Zigbee Based Wireless Sensor Networks and Performance Analysis in Various Environments

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Abstract— **To achieve a reliable and robust system for environmental monitoring, there is an available technology that can be used to resolve this problem and moreover provide for better living. Wireless sensor networks (WSN) have been successfully applied in many environmental monitoring. An ad-hoc wireless sensor network consists of a number of small and self-power sensing devices (nodes) connected using effective wireless networks. Compared to wired networks, there are several challenges that must be addressed in wireless networks. These challenges are limitiation in communication bandwidth and energy constraint in sensor node, therefore it is important to know their realibility and performance. This paper reports the development and performance analysis of an embedded wireless sensor network for temperature and humidity monitoring in the environment. The network itself consists of a coordinator or data gateway which wirelessly collect temperature and humidity data from several sensor nodes that are responsible to provide those data. Each sensor node is developed from an arduino based microcontroller, Xbee wireless module based on Zigbee/IEEE 802.15.4 standards, and temperature and humidity sensor devices. The network quality of service (QoS) is investigated in terms of delay, throughput and packet loss as a function of sensor node distance and transmitted packet size over line of sight (LOS) and non line of sight (NLOS) conditions. The throughput and packet delay are also measured as a function of the baud rate in point to point link. This experiment is performed to have an insight how the baud rate affect the latency of the communication over the Zigbee protocol. Next, we also considered the multi-hop scenario with the presence of router for relaying pakets from the sensor node to the coordinator. The performance of multi-hop configuration is compared to that of direct transmission. Based on our analysis, it is concluded that the Zigbee based WSN is more suitable for low data rate applications.**

Keywords—Performance analysis; Sensor node; Wireless sensor networks; Zigbee, Multi-hop configuration

I. INTRODUCTION

In the recent years, wireless sensor networks (WSNs) have used in many applications, such as military, agricultural, industry, home and domestic, health and medical, and environmental [1]. The development of WSNs is available due to low power sensor, low cost embedded microcontroller, and effective wireless communication technologies. WSNs have received considerable attention in environmental applications especially in physical parameters monitoring such as temperature, humidity, sound, vibration, pressure, and gas pollutant. WSN is a self-organizing adhoc multi hop network that consists of spatially distributed sensors nodes deployed in a wide area [2]. Those nodes are allowed to communicate and transmit/receive those sensing data. Thus, WSN enable all physical parameters sensing, data processing, and wireless communication simultaneously.

We have developed a prototype WSN for temperature and humidity monitoring, reported here [3]. This system is modularity developed from an arduino board, ZigBee based communication module [4], and low power temperature and humidity sensors.

In this paper, we focus particularly on analysis performance on the developed prototype system. In analyzing the performance, quality of service (QoS) parameters of communication are investigated. These parameters, i.e. delay, throughput and packet loss, are investigated as a function of sensor node distance and transmitted packet size over line of sight (LOS) and non line of sight (NLOS) conditions. Next, we also considered the multi-hop scenario with the presence of router for relaying pakets from the sensor node to the coordinator. The performance of multi-hop configuration is compared to that of direct transmission. This experiment work would give a better understanding about the performance and capability of ZigBee based WSN technology in real life applications.

The rest of the paper is organized as follows. Section II describes the methodology including hardware design and experimental setup. The research finding is presented in Section III. Finally, section IV concludes the paper.

II. METHODOLOGY

A WSN prototyped system is built based on modularity design [3]. The developed system has two types of nodes, i.e. sensor node and coordinator node. Sensor nodes play as an end device that senses physical parameters of environment, i.e. temperature and humidity. Then, the coordinator node is responsible to collect all data readings from the sensor nodes and subsequently send them to the user. In our developed system, an Arduino Uno [5] is used as the heart of the node. It has microcontroller chip Atmega328 and is controlled by the computer using USB connection. For the communication task, Xbee S2 is used on the system. It operates based on Zigbee protocol within 2.4 GHz frequency band with 250 Kbps RF data rate [6]. For the parameters sensing, LM35DZ [7] and DHT11 [8] sensors are used to read environment temperature and humidity, respectively. Arduiono Uno board is programed using open based application of Arduino IDE [8]. Arduino IDE is capable as a program editor, code compiler, and upload it to the microcontroller. Using X-CTU software provided by Digi [10], we can configure the Xbee module as end device or coordinator, upgrade the firmware and monitor system parameters. Docklight 2.0 software is used to monitor data packet flow, so that we can get the QoS parameters calculations. Our prototype system has three key role functions; they are data acquition, data collection and data retrieval.

For the experimental set up, two sensor and one coordinator nodes are prepared in order to see WSN performance in LOS and NLOS communications. These nodes are able to build a network. These nodes transmit and receive messages in the network via wireless communication link using Zigbee protocol. Zigbee supports a variety of network topologies, e.g. peer-to-peer, star and mesh toplogies. This toplogy indicates how the transciever or receiver nodes are logically connected to others.

III. RESULTS

In order to see the performance of our WSN, we measure the throughput and packet delay as a function of packet size and the baud rate over various distances in point to point link. This experiment is performed to have an insight how the baud rate affect the latency of the communication over the Zigbee protocol. The baud rate is defined as processing data rate in serial communication of Xbee module. For this experiment, the point-to-point link at LOS condition is considered between the sensor node which is located 3 m from the coordinator node. The sensor node is configured to send 120 data packets to the coordinator node with 1 second interval between consecutive transmissions. Therefore, the packet delay and throughput, respectively, are calculated as an average of the results from the total transmissions. Several experiments are carried out in comparison for different packet sizes and baud rates. In order to avoid reception overcharge, the transmitted packet size is below the 84 bytes which is the maximum size of RF payload for each fragmentation [6]. Thus, the transmitted packet size is varied from 10 up to 80 bytes. In the meantime, the baud rate was set at 9600, 19200, 38400, 57600, and 115200 bps.

Fig. 1 illustrates the throughput as a function of packet size for different baud rates. The throughput is calculated as a number of packets sizes (bits) over required transmission times (seconds) to succesfully receive in the receiver. The measurement results show that the throughput increases as the baud rate increases. A maximum throughput of 19.2 kbps was achieved at baud rate of 115200 bps using highest packet size of 80 bytes. Although, this number is still far lower than the guaranteed data rate of 250 kbps for Zigbee protocol using Xbee S2 modules.

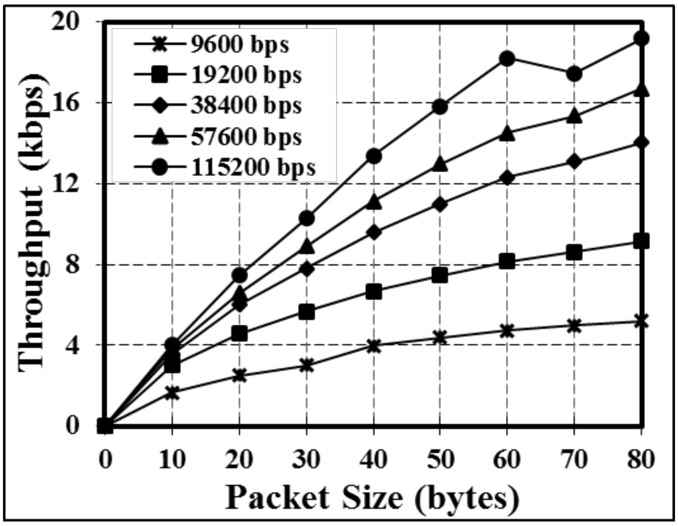

Fig. 1. Throughput measurments as a function of packet size at different baud rates.

Another key factor of communication performance is the packet delay between the transmitter and the receiver. The packet delay is expressed as the time duration between sending the packet until the packet has been received by the reciever. The delay measurement results at different baud rates and packet size are presented in Fig. 2. It is observed that the packet requires more times to get receiver when lower baud rate is used. The longest delay of 125.283 ms was achieved during transmission using the lowest baud rate of 9600 bps at maximum payload of 80 bytes.

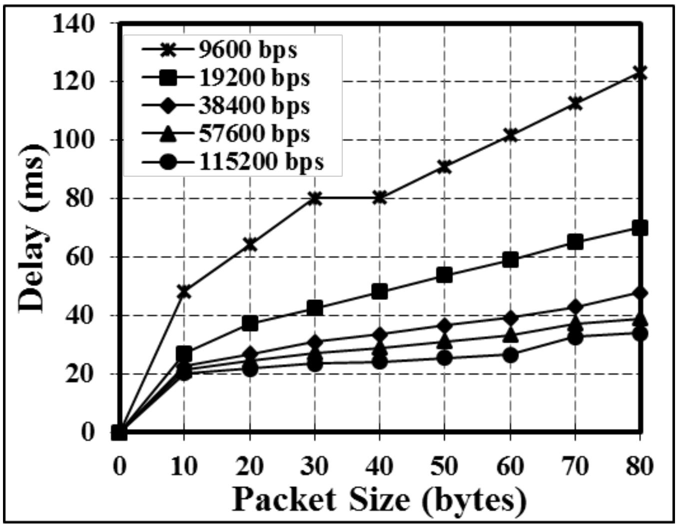

Fig. 2. Packet delay measurments as a function of packet size at different baud rates.

Another significant variable of communication performance is the packet loss. Packet loss is defined by the percentage of unsuccesfully packets to be received by the coordinator. Packet loss measurement is conducted in NLOS conditions over point-to-point communication. Fig. 3 shows the scenario of the measurements where we measure the packet loss in 4 (four) different locations. In the experiments, packets are sended in the text format which has size of 20, 40, 60 and 80 bytes. This transmission experiment is repeated 120 times with 2 seconds interval between consecutive transmissions.

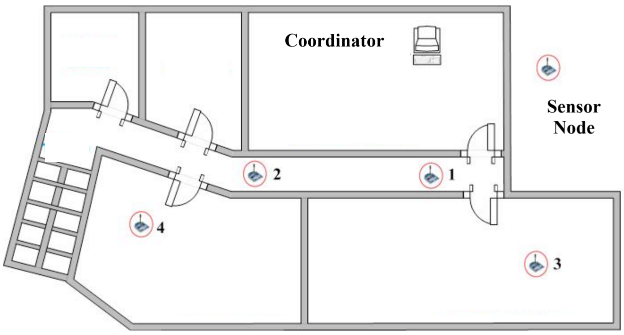

Fig. 3. Sensor nodes positions relative to the coordinator node in the study of packet loss over NLOS communication.

Fig. 4 shows the percentage of packet loss at four different location measurements. As expected that more packets are lost during transmission as the sensor node moves further from the coordinator node with additional wall as well. Given the results in the figure, the packet loss increases significantly as the transmitted packet size increases. It is observed that 95% pakets lost during transmission when we send 80 bytes packet from the most remote sensor node at location no. 4 to the coordinator.

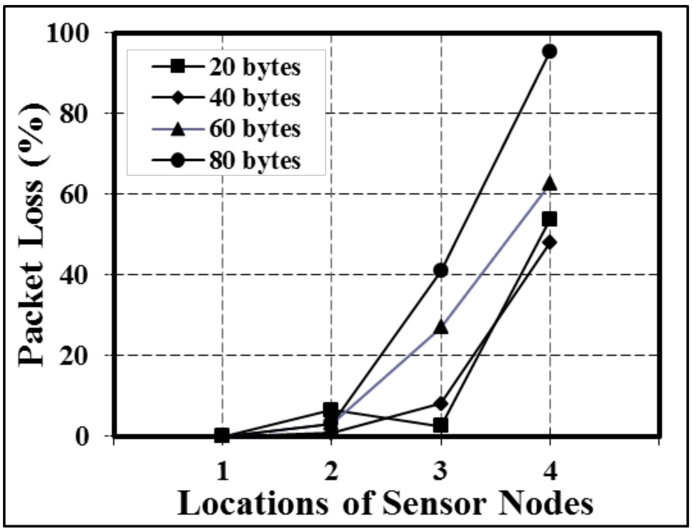

Fig. 4. Packet loss percentage at different packet size in four measurement locations.

In outdoor application, Xbee offers transmission range of 120 m. Therefore, in order to have more coverage area multi-hop configuration is essentially useful. Multi-hop network is realized using routers. Multi-hop performance is measured and compared to that of single-hop. In our experiment, network toplogy in Fg. 5 is considered where the packets transmitted from the sensor node relaying by the router to the coordinator. In this experiment, data throughput and packet delay are measured using baud rate of 9600 bps. Packets sizes of 10 butes up to 80 bytes are transmitted 120 times with 5 seconds of interval between consecutive transmissions.

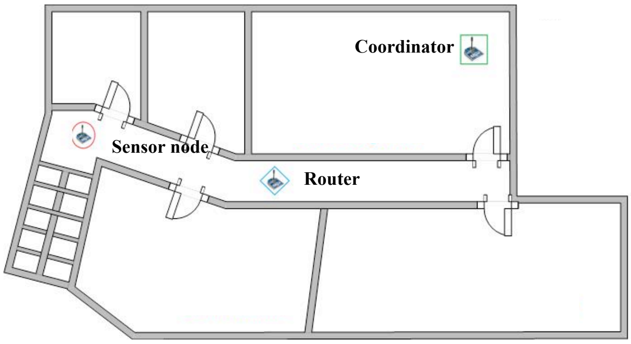

Fig. 5. Positions of end device, router and coordinator in the measurements of multi-hop communication perfomance.

As shown in Table I, the presence of the router (2 hops configuration) in the network give significant effects on the data throughput as well as the packet delay. In case of multi-hop configuration as shown In Fig. 5, when the router is relaying the data packet from the sensor node to the coordinator, the medium is employed. For the maximum payload (80 bytes), the packet delay for single hop is 122.488 ms and 180.4 ms for 2 hops. There is significant increasing of packet delay due to the additional processing time in the router. Similar thing happens in the throughput measurement. In the scenario of multi-hop, the throughput decreases as the packets need more time to get the receiver. Given the results from this experiments, it is observed that the performance of multi-hop configuration slightly decrease as a compensation for having more coverage area.

TABLE I. THROUGHPUT AND PACKET DELAY MEASUREMENTS FOR SINGLE AND MULTI-HOP CONFIGURATIONS

Packet size (bytes)	Throughput (kbps)		Delay (ms)	
	1 Hop	*2 Hops*	*1 Hop*	*2 Hops*
10	2.196	1.230	36.896	70.446
20	2.537	1.735	63.150	120.638
30	3.037	2.269	79.100	125.004
40	4.031	2.975	79.483	135.725
50	4.460	3.077	89.746	168.738
60	4.770	3.581	100.692	154.100
70	4.985	3.858	112.425	160.117
80	5.227	4.262	122.488	180.400

IV. CONCLUSSION

This paper reports the performance analysis of developed Zigbee based WSN. Several QoS parameters are considered in the analysis, i.e. throughput, packet delay and paket loss. We evaluate the performance in the LOS and NLOS conditions. It was observed, the baud rate affect the latency of the communication. When the baud rate increases, the throughput also increases however the packet delay decreases in performance measurement over LOS conditions. In NLOS experiment, it was found that more packets are lost during transmission as the sensor node moves further from the coordinator node due to additional walls. Furthermore, we also considered the multi-hop scenario with the presence of router for relaying pakets from the sensor node to the coordinator. The results show that the perfomance of multi-hop network is degrading compared to that of direct transmission in terms of data throughput and paket delay. Based on our analysis, it is concluded that the Zigbee based WSN is more suitable for low data rate applications.

Acknowledgment

We would like to extend our gratitude to the Ministry of Research, Technology and Higher Education through "Hibah Penelitian Unggulan Perguruan Tinggi" for financially support this research.

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