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SHARING RESEARCH EXPERIENCES OF WSN BASED SMART HOME

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Abstract*− *We are pursuing our research on ZigBee based WSNs for more than 8 years; a lot of realization stories are conveyed in literature on the development of wireless measurement of sensors data using ZigBee (XBee RF module). Many projects are fruitfully completed for applications such as smart home for elder care, environmental monitoring, big building monitoring and so on. Still a lot of design issues are there while the systems are designed using ZigBees. In this research paper the working experiences which may support other researchers to achieve success without wasting resources are reported. Moreover, presented research analyses of some unusual observations made in a proto-typed smart home monitoring system have been discussed. Packet delivery ratio (PDR) and latency are among a few reliability issues that have been analysed and addressed in this article to make the system more robust.

Keywords: Smart sensors, wireless sensor network, wireless sensors, measurement, instrumentation, XBee and IEEE 802.

I. INTRODUCTION

With the enhancement in wireless communications and networking technologies, the deployment and acceptance of wireless sensor networks (WSN) is improving. WSN have had achieved tremendous industrial acceptance, in the recent time it has improved the adaptation among people at domestic level a well in the home environment, and it is becoming the integral part of daily routine. Wireless sensor networks contain sensors connected with RF module, storing and processing devices with respective communication techniques. The wireless sensor networks provide numerous advantages in terms of cost, flexibility, ease of installation, continuous monitoring, reliable data collection and so on. In the last decade as well as in recent times, there has been massive research is done in the design, analysis, fabrication, development and deployment of wireless sensor networks but this field still offers many challenges which remain unaddressed. A successful wireless sensor networks system depends on many components, and the most important one is the smart sensors with associated instrumentation circuits including the communication module.

Currently, a lot of research and development related works are reported in literature, Figure 1 show the layout of home where we deployed wireless sensor nodes, and it is a home where people living their regular life. All the experiments is undergoing in realistic urban home scenario. A lot of research and development activities are reported in the literature. A few works on monitoring of electrical power parameters and home automation are reported in [1-6 & 19-20]. Moreover, home monitoring for elderly care has become an imperative research area in which ZigBee based wireless nodes is used [7 – 9 & 29-37].

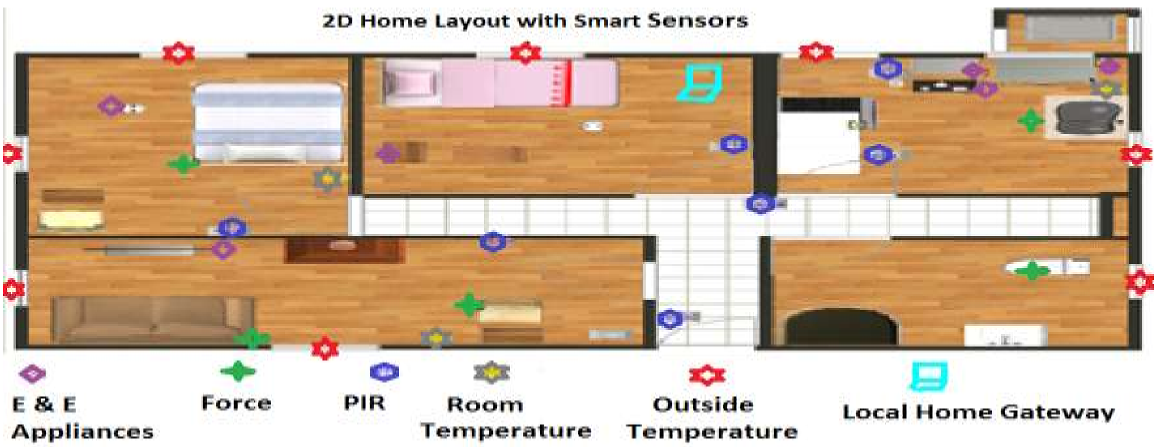

Figure 1: Placement of heterogeneous wireless sensor units using XBee (ZigBee) protocol in an old home.

ZigBee based urban environment monitoring catching special attention by the fact of unregulated and unlicensed ISM 2.4 GHz universal spectrum. For our research on smart home monitoring, we used ZigBee based XBee series-2 ZB RF chip. Limited research works have been completed using XBee on home monitoring, Physiological parameters measurement and solar panel monitoring [10 – 16]. There are some design issues such as optimum distance between nodes, interference, collision, data handling and storage, near real time data streaming on website, which will be very useful to share with fellow researchers working on a similar topic. It is very tough to include and address all issues of system level designing in this paper; so we are considering some of the issues related to smart home performance.

II. THE FIRST WIRELESS PROTOTYPE UNIT: Evolution of WSNs

The first prototype of wireless sensor was built based on microcontroller (Si-Lab C8051F020) along with the communicating device BiM-418-40 [14]. This was used widely at different level in home automation and monitoring; the BiM-418-40 is a Radiometrix make miniature low-power UHF module as is shown in Figure 2 and is capable of half-duplex data transmission at speeds up to 40 Kbps over distances of 30 meters “in building” and 120 meters in open ground. The BiM-418-40 operates at an operating frequency of 418 MHz; the packet delivery ratio is highly dependent on the receiver-transmitter distance. It was observed that after 15 meters the rate of success of packet delivery started decreasing.

Figure 2: Picture of the BiM-418-40

III. TRANSFORM TO IEEE WIRELESS PROTOCOL

There are some limitations to develop adhoc wireless network based on BiM-418-40, which make it weak candidate to smart home monitoring and automation system; the constraints are as follows:

i. It needs an external microcontroller or a processor for its operation.
ii. It is necessary to have a separate antenna for the communication of data. Consequently, it needs more power and the cost of the system increases.
iii. The 418MHz frequency of operation is officially allowed in some part of the world. The USA is legalised and UK exempt 418MHz spectrum, but this frequency spectrum does not documented in free licenced list of some of Asian and European countries [23-28].
iv. The communication protocol was developed in-house. This may be too difficult while the system is expanded.
vi. Multi-hop architecture is required to overcome the obstacles to transmission, and to have long distance communication.

Based on the above drawbacks, the next stage of development was taken place using ZigBee IEEE 802.15.4 protocol standard. The wireless communications protocols along with the associated wireless modules are shown in Table 1 [17, 21 and 22]. Based on the comparison, ZigBee has been chosen for applications in the home and environmental monitoring, the details of which are available in [18].

Table 1: Comparison of IEEE wireless protocols [17, 21 and 22].

Standard	**ZigBee (IEEE 802.15.4)**	**Bluetooth (IEEE 802.15.1 WPAN)**	**WiFi (IEEE 802.11 WLAN)**	**WiMax (IEEE 802.11 WWAN)**
Range	100 m	10 m	5 km	15 km
Data rate	250-500 Kbps	1 Mbps – 3 Mbps	1 Mbps – 450 Mbps	75 Mbps
Network Topology	Star, Mesh, Cluster Trees	Star	Star, Tree, P2P	Star, Tree, P2P
Applica-tions	Wireless Sensors (Monitori ng and	Wireless Sensors (Monitoring and Control)	PC based Data Acquisi-tion, Mobile Internet	Mobile Internet

	Control)			
Success metrics	Reliability, power, cost	Power, cost	Speed flexibility	Speed flexibility
Nodes	65,000	8	32	-
Spectrum	2.4 GHz	2.4 GHz	2.4, 3.7 and 5 GHz	2.3, 2.5 and 3.5 GHz
Complexity	Simple	Less complex	complex	More complex

In the hardware prototype using XBee series-2, it was used only for communication as shown in Figure 3 [13]. The RF XBee chip contain isotropic integrated chip antenna, transmit power 1.25mW (+1dBm)/ 2mW (+3dBm) boost mode and receiver sensitivity -95dBm in boost disable and -96dBm in boost enable mode; supply voltage range 2.1 to 3.6 VDC.

A separate microcontroller was used to collect all the sensors data. The processing and data formation was done inside the microcontroller. An adhoc protocol was developed for communicating data with the central controller. The disadvantage of this scheme is that the capability of ZigBee is not fully exploited and also the speed of operation of the system especially for communication is quite slow.

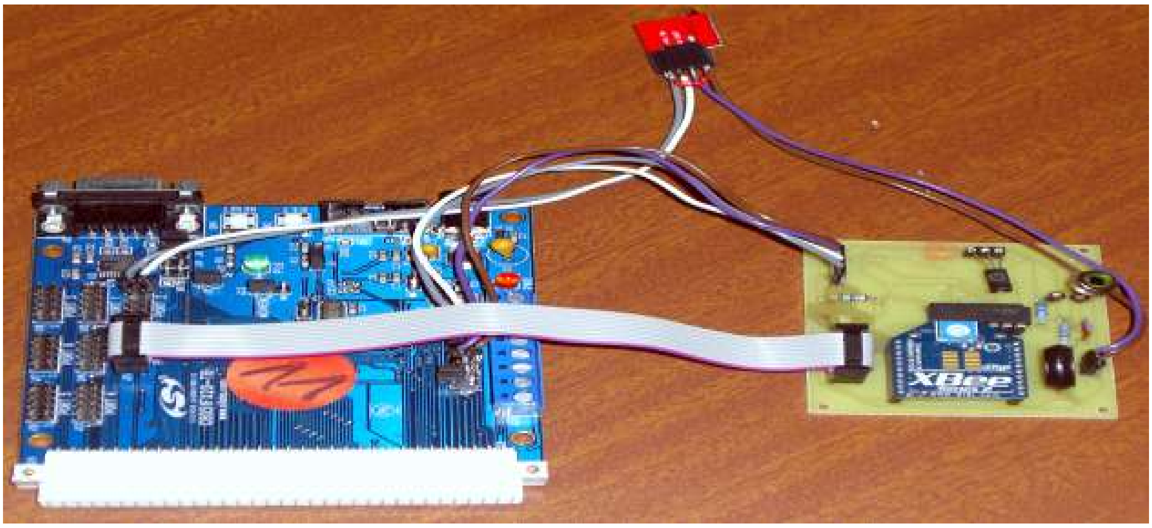

Figure 3: The developed system with ZigBee as only transceiver

Though a successful system has been designed without saperate microcontroller, there were a few problems encountered. The ZigBee is quite sensitive with voltage fluctuation resulting in damage of a few ZigBees. The handling of data from multiple sensors was not properly accessed. Microcontroller based wireless communication protocol does not offer sufficient data reliability.

IV. DEVELOPMENT OF WIRELESS SYSTEM WITH ONLY ZIGBEE

If the node does not have any complex processing requirement, there is no need to use a microcontroller in the sensor node. The XBee RF chip can directly collect the sensing data through conditioning circuit and send the data to the coordinator. The fabricated sensor node prototype is shown in Figure 4. With respect to a particular application we have to configure RF chip and set at essential command level; we do all these by using XCTU software.

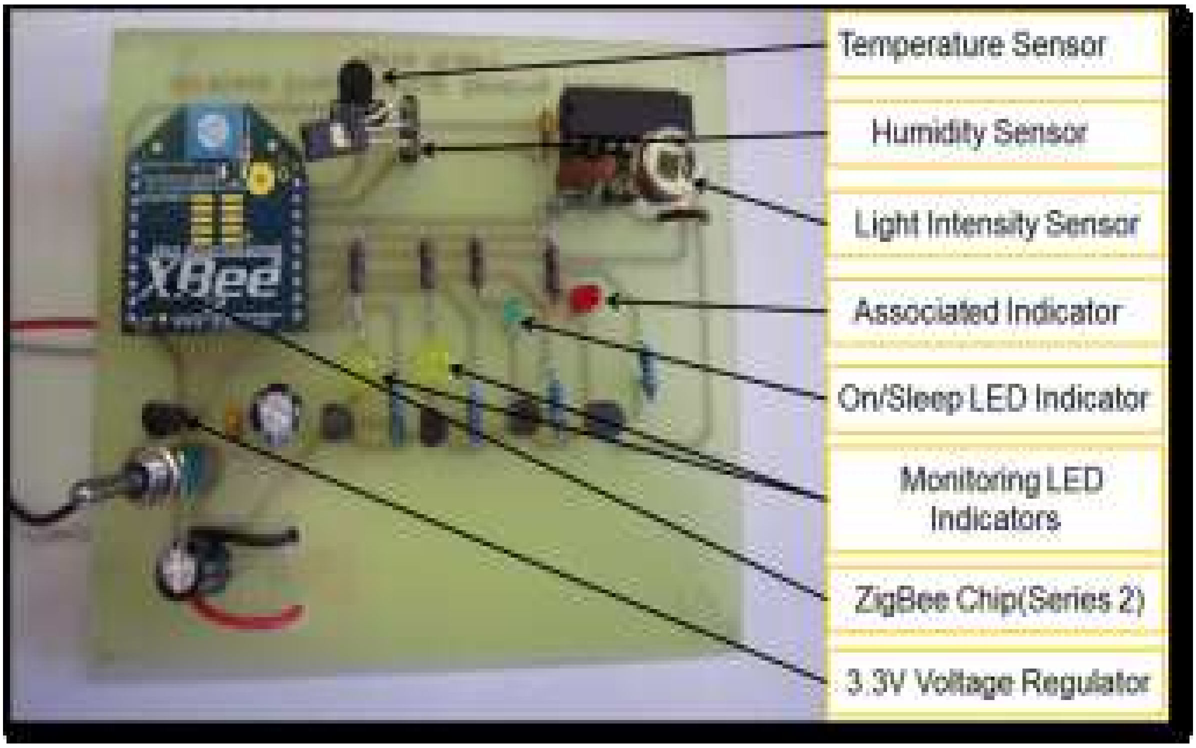

Figure 4: The fabricated sensor node with ZigBee.

The X-CTU (XBee Configuration & Test Utility software) was used to configure both the coordinators and the sensor nodes with proper Pan ID and other details [18]. A few projects were developed using the ZigBee working in the mesh configuration [10, 11, 15, and 16]. Depending on the applications, the ZigBee for the sensor node has been configured to handle a few inputs, hybrid both analog and digital.

A few issues during system design caught our attention were listed here:

1. Problem in opening module configuration in XCTU software, if we are using that particular XBee for a long time. In most of the instances, the XBee module was not possible to use. A significant number of XBee has been wasted due to this.
2. The problem of the firmware update comes when we take out existing XBee, which we are using for long time and reconfigure it.
3. While neighbouring pins are used to access signals, in some instances the influence of signals to the neighbouring signals was observed.
4. In some situations, it was difficult to read digital input data. It was not entirely clear whether the problem is in reading the data at the input stage, in the communication or in the receiving stage. Though this type of problem was not very common, it happens.
5. The sampling rate is set at a minimum of 20 ms. the rate corresponds to a sampling frequency of 50 Hz. This is quite low for many applications. Even with the sample rate of 50 Hz the data communication does not take place properly when a few sensor nodes are added in the system. As we incease number of wireless sensor nodes in the network, decidiing optimum sampling rate between them become issue. Optimal sampling rates are very much required for good wireless sensing devices for proper data transmission.

Usually in smart home environment includes heterogeneous sensing units, such as shown in Figure 5, and the local home gateway receiver with server.

Figure 5: Placement of movement monitoring sensor at front door of smart home.

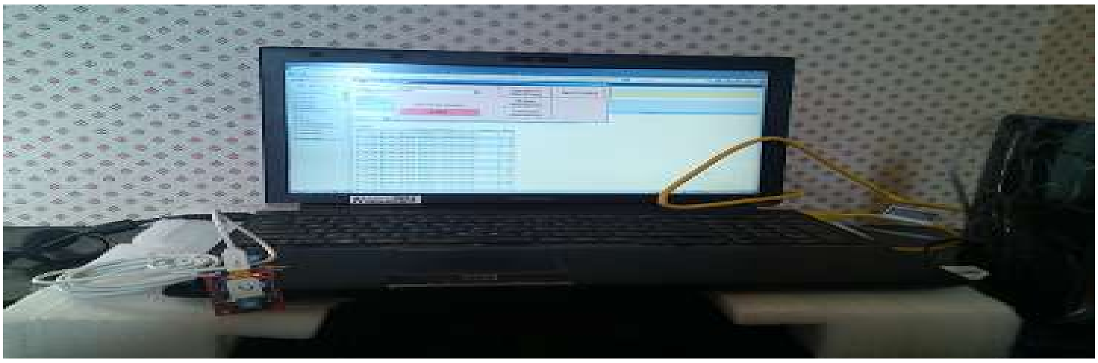

Figure 6: Local home gateway with XBee coordinator to receive data.

6. Throughput is decreasing, if obstacles are increased in between the coordinator and the router devices, this may be due to attenuation and multipath fading, and this ultimately leads to signal quality degradation.
7. The XBee of push button is configured with digital input. It requires multiple pushes of a button to reach the coordinator. (Note: Emergency push button is part of the various sensing devices used in the home monitoring system).
8. Sensing devices with digital I/O configuration requires multiple channel allocation. Sometimes, the data acquisition system will be able to recognize the digital signal only from the pins configured from different channels.
9. To extract useful data from received packet, we have to write comport data reception program. Comport data reception program design should be able to understand and discard any value out of range, such as spikes. This can be achieved by introducing proper exception handling mechanism. It is essential for the sensor data acquisition system.
10. There are a number of wireless sensor nodes, which are transmitting packets every moment of time. It means local gateway system has to extract data from received packet, and it should be in near real time without any considerable delay. This processed data has to be a stream on monitoring website, so handling of this data should be carefully undertaken to offer near real time monitoring effect. Big data handling is a separate topic based on the internet of things for smart home
11. If a single radio module is used to configure consecutive channels for two different devices to be interconnected, then the ADC values are sometimes swapped (interchanged).This is happening, when system is continuously collecting the data for long durations of time.
12. IEEE 802.15.4 ZigBee standards operate on the license-free industrial, scientific, medical (ISM) frequency band; it functions on the ISM bands 868 MHz, 915 MHz and 2.4 GHz. Consequently, packet delivery ratio (PDR) is highly affected by the interference caused by other ISM band based communication devices; which is operating within the same range of XBee network setup. Overall, unregulated and unlicensed spectrum is the favourite for other all wireless sensor network designer’s unfortunately increases the chances of interference.
13. The problem faced with a range of communication too. The fabricated sensing units are configured in the form of mesh topology so that reliable data communication is achieved. The Quality of Service (QoS) in the mesh topology is primarily a direct function

of packet delivery ratio (PDR) and received packet delay in transmission of sensing information is given in Table 2, 3, and Figur 7.

The sensors are deployed in various conditions to address the issues of ZigBee based smart home development. Sensors are scattered in two ways distributed single hop & multi-hop network routing, and both these pattern are analysed at different distance and obstructions between receiver-transmitter. For a normal XBee, the specified range is 30 m inside the building. But it is seen from Table 2 that the reliability decreases with the number of obstacles as well as with the range. Even though the data sometimes received there is a considerable delay taking place to receive the data from the farthest node. The data cannot be received if the ZigBee is configured in a star configuration. In the mesh configuration, the hopping takes place, and the data is received though it is not so frequent.

We are using term packet delivery ratio (%) to show packet reliability. More the PDR (packet delivery ratio) better the system data reliability.

PDR (%) = $\frac{N_r}{N_s}$*100……………………………….(1)

N_r= Total number of packet received by coordinator from an end device.

N_s= Total number of packet sent by end device.

Table 2: It represents how PDR varies with respect to Number of obstructions, spacing between nodes and type of hop.

Multi-hop(MH) or Single hop (SH)	**Router/ End Device (ED)**	**Range from Coordinators (m)**	**Obstacles**	**PDR (%)**
SH	ED	8	1 wall	97
SH	ED	8	2 walls	83
SH	ED	8	3 walls	66
SH	ED	8	4 walls	63
SH	ED	10	1 wall	58
SH	ED	10	2 walls	46
SH	ED	10	3 walls	40

SH	ED	10	4 walls	43
MH	Router-ED	8	3 walls	77
MH	Router-ED	9	3 walls	59
MH	Router-ED	10	3 walls	51
MH	Router-ED	11	3 walls	10

As more and more RF devices designed by various companies uses the unlicensed ISM frequency spectrum, designers have to deal with increased signals from other interference sources and this make designer's job more complex. In Table 3, we investigated XBee based WSN performance in interference scenario and interference free communication network. With increased in receiver-transmitter distance, the packet delivery ratio is more degraded in interference situation as compare to interference free. We are considering mainly in band interference caused by other ISM RF devices.

Table 3: It represents how PDR varies with respect to interference free and interference network.

Distance (m)	**PDR (%) Interference network**	**PDR (%) Interference free network**
4	100	100
4.5	100	100
5	100	100
5.5	100	100
6	100	100
6.5	100	100
7	98	100
7.5	94	99
8	77	83
8.5	69	74
9	59	67
9.5	55	57
10	51	54
10.5	46	50
11	27	33

11.5	9	15
12	2	10
12.5	2	2
13	2	2
13.5	0	2
14	0	0

In the experimental results as shown in Figure 7, the packet delivery ratio for different nodes as a function of distance is shown. The sensors are arranged in multi-hop network, where all sensors are configured as router-end device, the PDR1 node is the nearest node to XBee coordinator, followed by PDR2, PDR3, PDR4, PDR5, & PDR6 respectively, so farthest node is PDR6. PDR1 node is the nearest so its PDR value less degraded while PDR value of PDR6 node highly degraded with the increased in distance. PDR2 second least affected, followed by PDR3, followed by PDR4 and followed by PDR5. In below figure 5, we say constant distance, which means the distance between nodes in a multi hop is same, such as distance from coordinator to node A is 7 m, followed by B is 14 m, followed by C is 21 m, followed by D is 28 m, followed by E is 35 m and followed by F is 42 m.

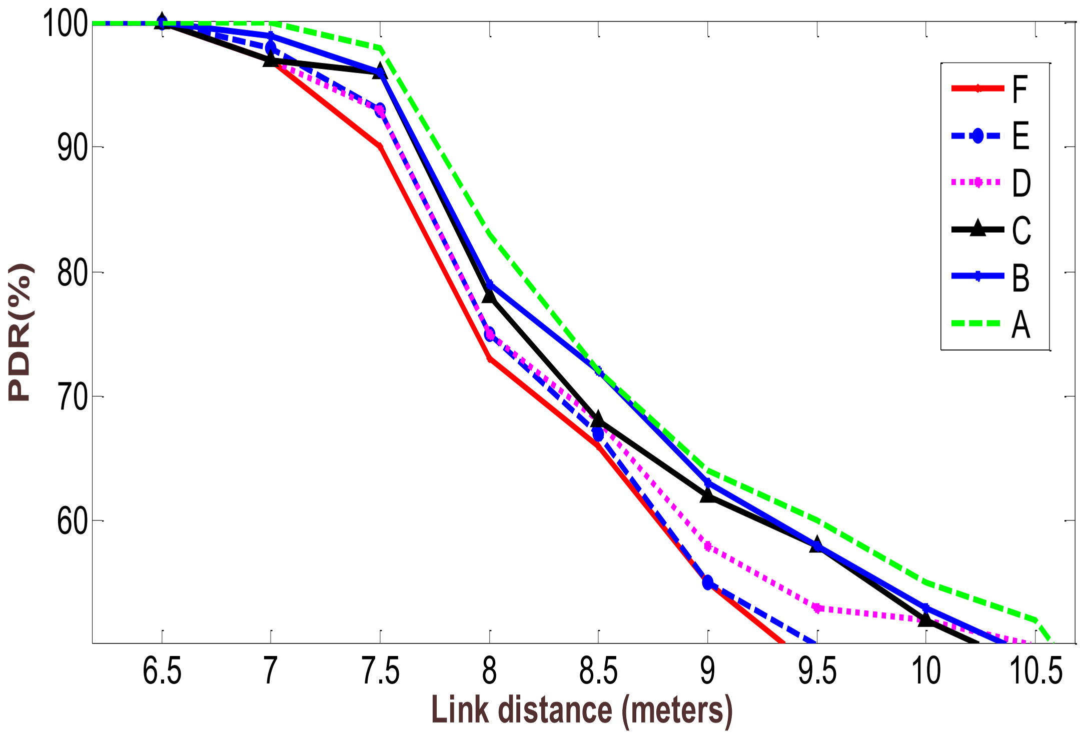

Figure 7: PDR vs. Distance for multi hopping with constant distance throughout the network for every node.

One more major pointer of ZigBee network performance is the packet delay between consecutive packets perfectly received by the Coordinator. Digi's XBee Series 2 radio modules run ZigBee 802.15.4 firmware, which allows them to transmit data in a point-to-point, peer-to-peer or point-to-multipoint (star) network architecture. The time it takes to transmit a data packet is a sum of the Time on Air, acknowledgment (Time for CSMA-CA and Retries) and propagates [38 and 39].

Total received delay time= Time on –air (T_A) + Time on-air Ack (T_{ACK}) + Time upload (T_{SCI}) + Propagation time (T_p) …………………………………………..(2)

Time on-air (T_A) = Packet length/ air data rate

$$T_A = \frac{8\ bit/byte\ .\ 1\ starting\ delimiter\ byte\ +8\ \ address\ bytes\ +N\ \ payload\ bytes\ \ \ +1\ \ CRC\ byte\ \ +2\ packet\ control\ bytes}{air\ data\ rate\ \frac{bit}{s}}$$

……. ………………………………………………………………… (3)

Time on air ACK (T_{ACK}) = Packet length/ air data rate

$$T_{ACK} = \frac{8\ bit/byte\ .\ 1\ starting\ delimiter\ byte\ +8\ \ address\ bytes\ +N\ \ payload\ bytes\ \ \ +1\ \ CRC\ byte\ \ +2\ packet\ control\ bytes}{air\ data\ rate\ \frac{bit}{s}}$$

………………………………………………………………………… (4)

Time upload (T_{SCI}) = Payload length/ serial peripheral interface

$$T_{SCI} = \frac{8\ \ bit/byte\ .\ N\ \ payload\ bytes}{air\ data\ rate\ \frac{bit}{s}}$$ ……………………………………… (5)

The propagation delay T_P is the time that it takes a signal change to propagate through the communication media from a node to the next node. It can be computed using the following equation. Here, D is the distance from the node to the next node and S is propagation speed of the media.

Propagation delay time (T_P) = D/ S……………………………………… (6)

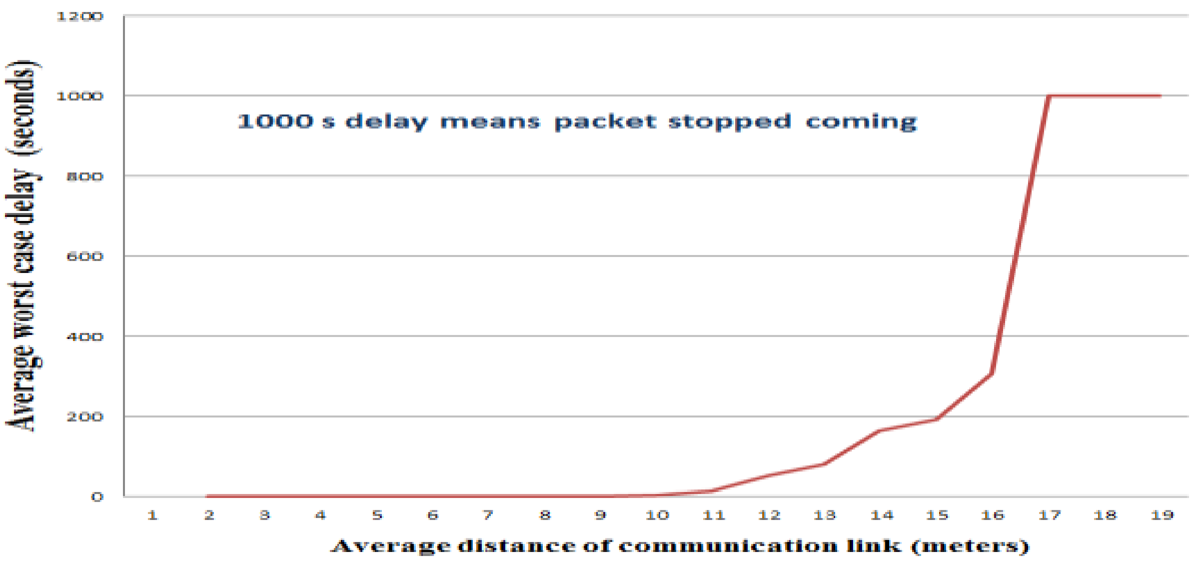

Figure 8: Avg. Delay vs. Avg. Distance, for multi hopping with constant distance throughout the network.

V. CONCLUSION

With our experimental research and analysis the PDR of a node which is at far distance from coordinator degraded more as compare to the nodes near to coordinator in a multihop network. The optimum spacing varies from one to another environment, so the spacing between nodes and deployment environment should be properly analysed by repeating sufficient number of experiment. Additionally, this paper has reported some of our working experiences with using ZigBee protocol (XBee RF module) as communication devices. According to classical theory receive delay is a function of sampling rate and packet length; moreover it is based on spacing between sensor nodes. For developing smart home though significant successes have been achieved using ZigBee, it is expected more successes if the issues are taken care of during the design stages. The sharing of our experiences will be useful to fellow designers working with ZigBee technologies for similar applications.

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