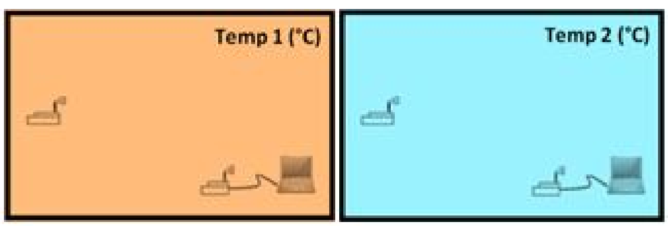

Figure 8: Performance test in two different temperature and humidity

Both devices were placed in the same air conditioned room. For the first experimental condition, the air conditioner was turned off and later turned on during the second test. The temperature and humidity reading were captured by using temperature and humidity digital sensor, as shown in Figure 9.

Figure: 9: Temperature and humidity digital sensor

The main purpose of the experimental tests was to analyze the effects of transmission link quality in different types of wall, different levels in multi-level building and also the changes of temperature and humidity. All of the effects were analyzed through the level of its RSSI.

These experiments were also setup to study the effect of existing 2.4GHz sources to the performance of the tested device. This study was conducted with the presence of WiFi signal in UiTM Dungun Terengganu. Energy scanning was carried out to view the noise level for every channel available in order to determine the best and worst channels at every tested scenario. The channel that had the lowest level of RSSI was considered as the best channel and vice versa.

The performance between the best and worst channels provided in 2.4GHz spectrum were compared by analyzing the percentage of successful packet received and its RSSI during packet transmission. The transmission data were monitored at the base node in the serial monitor window provided by the Arduino IDE software as illustrated in Figure 10. Samples of the saved data were analyzed for each tested scenario.

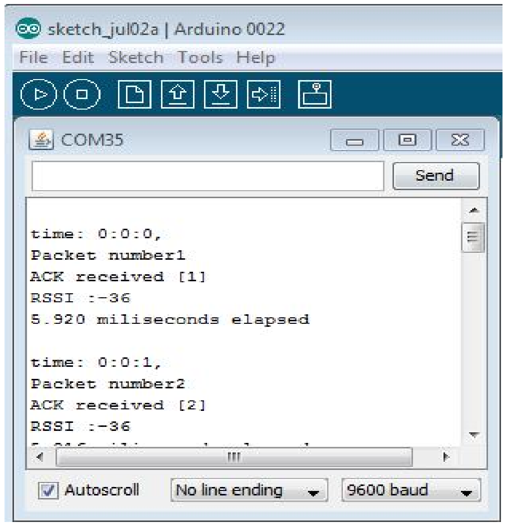

Figure 10: Output from Arduino serial monitor at the base node

RESULTS AND DISCUSSION

Performance Analysis in Multilevel Building

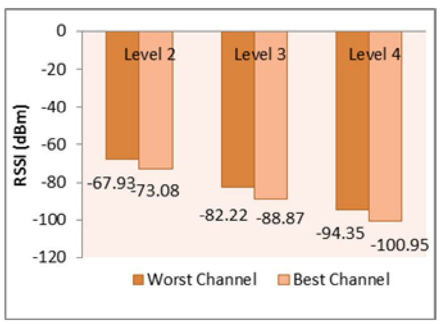

Figure 11: Average RSSI values versus number of level in multilevel building

Figure 11 shows the values of average RSSI at different level in a multilevel building. The decrement of RSSI values for both channels were almost at the same rate when the remote node was moved from second level up to fourth level which were about 20% and 13% respectively. Even at more than -100dBm for RSSI value, the packets were still successfully received.

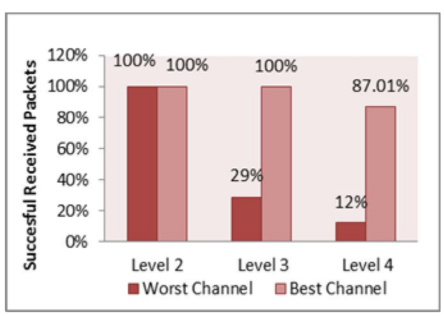

Figure 12: Percentage of successful received packet in every level

Although the average RSSI values for channel C were better compared to the best channel available, the rate of successful received packets dropped drastically from 100% to just 29% at third level and only 12% of the sending data were successfully received when it was measured at the fourth level. The successful received packets give us a measure of the transmission reliability. It does not only depends on the given signal strength, but also on the interference and other local specifics [12]. It can be seen that the RSSI value does not guarantee a high ratio of successful received packets. Therefore, this is useful only for quick evaluation range [9].

Performance Analysis at Different Types of Wall

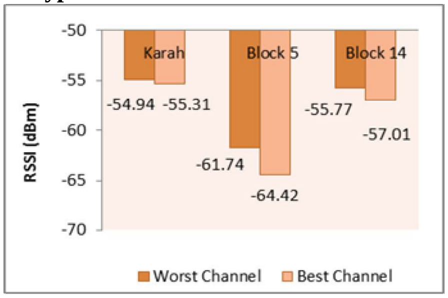

Figure 13: Average RSSI level versus location with different types of wall

Figure 13 shows that the average of RSSI for wooden wall is the best compared to the brick and GRC board walls. The main reason is the difference in the thickness of the walls as shown in Table 1.

Table 1: Location description and specification

Location	Types of wall	Thickness (mm)	WiFi	Best channel	Worst channel
Karah	Wood	90	Yes	17	C
Block 5	Brick	165	Yes	14	C
Block 14	GRC board	60	Yes	F	C

The structure for GRC board and wooden wall are made of a combination of two of the respective materials with some gap in between as illustrated in Figure 14.

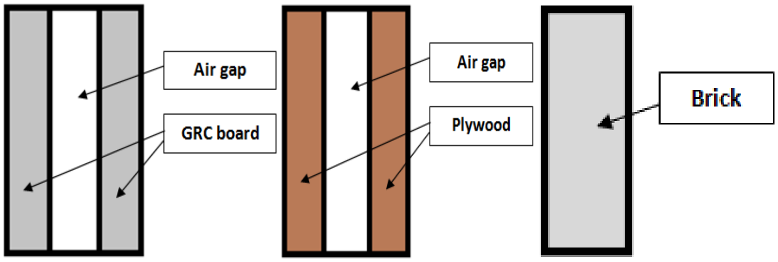

Figure 14: Structure design for GRC board, wood and brick wall

As a result, the designs of the walls are not as solid as brick or concrete wall. Solid wall is proved to provide much better resistance to the signal transmission compared to the hollow wall [3, 13].

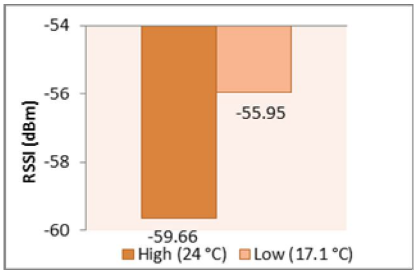

Figure 15: Average RSSI level in two different temperature and humidity

Figure 15 illustrates the effect of temperature and humidity to the link quality of packet transmission [10]. As presented in Table 2, a room where the air conditioner was turned off, the temperature was measured at 24.8°C and the humidity was at 78%. The second scenario is when the air conditioner was turned on and was to set to its lowest temperature. The temperature and humidity were measured at 17.1°C and 45% respectively.

Table 2: Room specifications at two different conditions

Condition	Temperature (°C)	Humidity (%)	RSSI (dBm)	Channel	WiFi
1	24.8	78	-59.66	C	Yes
2	17.1	45	-55.95	C	Yes

The average of RSSI value indicated a slight improvement when the temperature and humidity getting lower [9]. This is due to the improvement in transmission link quality since less humid air provide much better medium for wireless signal transmission.

CONCLUSION

In this paper, the performance of the Xbee based WSN has been tested in various indoor environments. Typical performance indicators including RSSI and rate of successful received packet have been analyzed throughout the tests. It is proven that absorption effect provides significant impact on the RSSI level as different types of wall give different value of RSSI level. Apart from that, distance between two communicating nodes is also proved to have impacts on the performance of the network. Other 2.4GHz sources signal such as WiFi and other wireless devices provide significant noise level that can affect the performance of Xbee based WSN device in such area.

From the obtained results, several considerations need to be taken into account before any deployment of the Xbee based WSN in indoor area which have similar characteristics with the test-bed. As been proven from the experiment, a solid obstacle provides greater resistance towards signal transmission compared to a hollow obstacle. While for deploying the device in a multi-level building, the results from the experiment show that the devices can still communicate between each other even when they are separated by the margin of two levels. The level of RSSI is inversely proportional to the height or distance between the deployed nodes. The greater the distance between the nodes, the weaker the strength of the signal received [12]. The result from the performance analysis also shows that the link quality of the transmission signal is much better when the air is less humid since humidity affects the strength of transmission signal by congesting the air and making it harder for the signal to get through.

The other main factor that needs to be put into consideration is selecting the best operating channel for Xbee radio. Some of the available channels might be prone to interference from other 2.4GHz sources. Hence, energy scanning must be carried out at any deployment areas in order to find out the best operating frequency channel to ensure a high quality signal transmission between nodes. These insights may provide useful information and knowledge for future deployment of WSN devices in such area.

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The authors declare that they have no conflicts of interest in this research.

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