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Wireless Tele-Auscultation for Phonocardiograph Signal Recording Through Zigbee Networks*

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***Abstract*— Some factors that arise from difficulties in identifying in detail the cardiac signal can lead to heart disease diagnosis process becomes biased. For example, diagnosis process is strongly influenced by the subjectivity of the doctor, this is primarily due to exposure of patient chest area during the process of measurement. One solution to cope with this problem can be done by allocating doctors and patients in separate rooms. Hence, this was the main motivation of our work. In this paper, we examine the use of a wireless tele-auscultation system for transmitting and recording phonocardiograph signal. The data is transmitted through the Zigbee-like (called the Xbee) networks in local area networks. Based on the study, it is shown that the Type A loss can be omitted without affecting the validity of the received signal as long as time length of measurement is longer than the transmission delay. In terms of the Type B loss, it can be argued that the transmission process is considered as valid, i.e. even though there are loss packets, the number of the loss packets is not significant. In addition to that, it can be observed that variation of the sampling period and the serial interface data rate do not contribute well to the improvement of the throughput the streaming heart sound signal transmission. The throughput of the system is probably influenced by the surrounding environment and hardware or memory capability of the Xbee.**

Keywords—phonocardiograph; cardiac signal; tele-auscultation; Zigbee networks

I. INTRODUCTION

A. Bacground

Based on the latest data released by the World Health Organization (WHO) in April 2011, deaths caused by non-communicable coronary heart disease has reached 37% of the total number of deaths in Indonesia [1]. In addition, in another WHO report states that in 2020, it is estimated that the coronary heart disease will be the major killer diseases in countries throughout Asia-Pacific [2]. The main cause of the coronary heart disease is the presence of excessive fat built up in the lining of the coronary vessel wall veins, causing the blood flow through these arteries become blocked. Modern medicine suggests that if the symptoms of heart disease can be recognized earlier, then the death caused by the heart disease can be reduced significantly.

In general, there are two types of signals that can be used for monitoring the performance of the heart and to diagnose cardiac signals, i.e., phonocardiogram signal (PCG) and the signal electrocardiogram (ECG) [3]. PCG signal is obtained by a doctor using a stethoscope to recognize the symptoms of abnormalities in the heart, while the ECG signal obtained by performing data retrieval through electrodes attached to some point of the body (right arm, left arm and right leg/left) [4]. The signal measurement using either a stethoscope or ECG is often referred to as auscultation.

In this study, we will focus on the PCG signal only. The PCG signal is obtained through process of recording an acoustic wave generated by the mechanical movement of the heart. It is known that there are two types of vibration that can be generated from measurements of the PCG, i.e. the heart sound and the heart murmurs. Based on the characteristics of heart sounds and murmurs, generally classic stethoscope can be used to detect early symptoms leading to a variety of heart problems. However, retrieving signal through the classic auscultation process often limited by low accuracy measurement results, this is mainly because the stethoscope produces a weak voice. Another weakness of the conventional methods is that the auscultation heart signal can never be saved for further analysis. Therefore, doctor's experience as well as physical limitations affects directly to interpretation of the results.

In addition to the difficulties in identifying detail of the cardiac signal, there are other factors that can lead to heart disease diagnosis process becomes biased, i.e., diagnosis process is strongly influenced by the subjectivity of the doctor [4], this is primarily due to exposure of patient chest area during the process of measurement. It is commonly known that the subjectivity due to the physical proximity can affect the interpretation of the diagnosis of heart disease. One solution to cope with this problem can be done by allocating doctors and patients in separate rooms. Such a process is known as remote auscultation (tele-auscultation). Applying tele-auscultation requires the use of network as a medium for data transmission. For example, wireless networking technology can be utilized as it has some advantages, i.e., ease of installation as well as flexibility in terms of the area that can be covered.

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B. *Objectives and Scopes*

The main contribution of this paper is developing a wireless tele-auscultation system for retrieving and storing the phonocardiograph signal through the Zigbee networks. Due to limited throughput of the Zigbee networks, they are not intended to provide high Quality of Service (QoS) for streaming data. In our case, it may limit our system for parallel heart signal recording. However, there are several applications like distributed video surveillance, emergency and rescue that require to run over low cost Zigbee networks [5]. Referring to the goal, we employed Zigbee networks as it has distance coverage suitable to what we need, i.e., local area networks. In addition to that, in Zigbee networks we can arrange in such a way that the operated frequency will not overlap with the WiFi and Bluetooth networks that have been common apparatus for accessing local area networks and the Internet. Hence, implementation of the Zigbee networks in this work is expected to be able to minimize interference completely between devices in common area such as in a hospital. Furthermore, the Zigbee networks have flexibility for covering larger area by creating a mesh networks topology. Thus, when it is needed for larger area coverage in the future, we can extent the network easily.

To achieve good justification in utilizing Zigbee networks, we will examine performance of the wireless networks while transmitting streaming phonocardiograph signal taken from real time auscultation. We will analyze some QoS metrics such as throughput and packet loss ratio over different number of signal sampling periods and serial interface data rates. All of the measurements were accomplished through a real setup using Zigbee-enabled devices deployed in a local area network environment.

II. Related Work

In the recent years, some works in the area of cardiac tele-auscultation system appears in some papers. Some of them will be covered shortly in this part.

Yuenyong in [7] focuses on heart sound signal processing method based on the artificial neural network. The data was acquired using a tele-auscultation system that consisted of an electronic stethoscope mounted to a robot arm and a video conference equipment. In his work, segmentation of the heart sound is performed using ECG signal as reference followed by segmentation, feature extraction and classification methods. The study concluded that classification can be achieved perfectly for limited set of heart sounds that were involved in his works. A work in [8] shows that the heart sound transmission could be realized by telephone correspondence system. In [9], a tele-auscultation system for recording audio signal captured from an electronic stethoscope is presented. The main motivation of the research is to create a system that is able to store the acquired signal into a remote server using the Internet web-based technology. In addition, the system enables users to upload medical audio recordings to a database server for further review by experts anywhere in the world. In a similar way, a paper in [10, 11] proposes an approach to use GSM mobile technology for transmitting cardiac sound signal. The idea was realized by building portable wireless cardiac sound transmission that was connected directly to a mobile device. The author claims that the new system has functionality for the health specialist to operate in hands free mode by receiving data and communicating the health worker at the remote area. A work in [12, 13] shows that a portable wireless sensor system can be developed from a microchip PICDEM to acquire and monitor human heart sounds. The primary focus of this work is on the utilization of the Bluetooth technology for transmitting the data. Based on their results, it could be seen that the Bluetooth technology had advantages of being high- throughput and low cost wireless system. Furthermore, the paper shows that removing noise in the heart signal using the Wavelet Transform can reduce the undesirable sensor signal drastically. Slightly different from the other previous works, a work in [14] utilizes the near-field communication (NFC) and Bluetooth technology as a means for transferring heart sound signal.

The above works in many ways have similarity to our design in terms of their effort to capture and collect the heart signal data and store it into a various storage systems. However, we stress our focus not only on the retrieval process of the signal but also on the performance analysis of the streaming phonocardiograph signal transmission by examining some of QoS metrics. We believe that understanding the signal transmission characteristics is highly important for designing topology as well as communications protocols that is suitable for transmitting phonocardiograph signal. Different from the other previous works, we confine our scheme in the local area networks only.

III. System Design

In this part, we will elaborate our tele-auscultation model as well as hardware specification used in the experiment. The teke-auscultation system consists of two components, i.e. (i) microcontroller and wireless platform, (ii) phonocardiograph sensor (stethoscope).

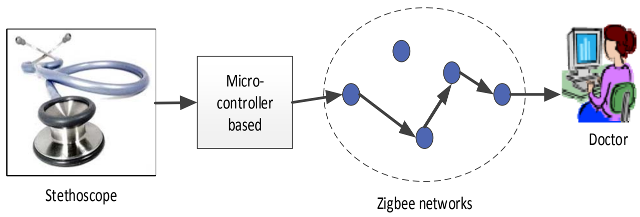


Fig 1. Tele-auscultation model.

A. *Tele-Auscultation Model*

The main focus of the study is in the design of real time wireless auscultation system through the Zigbee networks. The data retrieval processes is done by using an acoustic-based medical devices that are often used to capture the heart signal. The device is referred to as a stethoscope. The acoustic signal emanating from this stethoscope is passed through a microcontroller board that serves as a converter from analog to digital signal and transmitted the signal over wireless networks with Zigbee standard, i.e., IEEE 802.15.4.

In Zigbee wireless networks, it is possible to have some nodes as intermediary nodes between the source node and the destination node. The tele-auscultation model is shown in Figure 1. It should be noted that the stethoscope and the doctors are assumed to be in separate rooms.

B. Hardware Specification

The microcontroller board employed in this study is an Arduino Mega 2560 based on ATmega2560 microprocessor. It has 54 digital input/output pins (of which 15 pins can be used as pulse-width modulation outputs), 16 analog inputs, 4 UARTs (the hardware serial ports), a 16 MHz crystal oscillator, 256 KB flash memory, 8 KB SRAM, 4KB EEPROM, a USB connection, a power jack, an ICSP header, and a reset button. The analog inputs of the Arduino Mega 2560 are operated at voltage of 5V. Each of the analog inputs provide 10 bits of resolution that represents 1024 different values of the digital forms of the signal.

For transmitting the signal wirelessly, we utilized the Zigbee-like radio transceiver module produced by Digi International Inc. namely Xbee Series 2 equipped with a whipped antenna. According to the specification, Xbee S2 has indoor range up to 90m with low transmit power output 50mW (+17dBm). The Xbee S2 is designed with maximum radio frequency data rate 250 Kbps. It operates on the Industrial, Scientific and Medical (ISM) frequency band 2.4 GHz. This radio module can provide a maximum throughput of 35 Kbps.

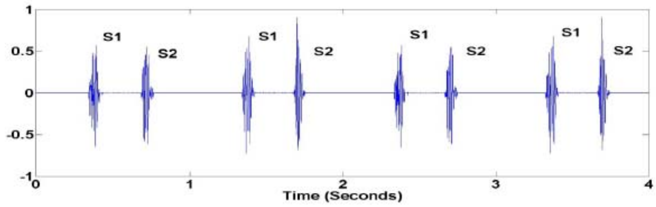
The stethoscope is constructed from a heart-sound sensor. It integrated micro-sound components which is made from polymer material. The sensor is also equipped with an anti-jamming system. The output of the sensor is connected directly to the analog input A0 of the microcontroller board that is then converted to digital forms. Subsequently, the digital forms of the heart-sound signal are transmitted through a Xbee 2 radio module.

The same radio module is used on the other side of the transmitter that represents a receiver of the heart sound signal. The receiver module is then connected to a computer through a USB port. In this way, the signal can be processed, stored and displayed in the computer.

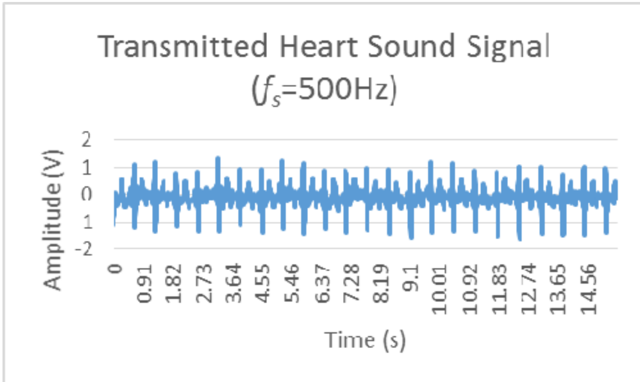
IV. Results and Discussion

In order to capture performance functionality of the phonocardiograph signal transmission, we had done real measurement of the signal by varying signal sampling period (T_s) and serial communication bit rate (R). In this way, we wanted to see the wireless transmission performance of the Zigbee networks carrying streaming data in terms of those two parameters. Clearly the first parameter signifies quality of the heart sound signal, while the latter is directly related to the transmission rate of the Xbee hardware. This is the dilemma that is mostly faced by engineers: increasing the signal sampling period gives better quality of the signal, while decreasing the transmission performance. Conversely, low signal sampling period is desired by transmission line, however it gives real disaster to the users of the signal.

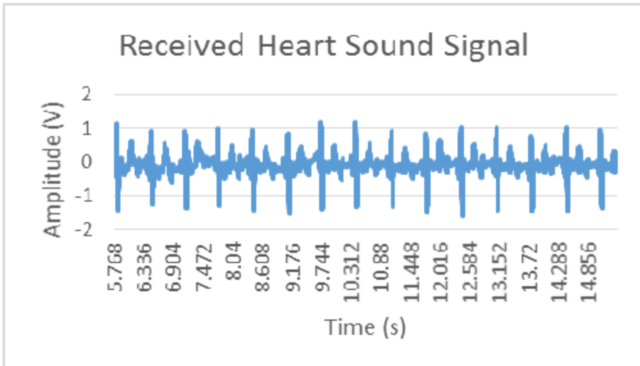
In our experiment, real heart sound signals were taken by varying the sampling periods in four different values, i.e., 0.5ms, 1ms, 1.5ms, and 2ms, while the serial interface bit rate were set to 38.4Kbps, 57.6Kbps and 115.2Kbps. We took 5 measurements for each case of sampling periods and 5 measurements for every serial communication bit rates. The periods of sampling characterize sampling frequency (f_s) of 2000 sampling per second, 1000 sampling per second, 666.67 sampling per second, and 500 sampling per second, respectively. Selection of these sampling frequency is based on the fact that heart sounds frequency content for normal heart rate lie in the frequency range of 20-200Hz for S1 and S2. See in Figure 2a. Thus, by considering the Nyquist principle sampling frequencies of 400 sampling per second or higher are desired.



(a)



(b)



(c)

Figure 2. (a) Fundamental heart sound signal; (b) the transmitted signal taken from 500 sampling per second; and (c) the received signal.

We examined the QoS parameters such as throughput and data loss ratio. It is clear that sampling frequency directly implies the number of transmitted data per second, or commonly called as throughput in the receiver part, while the data loss ratio signifies validity of the received heart sound signal, i.e. validity of the received signal compared to the transmitted signal. It was measured by comparing the number of loss data in the receiver to the number of the whole transmitted data.

We firstly show validity of signal transmission through observation of the transmitted and received signal in time domain. Figure 2 depicts (a) the fundamental heart sound, (b) transmitted signal taken using 500 signal sampling per second and (c) received signal.

Figure 2b and 2c show the third transmitted and received heart sound signal (out of 5 measurements) for a sampling period of 2ms in the transmit module. It can be seen in Figure 2b that the measurement was taken over period of 15s. The amplitude in volt is a normalized voltage of the signal matches with the operated analog inputs voltage of the microcontroller. Dynamic change of the signal clearly signifies a normal heart sound, which contains the S1 and S2 components as in Figure 2a.

Figure 2c displays the received signal. It can be seen that the received signal undergoes delay of 5.768s. Furthermore, by comparing Figure 2b and Figure 2c, it should be noted that the Xbee introduced data lost for all data before 5.768s. Therefore, based on this fact we define two kinds of data loss, i.e. Type A loss is data loss that occurred before the delay and Type B loss is all data loss counted after the delay. We will see that this conquer and divide strategy is useful in analyzing transmission quality of our phonocardiograph signal.

Our analysis to the transmitted phonocardiograph signals in Figure 2b and the received signal in Figure 2c show that the loss ratio between the received and the transmitted signal is 27% for the Type A loss and 0.34% for the Type B loss. Because the heart sound signal is a repetitive signal, we argue that the Type A loss is meaningless in assessing the quality of the received signal. In other words, the loss signal arises before 5.768s can be omitted without affecting the validity of the received signal as long as time length of measurement is longer than the transmission delay. Therefore, in this study we will emphasize on the Type B loss to evaluate the received signal quality. Based on phonocardiograph signal in Figure 2c and the Type B loss, it can be argued that the transmission process is considered valid. Even though there are loss packets, the number of the loss packets is not significant (only 0.34% for this signal).

Table I presents averaged loss ratio for every sampling period. Figure 3 is a graphic representation of the Table I. In terms of the averaged data loss ratio, our observation shows that the number of Type B data loss during transmission of the signal for all experiments are close to zero except for the signal that was sampled in 0.5ms duration. The averaged data loss for Type B loss is 10.69%. See Table I. Furthermore, if we remove the data with sampling period of 0.5ms, we get the averaged Type B loss as 0.35%. Conversely, we see from the table that the averaged Type A loss is large, that is 47.09%. This large number means that almost a half of the transmitted data did not reach the receiver properly. Fortunately, the heart sound signal is a repetitive signal as explained above. Hence, without loss of generality, we can exempt the Type A loss for indicating quality of the received signal.

It is evident that for both cases, major loss of the data arise from the phonocardiograph signal with sampling period of 0.5ms. As mentioned in Section IIIB, small sampling period indicated large sampling frequency. In the case of sampling period of 0.5ms, we expected there were 2000 sampled signal per second to be transmitted.

TABLE I. AVERAGED LOSS RATIO FOR DIFFERENT SAMPLING PERIODS

No.	Sampling period, T_s (ms)	Type A Loss (%)	Type B Loss (%)
1.	0.5	82.76	41.71
2.	1	35.54	0.92
3.	1.5	46.40	0
4.	2	23.66	0.14
	Overall Averaged Loss	**47.09**	**10.69**

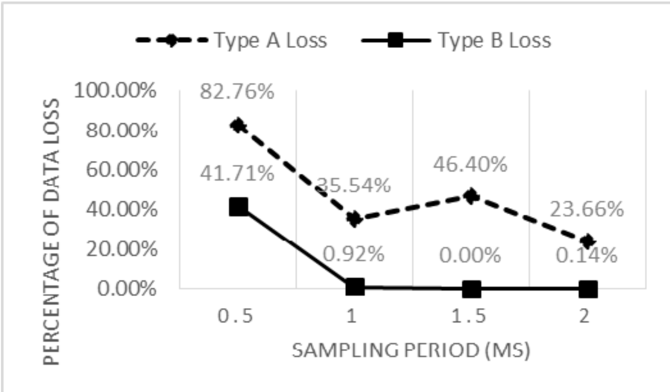


Figure 3. Percentage of data loss for the Type A loss and the Type B loss. The data is averaged over 5 measurements for each sampling period.

The low percentage of the loss ratio (Type B loss) of the tele-auscultation system suggests that the developed system is acceptable for transferring the streaming heart sound signal. However, the streaming signal that is sampled with sampling period of 0.5ms (f_s=2000 sampling per second) shows that it introduces very high data loss. Thus signal with sampling period of 0.5ms is not recommended for transmitting streaming signal through the Xbee radio link.

Table II shows averaged loss ratio against variation of the serial interface data rate. The graph representation of Table II is illustrated in Figure 4. It can be seen immediately that lower serial interface data rate initiates higher percentage of data loss (Type B loss). It is not surprising result, because theoretically low data rate gives contribution to the increase of the packet collisions at MAC layer. Hence, we observe the growth of the data loss number.

However, if we can utilize the maximum speed of the Xbee serial interface at 115.2 Kbps, we only get the data loss ratio 0.14% as in Table II. It should also be noticed that the trend lines of the Type A and Type B loss (dotted lines in Figure 4) show increment of data loss along with the decrease of the serial interface data rate.

TABLE II. AVERAGED LOSS RATIO FOR DIFFERENT SERIAL INTERFACE DATA RATES

No.	Serial Interface Data Rate, *R* (Kbps)	Type A Loss (%)	Type B Loss (%)
1.	115.2	23.66	0.14
2.	57.6	34.42	1.11
3.	38.4	27.81	4.04
	Overall Averaged Loss	**28.63**	**1.76**

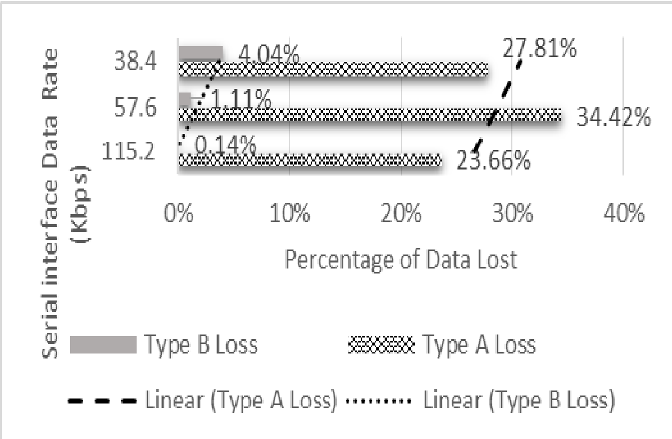


Figure 4. Percentage of data loss for the Type A loss and the Type B loss. The data is averaged over 5 measurements for each serial interface data rate. The dotted lines are the linear trend lines.

Next, we turn to the throughput analysis of the system as shown in Table III and Table IV. The tables reveal that variation of the throughput is not a function of T_s as well as the serial interface data rate, *R*. Figure 5 depicts a graph representation of Table III. From Figure 5, it can be seen that the transmission rate is decreasing following longer sampling periods. This is due to that the longer the sampling periods, the less data that are transmitted. Hence the transmission rate is shrinking accordingly. However, it can be observed clearly that a gradual increment of the T_s does not seem affect the throughput of the system. This conclusion also applies when the serial interface data rate is shifted from slow (38.4 Kbps) to fast (115.2 Kbps). See Figure 6. There is no significant change in the throughput of the system. The overall averaged throughput in Table III is 12.96 Kbps, whereas overall averaged throughput in Table IV is 10.71 Kbps.

It is more likely that this small and steady discrepancy of the throughput for both measurement in Table III and Table IV is largely affected by environment where the experiment took place, for example location of the obstacles around the radio Xbee including people, furniture, cupboards, electronic apparatus, etc. The second reason behind this peculiar behavior is probably the hardware or memory capability of the Xbee in transmitting streaming data like this heart sound signal. A further study will be needed to observe the Xbee behavior in carrying streaming or multimedia data in order to acquire a more insightful conclusion.

TABLE III. AVERAGED SIGNAL TRANSMISSION THROUGHPUT FOR DIFFERENT SAMPLING PERIODS

No.	Sampling period, T_s (ms)	Transmission Rate (Kbps)	Throughput (Kbps)
1.	0.5	60.0	10.35
2.	1	30.0	19.34
3.	1.5	20.0	10.72
4.	2	15.0	11.45
	Overall Average Throughput		**12.96**

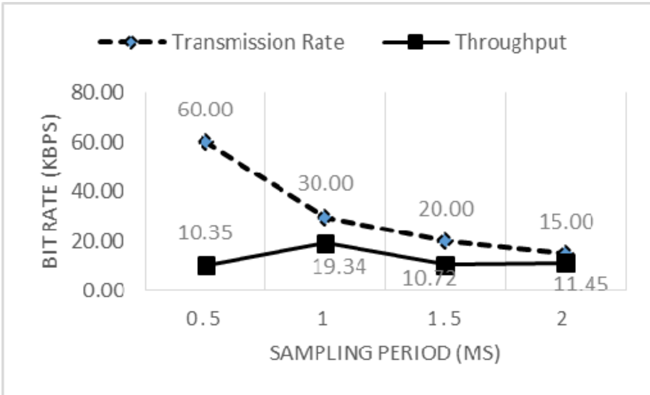


Figure 5. Averaged transmission rate and throughput of the system for different sampling periods.

V. CONCLUSSION

In this work, we aimed to build a wireless tele-auscultation system for transmitting and recording phonocardiograph signal utilizing Zigbee-like radio transceiver module produced by Digi International Inc. i.e. Xbee Series 2. The data was transmitted in local area networks. In order to identify the data loss in the system, we define Type A loss and Type B loss. The Type A loss is data loss that occurred before the delay whereas the Type B loss is all data loss counted after the delay. Based on our study, it is evident that the Type A loss can be omitted without affecting the validity of the received signal as long as time length of measurement is longer than the transmission delay. Conversely, in terms of the Type B loss, it can be argued that the transmission process is considered as valid, i.e. even though there are loss packets, the number of the loss packets is not significant. In addition to that, we examined that variation of the sampling period and the serial interface data rate do not contribute well to the improvement of the throughput the streaming heart sound signal transmission. The throughput of the system is probably influenced by the surrounding environment and hardware or memory capability of the Xbee. Hence, a further study will be needed to observe the Xbee behavior in carrying streaming phonocardiogram signal in order to acquire a more insightful conclusion.

TABLE IV. AVERAGED SIGNAL TRANSMISSION THROUGHPUT FOR DIFFERENT SERIAL INTERFACE DATA RATE

No.	Serial Interface Data Rate, *R* (Kbps)	Transmission Rate (Kbps)	Throughput (Kbps)
1.	115.2	15.0	11.45
2.	57.6	15.0	9.84
3.	38.4	15.0	10.83
	Overall Averaged Throughput		**10.71**

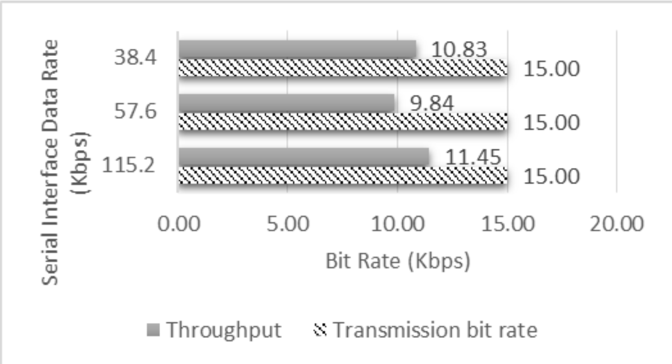


Figure 6. Averaged transmission rate and throughput of the system for different serial interface data rates.

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Nama Instansi	: ....
Jabatan Penerima	: ....

Tanda Tangan & Stempel	: .... APWiMob
Nama Terang	: Anggunmeka L.P

CERTIFICATE

THIS IS TO CERTIFY THAT

JUSAK

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