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Test Bed Implementation of IEEE 802.15.4 WSN for Outdoor Environment

[1]Mohamad Taib Miskon, [1]Zairi Ismael Rizman, [1]Fadhli Dzul Hilmi Mohd Fauzi,
[1]Ahmad Shahran Ibrahim, [1]Mohamad Yusof Mat Zain,
[2]Nurul 'Uyun Ahmad and [3]Nur Hafizah Rabi'ah Husin

[1]Faculty of Electrical Engineering
[2]Faculty of Chemical Engineering
[3]Academy of Language Studies Universiti Teknologi MARA Terengganu,
23000 Dungun, Terengganu, Malaysia

Abstract: This paper presents the development and the performance analysis of IEEE 802.15.4 Wireless Sensor Network (WSN) test bed for outdoor implementation. In particular, the analysis is focusing on the effect of environmental parameters including absorption, Line-Of-Sight (LOS) condition, humidity level and the presence noise frequencies to the link quality between nodes. The WSN platform is developed using an Arduino microcontroller board and SKXbee Pro module, a low cost Xbee series 1 IEEE 802.15.4 standards prototyping kit. Results indicate a substantial effect on Received Signal Strength Indicator (RSSI) values and packet loss indicator (PLI) in LOS condition and high noise environment. A proper procedure in outdoor WSN deployment planning is proposed and further studies can be done in various aspects such as using complex network topology and user interfacing.

Key words: Arduino · IEEE 802.15.4 · WSN · Outdoor and Xbee

INTRODUCTION

The term wireless sensor networks or WSN can be referred to a network of sensors deployed to collect or sense the environment which include physical world, a biological system, or an information technology (IT) framework. The WSN technology is seen by researchers as an important technology that will experience major deployment in the next few years. Typical applications include, but are not limited to, data collection, monitoring, surveillance and medical telemetry. In addition to sensing, WSN can also be integrated with control and activation capabilities [1].

Simulation analysis presented by [2] has pointed out several issues contributing to the performance of WSN. Among them is the location of sensor motes, power consumptions, sensing capability, operating environment and connection quality with the Personal Area Network (PAN) coordinator. Authors in [3] studied the characteristics of the packet delivery at physical and medium-access layer over different observation scenarios including indoor, outdoor and habitat environments. They found out that there is an area within the communication range between nodes in which the reception rate shows a discrepancy and that physical layer coding schemes cannot reduce this problem. The works described in [4] analyzed the temporal characteristics of sensor network links based on outdoor experiments. Weather conditions such as rainfall, fog, humidity and hours of sunshine certainly could influence protocol performance and reliability. It might be useful in protocol analysis to use such information to predict good transmission times or to avoid transmission during bad weather condition.

There are several WSN hardware platforms available. The test-bed that has been used in this project is SquidBee, an open hardware and open source wireless sensor device designed by Libelium. SquidBee works by collecting values from environment parameters such as temperature, humidity, light, presence, pressure or any other parameters. Next, it processes those values and transmits using Xbee type of ZigBee radios. The hardware of each mote consists of an Arduino board, an Xbee shield that supports an Xbee module and sensors.

Corresponding Author: Mohamad Taib Miskon, Faculty of Electrical Engineering, Universiti Teknologi MARA (UiTM), 23000 Dungun, Terengganu, Malaysia.

Although the prototype hardware platform is not optimized for WSN applications in term of cost, energy consumption, size, nor real-time application support; the platform allows easy development of a WSN due to the simplicity of programming implemented in an Arduino microcontroller board [5].

In this project, the performance of IEEE 802.15.4 standards wireless sensor networks in various outdoor scenarios has been analyzed. Common performance indicators such as RSSI and packet loss indicator are important in order to characterize the network link behavior in outdoor environments. Besides, the effect of other 2.4 GHz sources such as WiFi has also been analyzed. The results obtained help to provide insight to the deployment planning of WSN in such area.

MATERIALS AND METHOD

Figure 1 shows a flow chart which describes the overall process that has been carried out in completing the project. Three major processes involved are the development of hardware, software development and experimental studies to investigate the performance of the test-bed in outdoor environments. In general, the hardware platform is selected based on few factors such as cost, the availability in the local market and the ability of the device to work under outdoor environment with minor modification. Once the hardware setup is completed, the software development is carried out. This process includes updating the Xbee firmware with relevant configurations and programming the base station. In this project, the base station is programmed to interpret the arriving data packets from remote nodes and also has the capability to do loopback test. Next, a study on the effect of several outdoor environments towards the device performance is carried out.

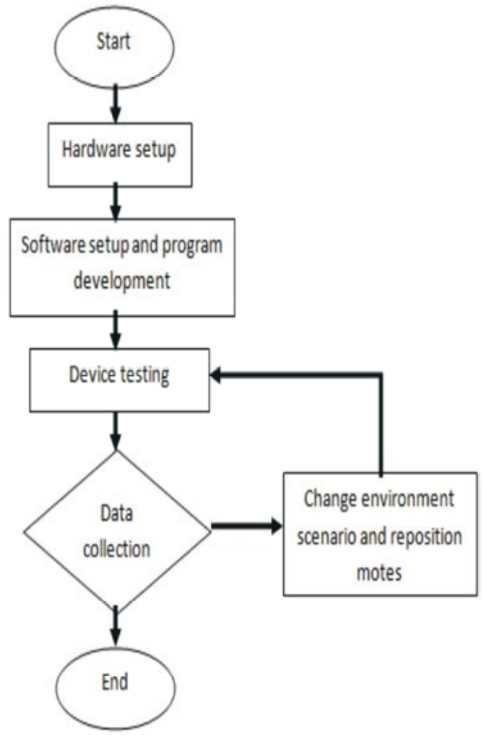

Fig. 1: Flow chart of research implementation

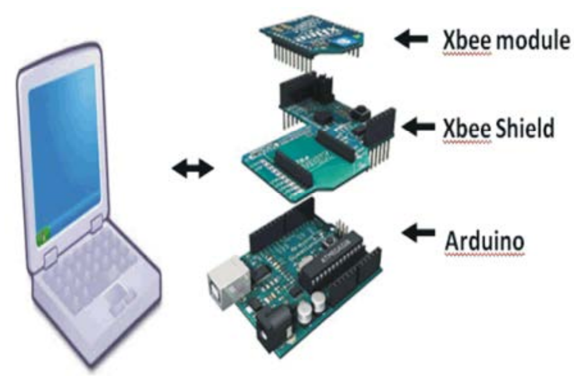

Fig. 2: The connection of base station to a computer

Hardware Specification: An Arduino board is used in the base station. It employs ATMEGA328 chip as a processor. The board contains 5 analog I/O pins and 13 pins for digital I/O which can also be connected to other devices such as SPI and I2C. Every node employs Xbee Pro radio from DIGI International as its communication module that supports IEEE 802.15.4 standards. The test-bed has been implemented based on two topologies. The first topology is based on the point-to-point topology that has been used for experimental measurements while multipoint-to-point topology [6] has been used for the general environment monitoring test. The base station consists of the Arduino board, Xbee Pro, Xbee shield that are connected to a computer [7]. On the other hand, the remote node consists of SKXbee module attached with temperature sensor LM35Z and humidity sensor HSM-20G. The hardware setup is illustrated in Figure 2, Figure 3 and Figure 4.

Software Specification: Arduino IDE software has been chosen as a code editor and compiler. The Arduino board has been programmed using Arduino-compatible C language. The program algorithm for the base station has been developed to receive and interpret a series of data packets transmitted from the remote stations. A NewSoftSerial.h library was used to create a virtual

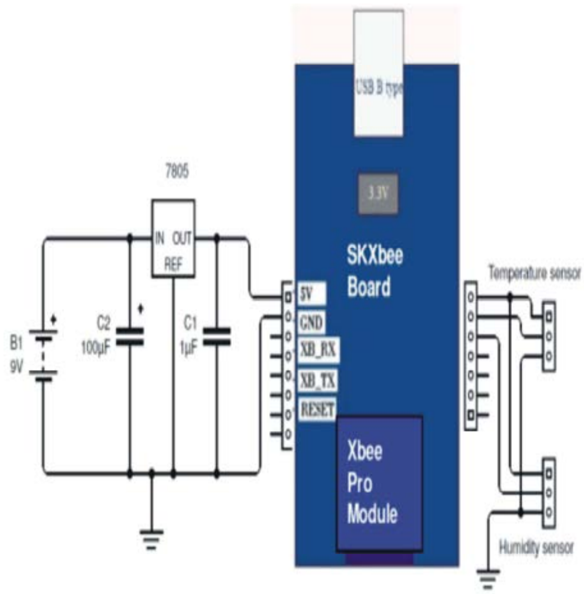

Fig. 3: The modification of SKXbee board at remote station

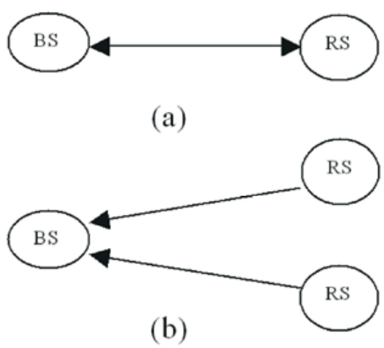

Fig. 4: Network topologies for experimental measurements: (a) Point-to-point communication between base station (BS) and remote station (RS) and (b) multipoint-to-point communication between remote stations to base station

communication port at the base station so that it can communicate with other remote nodes and at the same time send data packets to the computer for serial monitoring display.

7E, 00, 0A, 83, 88, 88, 46, 00, 01, 04, 00, 00, 4C, D5

Figure 5 shows a sample of received data packet at the base station. The Xbee Pro modules were configured in API mode where all data entering and leaving the module is framed and it dictates how the module will respond to data exchange via its UART. In this project, firmware version 1xCD was implemented for the radio modules and it offers thirteen packet types that can be sent or received within the modules. Every packet has a three-byte header, a payload and single-byte checksum. The first byte of the header is always 0x7E. The second byte of the header is the most significant byte of the payload length and it is always zero because normally no packets are longer than 255 bytes. Thus the payload size is represented by the third byte of the header. The checksum is calculated by subtracting the sum of the payload bytes with 0xFF. Figure 5 shows an input line states packet. This type of packet was used by the remote nodes to send data to the base station. The second and third bytes represent the source address of 8888 remote node.

7E,00,0A,83,88,88,46,00,01,04,00,00,4C,D5

Fig. 5: Example of received data packet

Digi International's X-CTU software has also been used to configure the Xbee Pro module [8]. All the modules used in this project were set to use the same PAN ID. Other settings include the destination address, node address, API configuration, sampling rate and input/output assignment.

Experimental Setup: Three experiments have been conducted to investigate the performance of the test bed at three different test fields such as beach, school and campus building area specifically in Dungun, Terengganu. The first experiment has been done to investigate the effect of distance on the RSSI level between the nodes in LOS and non LOS environment. To provide LOS between the nodes, a large and open beach area at Pantai Teluk Bidara as illustrated in Figure 6 was selected and the remote node was positioned at distances within 1000 meters from the base station. Besides, a non LOS test condition was executed near Sura Secondary School as shown in Figure 7.

In order to study the effect of humidity level towards the transmission link quality, a remote node was placed about 50 meters from the base station and was set to send data packet continuously for ten hours. The data packet sent to base station contains information of the humidity level at the remote station. The experiment was done at one of the campus buildings in UiTM, as illustrated in Figure 8.

Besides, another experiment was carried out to study the effect of existing 2.4 Ghz sources to the test bed. This study was done at the WiFi zone within UiTM Terengganu as illustrated in Figure 9.

Fig. 6: Test field at beach area

Fig. 7: Test field at school area

Fig. 8: Test-bed at campus building area

Other than that, the selected location is also close to celcom 3G base station and four spots were selected around the base station. An energy scan was carried out at every spot shown in Figure 9 using the ATED command on the X-CTU interface to view the noise level at every frequency channel provided in 2.4 GHz spectrum band.

Fig. 9: Test location within WiFi zone in campus area

RESULTS AND DISCUSSION

Test-Bed Implementation: The test-bed had been successfully developed and tested. Figure 10 demonstrates the base station and two remote nodes designed for outdoor implementation. The data received from the remote nodes were monitored by the base station using serial monitoring window provided in the Arduino IDE software as illustrated in Figure 11.

Experiment 1: Rssi Versus Distance: Figure 12 shows the RSSI of the remote node plotted against distance. As expected based on results in [9], the RSSI decreases over distance in both LOS and non-LOS environment. The maximum detection distance in LOS environment was 1000 meters with-100 dBm RSSI. This was due the minimum noise level at the test area as the location is isolated from other 2.4 GHz resources such as WiFi or any telecommunication base station. The highest recorded RSSI value was -36 dBm and it was obtained when the remote node was placed within one meter from the base station.

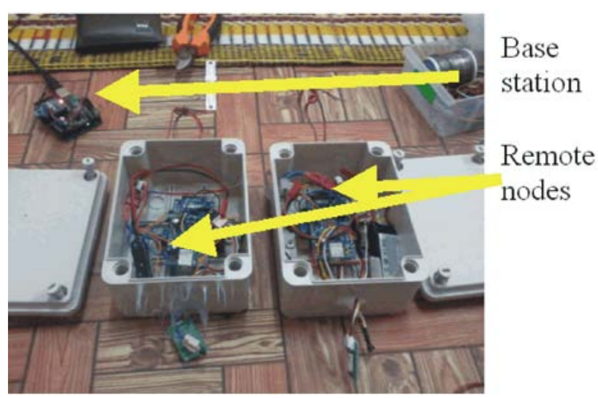

Fig. 10: Base station and remote nodes

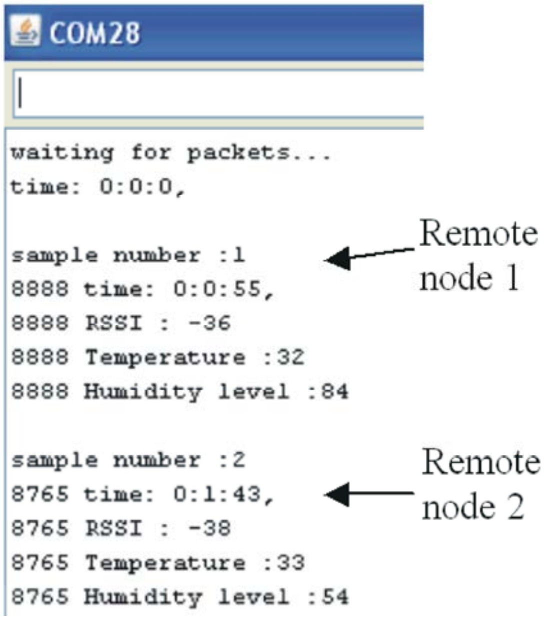

Fig. 11: Base station output

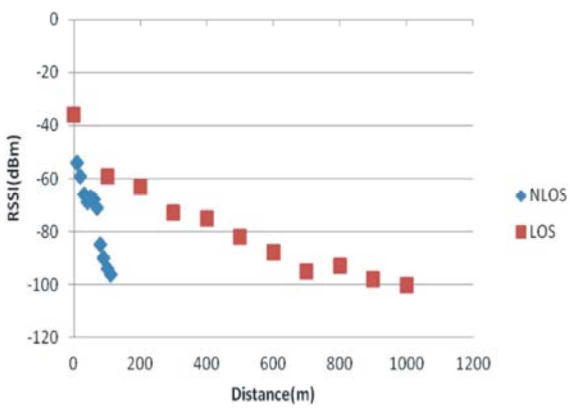

Fig. 12: RSSI versus distance in LOS and NLOS environment

As for non LOS environment, the maximum detection range was significantly decreased compared to maximum detection range achieved in LOS environment. As agreed in [10], this was due to signal obstruction and absorption caused by the trees and other plants within the test area.

Experiment 2: RSSI Versus Humidity: Figure 13 (a) and (b) show the results taken from this experiment. The results demonstrate that the increasing humidity level did not affect the RSSI values. This was because water molecules in the area were not dense enough to affect the signal energy. As the humidity level increases over time, the RSSI level is maintained at between-72 and -73 dBm.

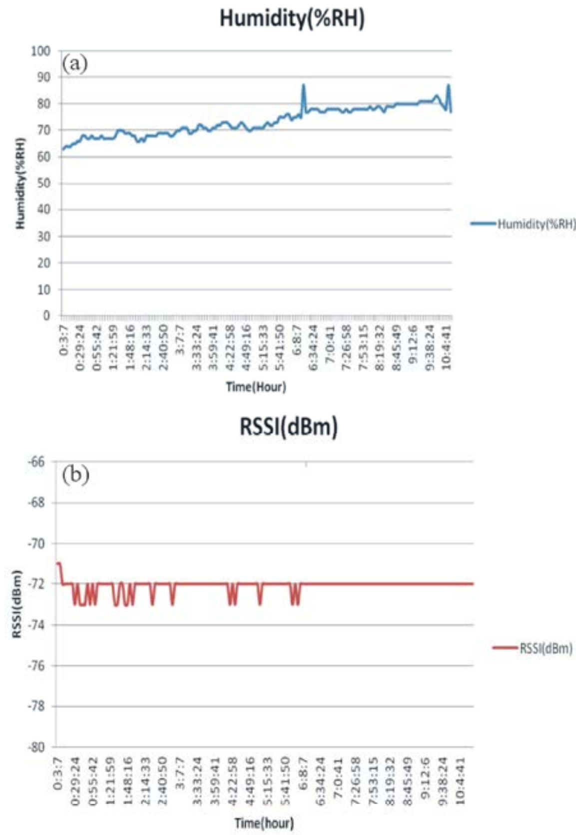

Fig. 13: (a) Humidity level vs. time and (b) RSSI vs. time

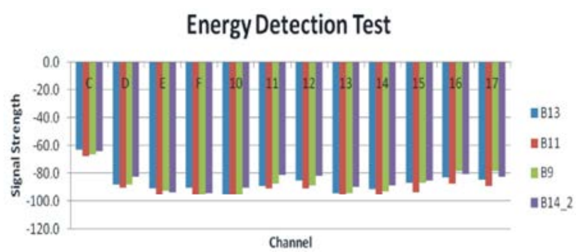

Fig. 14: Noise level at various frequency channel in 2.4 GHz band

Experiment 3: Energy Scan And PLI: Figure 14 illustrates the noise level measured at all 12 frequency channels within the 2.4 GHz spectrum band of the Xbee Pro module. It was clear that C channel had the highest noise level at most of the location. The differences of noise level can be associated with the presence of other 2.4 GHz resources in the area such as WiFi networks and celcom 3G base station. Those resources might have been operating using frequency signal close to C channel within the 2.4 GHz band. This was supported by another energy test carried out at the non WiFi area where there were almost no noises at C channel.

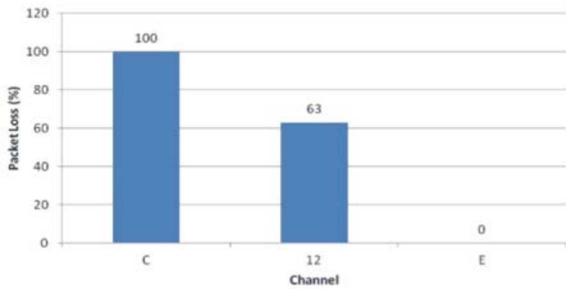

Fig. 15: RSSI versus distance in LOS and NLOS environment

PLI had been measured at three different channels including C, 12 and E channel. The results are as shown in Figure 15. During the test, a total of 200 packets sent using C channel were lost resulting the PLI to be 100%. Besides, when channel 12 was used, 63% of the packets sent were lost while none of the packet sent were lost when E channel was used.

CONCLUSION

In the project, the performance of the test-bed has been tested in various outdoor environments. Common performance indicators such as RSSI and PLI have been used. Distance between nodes provides significant impact on the RSSI level as the distance increases, the RSSI level decreases. Other resources of 2.4 GHz signal such as WiFi and other wireless devices provide significant noise level that can affect the test-bed deployment.

From the results, it was learnt that there are several considerations that need to be taken into account before the test bed can be used in real-life deployments. First consideration would be LOS condition of the desired deployment area. As proven by the first experiment, a non LOS condition between nodes severely decreases the reliability of the signal especially in terms of detection range. Thus, a clear area is important if the sensor network is expected to perform at its maximum. Besides, across a distance, amount of water molecules in the air must be dense enough in order to absorb RF energy. This was proven by the results shown in experiment 2 as high humidity level did not provide significant impact on the RSSI values. Other than that, the operation frequency in the Xbee radio might be prone to noise from other sources in the 2.4 GHz spectrum. Therefore, there is a need to perform energy scan within the deployment area, so that the operating frequency channel with less noise can be selected to ensure higher link quality between nodes.

In short, the noise level of any desired WSN deployment area need to be scan, so that the best operating frequency can be used. Next, the placement of sensor node must consider the LOS condition to ensure maximum distance and signal reliability.

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