Performance Evaluation of Hybrid ZigBee-Fiber Optic for Wireless Sensor Network System

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Abstract

The development of WSN is getting advanced according to the needs of IoT. the amount of data flow in the system will be greater. This massive WSN requires a backbone transmission that has low latency and large bandwidth. Fiber optics is one solution for it. This paper proposes the Hybrid WSN using ZigBee and Fiber Optic system and discusses its performance evaluation and characteristics. To obtain information related to system evaluation, system testing is carried out by observing the performance of data transmission. The main system design consists of two ZigBee routers, one ZigBee gateway, two E/O media, FO cable, and a computer as a display monitor. Data retrieval is done by sending text data and sensor data with 1000ms in intervals per-each package data. The indicators analyzed for evaluation are throughput, interval delay per meter, package loss, and error. Data results are also compared with the commonly ZigBee to the WiFi system. The results were obtained from testing the throughput, interval delay per meter, and package loss and error. Based on the results, it can be concluded that a ZigBee-FO hybrid system is implemented, and results better performance in lower latency, and higher throughput than commonly WSN-WiFi systems.

Keywords: Massive WSN, ZigBee over Fiber, Throughput, Interval Delay, Package loss and error.

1. Introduction

Wireless Sensor Network (WSN) technology is widely implemented for monitoring or controlling system. There are many examples of the implementation, such as water or air quality monitoring (Arya, Tri F. Faiqurahman, Mahar. Azhar, 2018), smart farming, smart city, etc. There are many challenges in building the WSN system (Akbar & Hambali, 2018; Khanh et al., 2017; Patel et al., 2016; Prihtiadi & Djamal, 2017). Facing the era of industry 4.0, wide applications of monitoring or controlling will be built, which will implement more sensors or nodes. For a ZigBee-based WSN, the number of nodes that can be built in more than 1000 nodes interconnected together (Djedouboum et al., 2018). Therefore, the flow of the data network and capacity is raised, especially in the central system or sink node which will be entering the backbone network to the monitoring center.

There are many kinds of system designs for such WSN applications. Usually, WSN is interconnected with the Internet of Things (IoT) technology so the data will be stored in the cloud and through the internet (Djedouboum et al., 2018). The backbone that connects between the sink node to the gateway can use many various options. Commonly, WiFi is used (Doherty et al., 2013) because of its high bandwidth and flexibility. However, WiFi since it is wireless, the connection may be disturbed by the environment, obstacles, or when the bandwidth reaches its maximum capacity.

For massive WSN, with more sensor or high capacity data, it requires the backbone which has high bandwidth and also low latency, especially for real-time monitoring applications. Besides WiFi, optical fiber transmission can be used as an alternative to transmitting the data from the sink node to the monitoring center. The hybrid WSN can be implemented using a media converter from E/O and the opposite. The protocol, data conversion, and signal processing are needed to be configured for this kind of hybrid system. the performance of the WSN hybrid system also needs to be analyzed. This paper evaluates the performance of the WSN Hybrid ZigBee-FO. The performance observed are the throughput, interval delay per meter representing the system latency, and package loss and error.

1.1 Objectives

This research aims to design and configure a hybrid Zigbee-FO system for wireless sensor networks and evaluate its characteristics performance. The performance observed are the throughput, interval delay per meter, and package loss and error.

2. Literature Review

2.1 Wireless Sensor Network

A wireless sensor network (WSN) can be defined generally as a network of sensor nodes that wirelessly connected and communicate with each other cooperatively to sense data. WSN may do controlling based on different conditions, such as enabling interaction among computing devices, persons, and the surrounding environment. WSN basic node construction is sensor-equipped with a wireless communication device. Functionally it is used to sense physical phenomena such as temperature, light, pressure, humidity, etc. data sensor is collected and transmitted to the sink or base station for further processing and analyses (Doherty et al., 2013; Modares et al., 2013). WSN nature is heterogeneous, in some cases, usually, it contains thousands of sensor nodes that have different characteristics. Normally nodes build up with very low processing, storage, and transmitting capability performance.

ZigBee technology is a wireless communication protocol standard that is regulated in IEEE 802.15.4, wireless technology with low-cost, low-power basic characteristics. The basic network model of ZigBee is multiple nodes that are connected for a wide coverage of the network. Standard characteristics of ZigBee are working in 868/916 MHz and 2.4 GHz frequency band, 10-100m range, 255-65.000 number of nodes, 1mW power consumption, and up to 250 kbps data rate (Heile, 2015).

2.2 Optical Fibers

Optical fibers are an isolated transmission medium with a variety of applications related to information transmission (Sharma et al., 2013). The basic concept of this technology is transferring signal data using optical rays as the signal media. By using optic rays, the signals can have transferred far faster than usual using electric signals. Fiber optic network is used for Distribution Automatic systems (DAS) primarily because of its high bandwidth and dielectric immunity. There are several benefits of using Fiber Optic for communication such as long transmission distance, large information capacity, small size, and low weight, immunity from electrical interference, enhanced safety, and increased signal security (Green & Watson, 1991; Kehagias et al., 1987; Sharma et al., 2013).

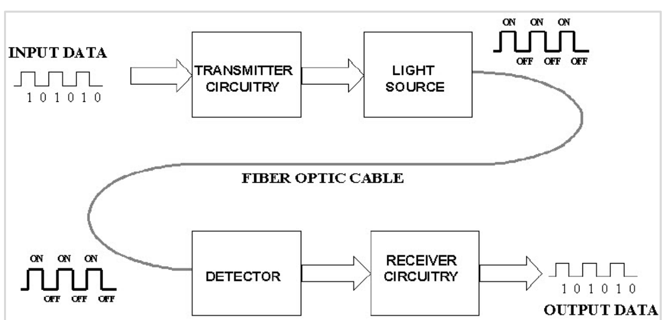


Figure 1. Optical Fiber Communication System (Urquhart, 2012)

In the performance capability of a Fiber, according to (Giallorenzi, 1978; ITU-T, 2012; Urquhart, 2012), the bandwidth spectrum of FO is in 850nm, and 1260nm to 1625nm wavelength, in this spectrum range, the bandwidth is divided to 85mnm band, O-Band, E-Band, S-band, C-band, and L-band. Single-mode Fiber and multi-mode Fiber has different performance speed and distance. For single-mode fiber optic cable speed, no matter data rate is at 100 Mbit/s or Gbit/s, the transmission distance can reach up to 5 km. In that case, it is usually used for long-distance signal transmission. The multimode fiber optic cable speed and the transmitting distance limits are 100 Mbit/s for distance up to 2 km and 10 Gbit/s up to 550 m. Commonly FO application is used as high bandwidth media transmission. Here is the general comparison of FO performance with other network media transmission.

Table 1. Comparison of Network Media transmission (Giallorenzi, 1978; IEEE Computer Society, 2012; ITU-T, 2012; Sharma et al., 2013; Urquhart, 2012)

Standard	Fiber Optic	WiFi	4G	Ethernet
Data Rate	1 Gbps	54 Mbps	20 Mbps	0.1-1 Gbps
Length Range	5 km	30-100 m	5-20 km	100 m
Power Consumption	~1 W	~20 W	~6 kW	~14 W

2.3 Data Frame Network Protocol

Every transmission media has a different protocol for purpose of converting the data input into a suitable signal to the transmission media. Zigbee wireless transmission has a standard protocol that has been regulated in IEEE 802.15.4. according to (Fadulii, 2011; Mor et al., 2018), for the Xbee module, in AT mode, frame data has a special format. AT-type commands can be sent via API frames to configure your local radio. They can query the settings on the local radio or set parameters. These are all the same commands typed in transparent/command mode. The frame format is sent in HEX format data.

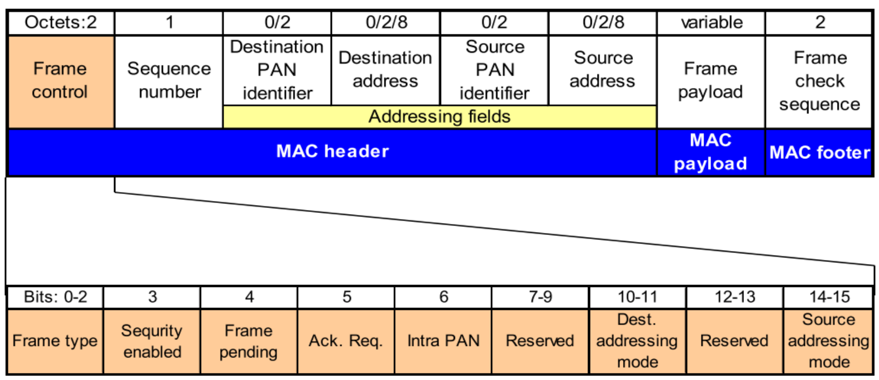


Figure 2. General MAC Frame for Zigbee Protocol (Heile, 2015)

Ethernet protocol has a standardized format in transmission data and communication. Commonly, for the data link, a TCP/IP is the protocol is used for the purpose. According to (Fadulii, 2011), the frame format of an Ethernet has 8 frames inside. With data load up to 1500 Bytes. The illustration of the frame format is shown below.

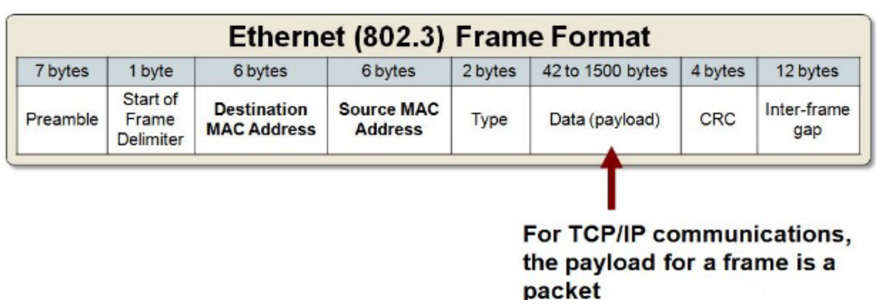


Figure 3. General MAC Frame for Zigbee Protocol (Heile, 2015)

Fiber Optic works in the Physical Layer of the OSI Layer. According to (IEEE Computer Society, 2012), an Optical Fiber only functioned to transmit data through its optical media. for the encrypted protocol, data frame, and other Data Link and network protocol is follows the input signal type. Few examples exist for implementation of the Hybrid ZigBee-fiber optic, or ZigBee over fiber. One of the examples is applicated for sensor monitoring like in (Sittakul et al., 2019). The system consists of two sub-systems, namely the ZigBee network and the optical network. The ZigBee network consists of the Xbee 2.4 GHz module of the IEEE 802.15.4 standard. the ZigBee network consists of a coordinator and a router. The temperature/humidity sensor is connected to the router for monitoring function, so it can simulate with data from the sensor sent through the system. The coordinators are connected to the router via an optical network and can still wirelessly connect via ZigBee radio. These two transmission lines are both used to send sensor data.

For optical networks, there are two optical transmitters (laser sources) to transmit optical signals that are modulated by electrical signals, on the other hand, there are two optical receivers (photodiodes) attached to demodulate the optical signal into an electric signal again. The optical network operates at a wavelength of 1310 nm using single-mode fiber (SMF). This creates a two-way link on the radio via fiber.

3. Methods

The research began by conducting a literature review on the Hybrid RF-Fiber Optic (FO) in general, WSN that integrates ZigBee and its performance, fiber optic for data transmission purposes, and networking protocol for transmission data. Then proceed to the design of the hybrid ZigBee-fiber optic system for experimental data transfer purposes in the UAI's Laboratory environment. The system has 3 main sub-systems. The sub-system of it is the ZigBee WSN system, optical backbone system, and monitoring device system. Before testing is performed, configuring the hardware and software of all systems is required. Xbee configuration is using the XCTU software, configuring the optical media converter, configuring the application that is suitable to read the transferred data such as Hercules and Digi user interface, and setting up the data to be Ethernet protocol data. Setting up the data protocol is in purpose to make the data transferred can be detected by all the system, since all the system is internet protocol based. Input data is getting set in the XCTU. Then only after that, testing can be done. This test is evaluating the performance of a data flow from the Xbee router-Xbee gateway-FO backbone-monitoring device. The data flow result is get used for testing Throughput, Delay per meter, Package loss, and Package Error. For a result comparison, a system design WiFi-based is built up and gets the same testing process as the core system. After processed test data is obtained, then an analysis of the test data is carried out, which then leads to the conclusion.

3.1 System Design

This research is deto signed and implemented a Hybrid ZigBee-FO for the WSN system. The system is designed from a different fabricated component that is integrated into one system. The system is divided into 3 sub-systems, WSN system, Backbone System, and Monitor System. Each sub-system is connected by an Ethernet cable. The component of the system is the Xbee S2C radio module (as Router), Xbee Gateway, Media Converter, Single-mode Duplex FO cable, and a personal computer. Xbee module is used as a WSN device and component that gives input data for the system, XBee Gateway is used as a ZigBee coordinator and signal converter, from ZigBee radio signal to Ethernet. A media converter is used as an E/O signal converter, so the signal can through the FO cable. The personal computer is used as a receiver device and used as a monitor to display the data received. All the components are integrated as one system to transmit data flow.

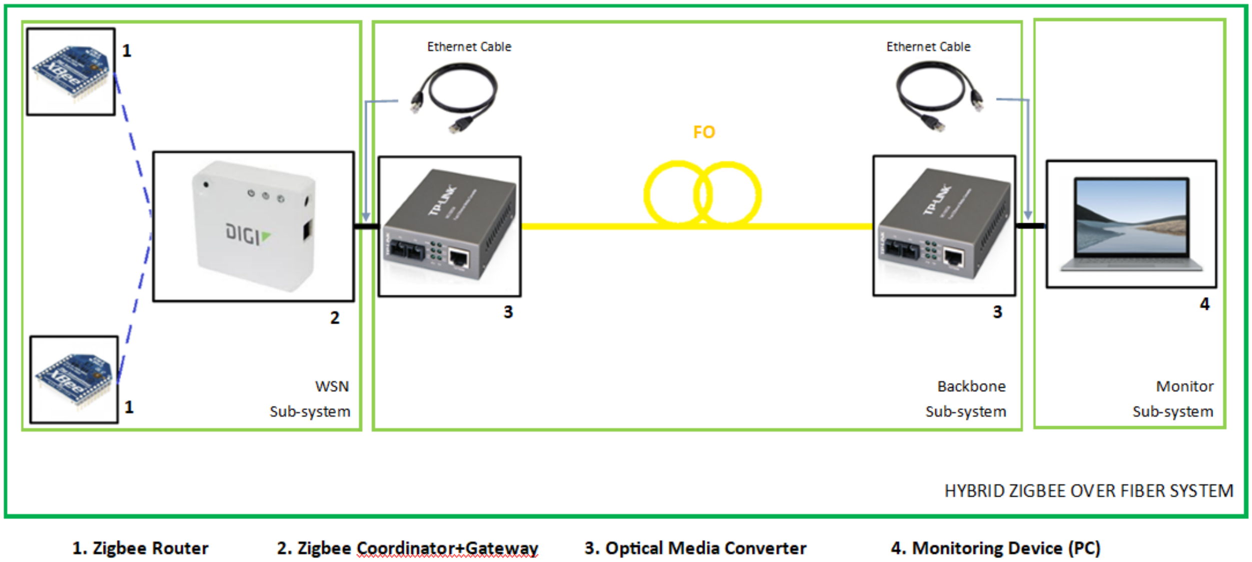


Figure 4. System Design of ZigBee-FO system

To compare the result performance, another system design is built up using WiFi. The following design is a ZigBee-Wifi system. WiFi WSN-based is chosen as the comparison system because it is also a wide transmission used for WSN.

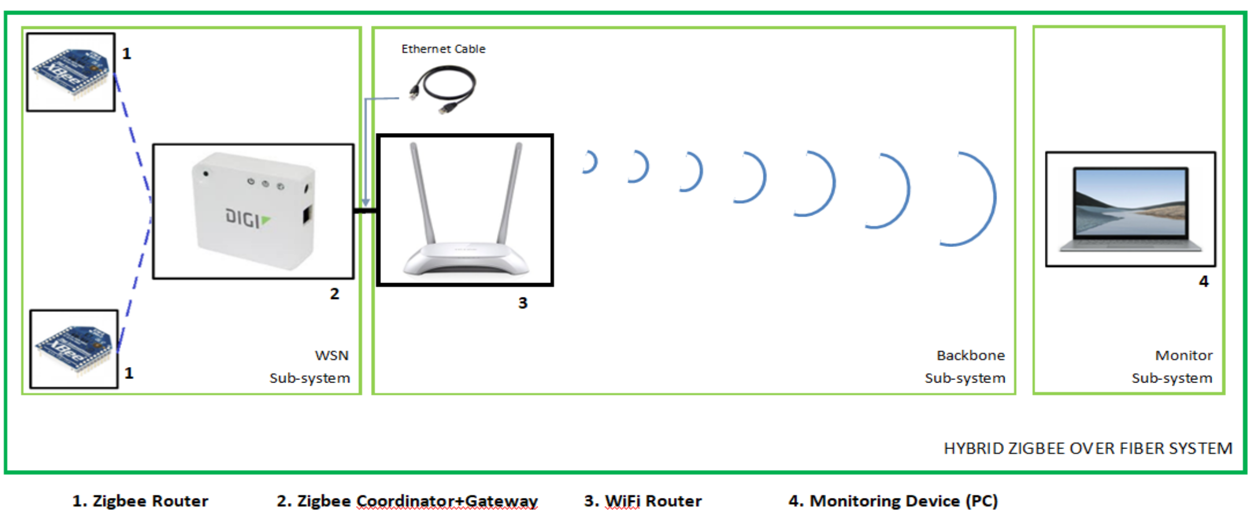
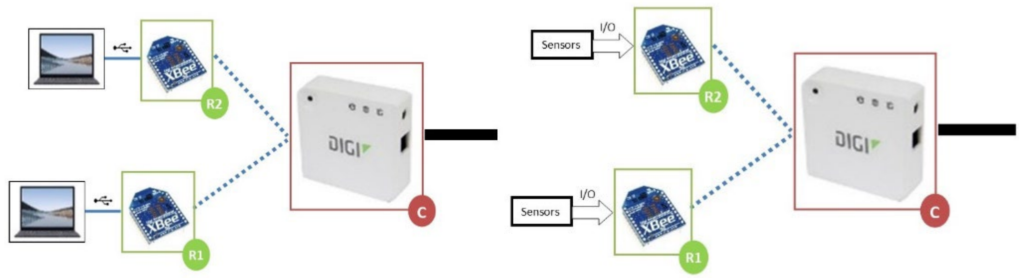


Figure 5. System Design of ZigBee-Wifi system

3.2 Input Configuration

The design of WSN in this project uses a ZigBee-based wireless protocol. WSN network design used in this project uses two Routers as an end node and one Coordinator as the sink node. The component is used for this sub-system is the Xbee S2C radio module (as a router) and Xbee Gateway (as Coordinator). Xbee Gateway will pass the radio data through Ethernet cable to the media converter in the Backbone sub-system. WSN network Design in this project is from a star Topology. The connection between the router and the coordinator is in a straight line. In this project, the type of input signal is used in 2 different types. First is text console data input, and the second is sensor reading input. The WSN system design is getting different also according to the type of input. The design of the WSN system is shown in figure 6. below.



(a) (b)

Figure 6. (a) WSN design Text Console Input (b) WSN design for Sensor Reading Input

3.3 Data Variable

There are several kinds of data that are taken and carried out as a testing result. The input data is divided into 2 types, text console, and sensor reading. For each type of data, it varies for some range. The data varies is illustrated in table 2. below.

Table 2. Variation of Data Sample (data sent per second)

	Text Console (Data/s)	Sensor (Data/s)
	100 Bytes	2sensor
	200 Bytes	4sensor
	300 Bytes	6sensor
FO	400 Bytes	8sensor
	500 Bytes	10sensor
	600 Bytes	-
	700 Bytes	-
	800 Bytes	-
	900 Bytes	-

	Text Console (Data/s)	Sensor (Data/s)
	100 Bytes	2sensor
	200 Bytes	4sensor
	300 Bytes	6sensor
WIFI	400 Bytes	8sensor
	500 Bytes	10sensor
	600 Bytes	-
	700 Bytes	-
	800 Bytes	-
	900 Bytes	-

Text Console data is taken as represented by a massive number of data. As an example of representation, a hundred nodes that send single data are replaced with 2 nodes but send multiple data. The range of text console capacity is set from 100 Bytes to 900 Bytes. Text console is only set up to 900 Bytes because considering the Xbee sending limit that only up to 250Kbps. When the Byte range is increasing, the testing result is get weakened and unstable value, which makes the result is not appropriate for this system anymore. Sensor reading is taken as represented by the actual implementation of WSN. WSN is usually used for monitoring purposes and monitoring is using a sensor, that why sensor reading input is chosen as one of the data input types. The number of the sensors is ranged from 2 to 10 sensor, according to the maximum I/O pins that Xbee have. In the sampling process, the data samples that are taken to be processed are 5 times sending data, with interval per sent is set to 1000ms. In this case, the relation between the sampling process and data variation can be described as data rate.

3.4 Evaluation Parameter

Throughput is the ratio of the number of packages that were successfully sent or the speed of data transmission. The test for this parameter is tested from WSN to the Monitor Device when through the FO Backbone and when through a WiFi Router. The testing result is observed from the monitor Device (PC) and processed by some calculations. The throughput result is getting from the calculation between the total successfully sent bit and sending time. the calculation is getting from this equation:

$$Throughput\ (bit/s) = \frac{Total\ data\ Receive\ (bit)}{Total\ Time\ (s)} \quad (1)$$

Interval Delay is the number of time error between the measured time interval and the reference time interval. Interval delay per meter is a number of the delay per unit of distance. The test for this parameter is tested from WSN to the Monitor Device when through the FO Backbone and when through a WiFi Router. The testing result is observed from the monitor Device (PC) and processed by some calculations. Interval Delay per meter result is obtained from the calculation between Interval Delay Time and Distance. the calculation is getting from this equation:

$$Int. Delay\ per\ meter(s/m) = \frac{Int.Delay\ time\ (s)}{distance\ (meter)} \tag{2}$$

The Interval delay time is calculated by:

$$Int. Delay\ time(s) = t_{measure\ Int} - t_{refference\ Int} \tag{3}$$

Package loss is ratio of packages that are lost during the transmission process. The test for this parameter is tested from WSN to the Monitor Device when through the FO Backbone and when through a WiFi Router. The testing result is observed from the monitor Device (PC) and processed by some calculations. Package loss result getting from the calculation of the ratio between data received and total data Transmitted, is obtained by:

$$Package\ loss(\%) = \left[\frac{P_{Tx} - P_{Rx}}{P_{Tx}}\right] \times 100\% \tag{4}$$

Package error is the ratio of similarity between that transmitted package and the received package. The test for this parameter is tested from WSN to the Monitor Device when through the FO Backbone and when through a WiFi Router. The testing result is observed from the monitor Device (PC) and processed by some calculations. Package error is getting from comparing the similarity between the Package Tx and the Package Rx. If the package is not perfectly similar, it's counted as an error package. The percentage of the error is calculated by:

$$Package\ error(\%) = \left[\frac{P_{error}}{P_{Total}}\right] \times 100\% \tag{5}$$

4. Data Results

This section discusses the results of the tests that have been carried out. The main purpose of this project is to evaluate the performance of the ZigBee-FO system for a massive WSN. To obtain the evaluation result, the test is carried out by sending 2 types of data. The first experiment is text console data with multiple varies of the amount of data, the second is sensor data with a varies sensor number. These types of data are purposed to identify a different performance identity. Text console is represented as the amount of data in a massive node number of WSN. Sensor data is represented as the actual implementation of WSN. A scenario of transferring files between 2 PC through FO and WiFi is getting tested. This scenario is a scenario of real use for the WiFi and the FO application. From the result of this scenario, it will be suggested as the hypothesis of this project. The parameter that is used for the evaluation is throughput, interval delay parameter, Package Loss, and Package error. The result is getting compared with a WiFi-based system in purpose to see the effectiveness of the ZigBee-FO hybrid Design.

4.1 Basic Transmission (PC-PC Transfer)

FO and WiFi application is used for Computer and Server networks. For taking hypothesis purposes, a scenario of PC to PC through FO and WiFi, transfer file test is carried out in this final project. This scenario is taken as a hypothesis because this scenario represented the basic concept of the hybrid FO-ZigBee system. The result of the scenario test is shown in table 3. below.

Table 3. Performance result of pc-pc scenario

		FO		WIFI	
Txt. (0.6 MB)	P. Error	0.0	%	0.0	%
	Transfer Time	0.2	s	0.8	s
	Throughput	3.6	MB/s	1.0	MB/s
	P. Error	0.0	%	0.0	%

Jpg. (7.1 MB)	Transfer Time	0.8	s	3.1	s
	Throughput	5.9	MB/s	1.6	MB/s
Mp4. (367 MB)	P. Error	0.0	%	0.0	%
	Transfer Time	35.7	s	155	s
	Throughput	10.5	MB/s	2.4	MB/s

From this result, can be concluded that the FO transmission media has a greater rate of transfer speed, and is more stable even for bigger data capacity. From this result, a hypothesis can be taken that FO transmission media have a greater speed and greater transmission capacity performance than the other transmission line, in this case, WiFi.

4.2 Throughput Performance

Result Comparison for the Throughput performance is shown in the diagram below.

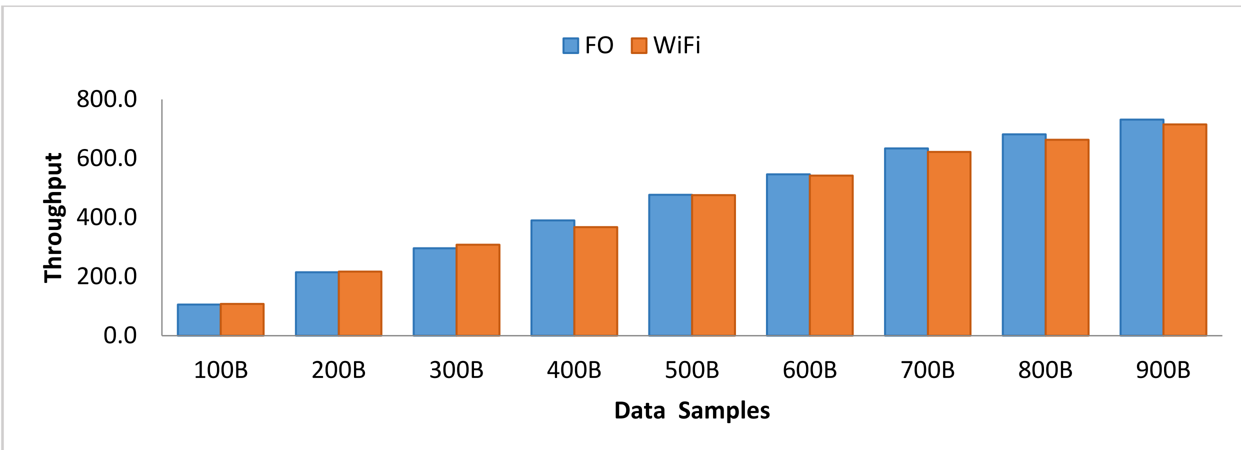


Figure 7. Throughput Performance Comparison. Text Console Input

It can be observed that when in below 300 Bytes per Package parameter, the throughput of FO is lower than WiFi. It is because the data flow is still so small. The optimum performance of the FO is not functioning as usual and it just works in standard performance. From this result, it can be concluded that when the system is using FO, the throughput has a greater value when it is applied for a massive WSN number of nodes.

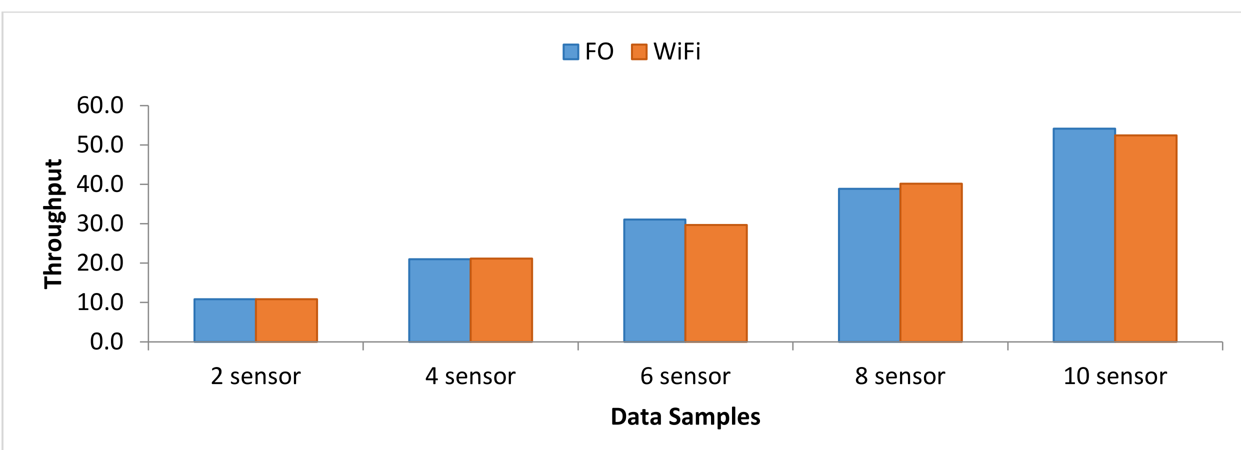


Figure 8. Throughput Performance Comparison. Sensor Reading Input

The same performance happens when the input signal is changed to sensor reading. It can be observed that when in below 300 Bytes per Package parameter, the throughput of FO is lower than WiFi. It is because the data flow is still so small. The optimum performance of the FO is not functioning as usual and it just works in standard performance. From this result, it can be concluded that when the system is using FO, the performance characteristic is in the same character even when the system is applied for transmitting sensor data.

4.3 Interval Delay per Meter Performance

The result for the Interval delay per meter performance is shown in the diagram below,

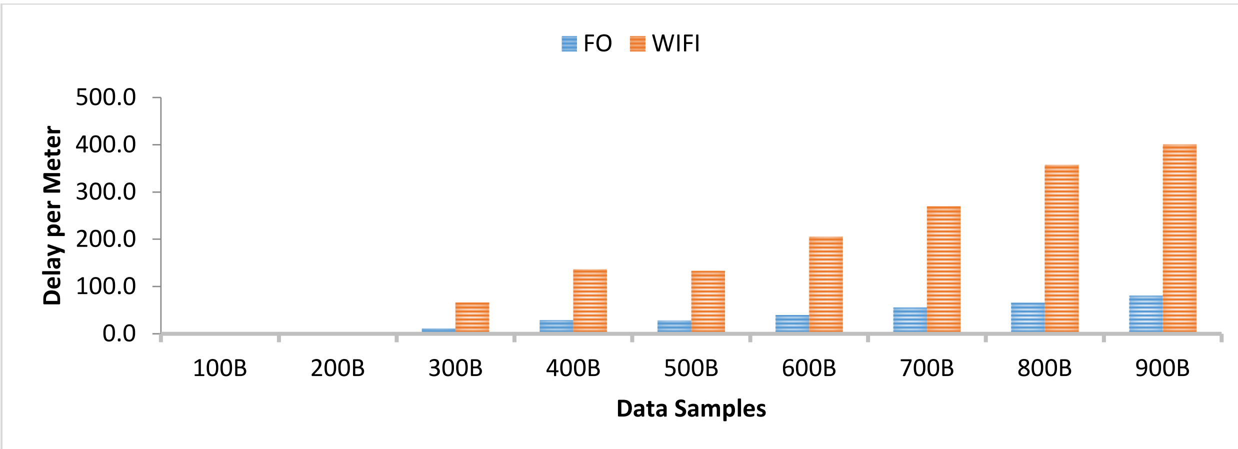


Figure 9. Throughput Performance Comparison. Text Console Input

It can be observed that the delay per meter for the FO is far lower than the WiFi. This means FO can send data faster than using WiFi. The performance is stable from a low data rate to a high data rate. From this result, it can be concluded that when the system is using FO, the Interval delay per meter is have a low time delay when it is applied even for a massive WSN number of nodes. The same performance happens when the input signal is changed to sensor reading. The delay has some minus value because of the sampling error from the Xbee module device. It makes some data can be being get sent faster or more later. This causes the Delay performance to be not stable in sensor input. FO delay performance is more stable than the WiFi. It is because the FO is an isolated transmission line, so the signal is not getting interfered with by the environment especially, other electromagnetic waves. From this result, it can be concluded that when the system is using FO, the Interval delay per meter is have a more stable performance even it is applied for sensor data application.

4.4 Package Loss

Result Comparison for the Package loss performance is shown in table 4. below.

Table 4. Package Loss Performance Result

PACKAGE LOSS				
Data Type		Data Transmitted	Data Received	Package Loss
FO	100B	100	100	0 %
	200B	100	100	0 %
	300B	100	100	0 %
	400B	100	100	0 %
	500B	100	100	0 %
	600B	100	100	0 %
	700B	100	100	0 %
	800B	100	100	0 %
	900B	100	100	0 %

WIFI	100B	100	100	0 %
	200B	100	100	0 %
	300B	100	100	0 %
	400B	100	100	0 %
	500B	100	100	0 %
	600B	100	100	0 %
	700B	100	100	0 %
	800B	100	100	0 %
	900B	100	100	0 %

It can be observed that the performance of all systems is excellent for Package loss. All the results is having 0% package loss. It is because the Xbee the system can detect a failed package send and immediately resend it. According to practical data results, resend ability is done only when a failed package got detected. After the failed package is detected, resend package is getting sent 30 ms on average after it.

4.4 Package Error

Result Comparison for the Package Error performance is shown in table 5. below.

Table 5. Package Loss Performance Result

PACKAGE ERROR				
Data Type		Data Transmitted	Data Received	Package Error
FO	100B	100	100	0 %
	200B	100	100	0 %
	300B	100	100	0 %
	400B	100	100	0 %
	500B	100	100	0 %
	600B	100	100	0 %
	700B	100	100	0 %
	800B	100	100	0 %
	900B	100	100	0 %
WIFI	100B	100	100	0 %
	200B	100	100	0 %
	300B	100	100	0 %
	400B	100	100	0 %
	500B	100	100	0 %
	600B	100	100	0 %
	700B	100	100	0 %
	800B	100	100	0 %
	900B	100	100	0 %

The result shows all transmission works with 0% package loss. It is because the Xbee system can detect a failed package send and immediately resend it. According to practical data results, resend ability is done only when a failed package got detected, then after the failed package is detected, resend package is getting sent 30ms on average after it.

5. Discussion of Results

From the result performance that has been shown before, it can be analyzed the performance of the ZigBee-FO system is compatible to be implemented. The performance of the system is stable according to the linearity escalation of the throughput and delay per meter value shown in figure 7, figure 8, and figure 9, and also has a good result for all of the tested data types. Data is successfully sent through the system proven by the 0% value of package loss and error.

Discussion 1, The comparison between ZigBee-FO performance and ZigBee-WiFi performance is proofed has the same characteristic as the hypothesis scenario. Proof of the state is conducted from the comparison between ZigBee-FO and ZigBee-WiFi throughput and time transfer performance. The FO flows data is faster and with a bigger throughput than when the transmission uses WiFi. Proven with FO Throughput value is 105,5 to 731,7 Bytes/s (for 100B to 900B text console) and 10,9 to 54,1 data/s (for 2 to 10 data sensor). FO Interval delay per meter value is 2,7 to 80, 8 second (for 100B to 900B text console) and -4,1 to -47,1 second (for 2 to 10 data sensor). WiFi Throughput value is 107,1 to 715,3 Bytes/s (for 100B to 900B text console) and 10,8 to 52,2 Bytes/s (for 2 to 10 data sensor). WiFi Interval delay per meter value is 3 to 401 second (for 100B to 900B text console) and -16,7 to 70,7 second unstably (for 2 to 10 data sensor).

From this result, can be concluded that the ZigBee-FO system can be implemented and have better performance (higher throughput and lower delay).

Discussion 2, For comparison results between data types (text console and sensor reading), performance between it is shown in figure 7, and figure 8. Those diagrams in figures 7 and 8 show the result of the same characteristics. The characteristic result is that FO has better performance and a more stable escalation value. For better throughput, it is because FO does have a higher transmission bandwidth. For more stable escalation, it is because FO does not interfere with electromagnetics as WiFi does.

As mentioned before, text console data is used as a representation of massive nodes of data, which means that this system design is compatible with massive nodes data. Have mentioned also that sensor reading data is used as a representation of an actual implementation of WSN. Since sensor reading data shows the same characteristics, it is proof that this system can be actually implemented as it used. From these two statements, it can be concluded that the ZigBee-FO system is actually can be implemented for massive nodes of WSN use.

From discussion 1 and discussion 2, it can be concluded that this system is can be actually implemented and does have higher throughput and faster transmission.

6. Conclusion and Future Research Direction

Based on the results and analysis, it concludes that the Hybrid system ZigBee-FO is designed and implemented for the WSN system, with the performance result as:

- System is can be actually implemented and does have higher throughput and faster transmission.
- System can transmit and receive data successfully, with 0% package loss and error. Hybrid ZigBee-FO WSN system also shows better throughput and transmission speed compared with WiFi-based WSN system. The FO system throughput is up to 731.7 Byte/s while WiFi system throughput is up to 715.3 Byte/s.
- Throughput value is increased correspond with the number of data rate (for 100B to 900B text console, get a 105,5 to 731,7 Bytes/s throughput and for 2 to 10 data sensor, get a 10,9 to 54,1 Byte/s). Interval delay parameter is also increased with the number of data rate (for 100B to 900B text console, get a 2,7 to 80, 8-second delay and for 2 to 10 data sensor, get a -4,1 to -47,1 second).
- The interval delay per meter performance for FO-based system is lower; -4,1s; -8,7s; and -47,1s, while the interval delay per meter for WiFi-based system is -16,7s; -16,7s; and 70,7s.
- In summary, the performance of Hybrid FO-ZigBee WSN is, for throughput value is 105,5 to 731,7 Bytes/s (for 100B to 900B) and 10,9 to 54,1 Byte/s (for 2 to 10 data sensor), interval delay per meter is 2,7 to 80, 8 second (for 100B to 900B text console) and -4,1 to -47,1 second (for 2 to 10 data sensor), and 0% of Package error & loss.

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