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Investigation of Wireless Communication from Under Seawater to Open Air with Xbee Pro S2B Based on IEEE 802.15.4 (Case Study: West Java Pangandaran Offshore Indonesia)

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Abstract. Under seawater wireless communication by using 802.15.4 protocol and 2.4 GHz frequency is used to support the topology of Underwater Wireless Sensor Network (UWSN). Some studies have been conducted to analyze underwater wireless communication at a close range which is less than 1 m. However, if the communication is conducted from under seawater to the open air, it is necessary to determine whether the change of media, that is water and air, will influence the communication. This research offers the results of wireless communication performance point to point under seawater by using ZigbeePro S2B module based on IEEE 802.15.4 protocol. The measurements were conducted in the offshore area at a distance of 1 km from the coast. The measurement of radio range test was undertaken by using XCTU version 6.3.8 application. The findings suggest that after 3 tests, the performance of ZigbeePro S2B ran optimally only at a distance of 20 cm depth. Although it had been tested to a distance of 500 cm depth, it seemed that there was a significant decrease in performance after 20 cm deep. Furthermore, at a distance of 500 cm, a total failure in data transmission occurred.

Keywords: Zigbee Pro S2B · Seawater · Wireless communication XCTU · Conductivity

1 Introduction

1.1 Underwater Communication

The smart system technology, especially in wireless communication, is rapidly developing today, thus, several supporting protocols have been widely introduced and discussed. The wireless communication technology is built to meet the people's increasingly complex needs. Nowadays, communication between machines requires large data, high speed, high accuracy, different environments, which is sometimes extreme, including under seawater.

Pure water is an insulating material; however, in natural conditions, water contains dissolved material which turns the water into a conductor. The higher the water conductivity, the higher the attenuation of the radio wave [1]. It means that within the

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media with high attenuation coefficient or media conductivity, radio waves with high frequency are needed.

The value of water conductivity is also influenced by water salinity and temperature. Water with high salinity has a high conductivity, for instance, Red Sea water with conductivity value σ = 8 S/m (1 S/m equivalent 1 mho/m). Meanwhile, in the arctic region, the conductivity value σ = 8 S/m. Generally, seawater has a conductivity σ = 4 S/m [2], while warm seawater has a conductivity value (σ) up to 8 S/m [3].

Table 1 shows the variation of conductivity values by water type. The electromagnetic wave (EM) velocity in water will decrease as a result of media change that is from water to air [2].

Table 1. Water conductivity [2]

Water	Conductivity values
Freshwater	$0 \leq \sigma < 1$
Riverwater	$1 \leq \sigma < 2$
Seawater	$\sigma \geq 2$

Figure 1 shows that the salinity (NaCl) in water affects the value of water conductivity since the NaCl in water forms anions and cations which then form a positive and negative charge [4]. However, the existence of the charge is the same, hence the salt water is electrically neutral.

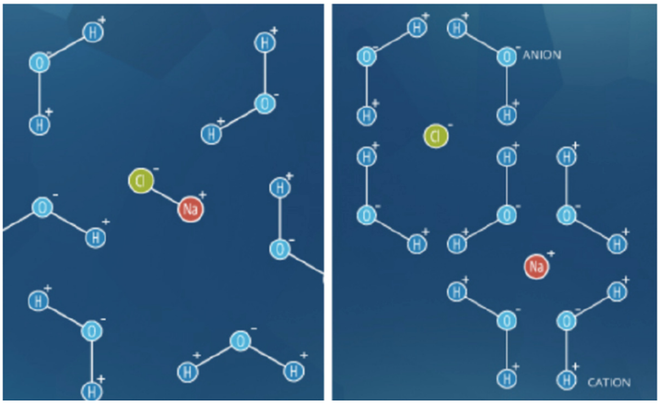


Fig. 1. Anions and cations formed in salt water [4].

ZigBee or ZigBee Pro is a product of Digi International. ZigBee or ZigBee Pro works on the IEEE 802.15.4 standard communications protocol [5]. This RF module is designed to be used on WSN or UWSN networks. Therefore, many researchers use Zigbee as a water-based communication test [6–9] and many more.

1.2 Related Work

Many researchers have conducted research on undersea wireless communication, but only several studies that examine how optimal communication between sensors in the water. Research by [10] has successfully carried out wireless communication testing using IEEE 802.11 protocol with 2,412 GHz and 2,442 GHz frequency ranges at 0–20 cm depth. The research suggests that optimal communication occurs in the range of 0–15 cm deep in the water. Then, at a distance of 18 cm deep, the communication cannot significantly occur. Whereas [6] has proposed the results of measurement of Zigbee-based wireless communications at a frequency of 2.4 GHz and low power. The test was also performed in the water. The study reveals the lowest error value that is 0–10% occurred at a depth of 0–40 mm for testing in seawater, while in freshwater, it occurred at a depth of 0–200 mm.

Furthermore, [3] examined statistical correlations between the conductivity of seawater and signal GSM (dBm) strength. The results show that the signal strength is inversely proportional to the conductivity and is proportional to the frequency. It means that the higher the frequency and the lower the conductivity of the seawater, the higher the signal strength in the water. This study is synergistic with what has been done in [7] data collection strategies on WSN networks in water regardless of EM performance in water. Sensor with WSN network topology was divided into three levels with level 3 was the position of the deepest sensor while level 1 was the closest sensor to the water surface.

Some studies also offer underwater sensor networks topologies, as [11] propose research on the configuration of underwater communications architecture named UWSN. The result of this study suggests that UWSN consists of five-class classification, namely, monitoring, disaster, military, navigation, and sports. The sensor deployment technique with underwater sensor networks topology (UWSN) is introduced in [12]. Figure 2 shows that communication based on UWSN topology is a blend of wireless

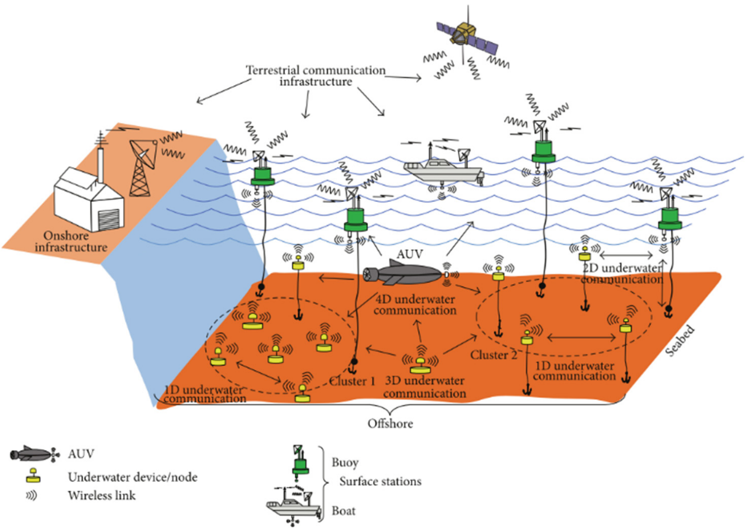


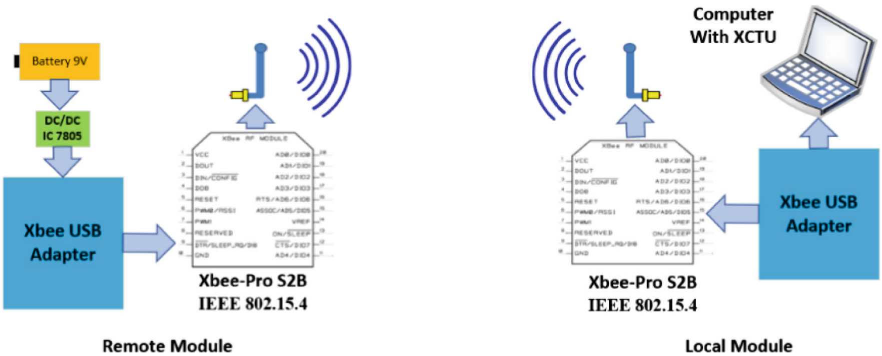
Fig. 2. Underwater sensor network architecture [11].

communication technology with micromechanical and smart sensor devices, smart computing, and intelligent communication skills [11].

2 Methodology

The system utilized a point-to-point communication method with the Xbee-Pro S2B wireless communication module placed on the Xbee USB Adapter board. The standalone power supply was a 9 V 6KR61 (Ni-Cd) battery which was converted to 5v by using DC to DC IC 7805 converter.

Figure 3 shows the procedure of this study. The communication system consisted of remote module as the data sender and local module as the data receiver. Remote module was positioned under seawater, while the local module was placed above of remote module, on a in an open space of in the boat exactly. XCTU Version 6.3.8 application was employed as the arrange test gauge. The measured variables were the distance between the local module and the remote modules (m), RSSI Local Module (dBm), RSSI remote module (dBm), Packets sent, Packet Sent error (%), Packet Sent error, Packet received, Packets Received error, and level of success (%).



(a). Remote module (b). Local module

Fig. 3. Architecture of remote module architecture and local module.

The test was conducted in the Pangandaran coastal region, which is the part of southern coast of Java island, in West Java Province, Indonesia. The distance between the test site and the nearest beach was 1000 m, precisely at the coordinates 7°42’04.4 “S 108°40’03.4”E (Fig. 5). The test was performed at 04:00 PM.

The test was conducted as illustrated in in Fig. 4. The remote module Fig. 3(a) was sunk from the surface of the water up to 5 m deep, while the local module Fig. 3(b) was placed on a boat, 0.8 m from the water surface. Communication test was carried out for 3 times. XCTU application was utilized to record the communications data from remote module to local module. The data consisted of signal strength of local and

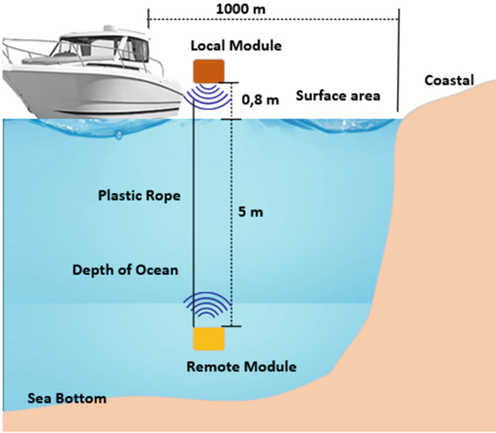


Fig. 4. Methodology of testing.

Fig. 5. Test location (Satellite view).

remote modules, Packets sent, Packet Sent errors, Packets Received, Packets Received error, and level of success.

3 Results and Discussion

In the system modeling, 2 Xbee Pro modules were applied, namely, one Xbee-Pro module as a local node (Fig. 7(b)) and another xbee as Xbee-Pro remote (Fig. 7(a)). In the test of XCTU software Version 6.3.8., the salinity was 25% which was obtained by using a refractometer. Figure 6(a) is a remote module equipped with a self-supporting power supply as in Fig. 3(a), while Fig. 6(a) is a local module connected to the laptop through XCTU application as shown in Fig. 3(b).

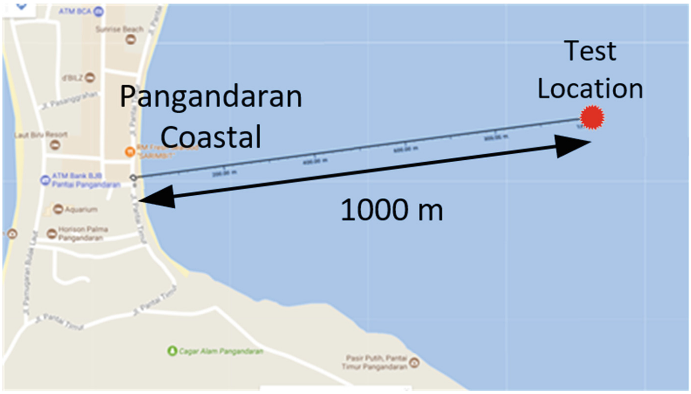
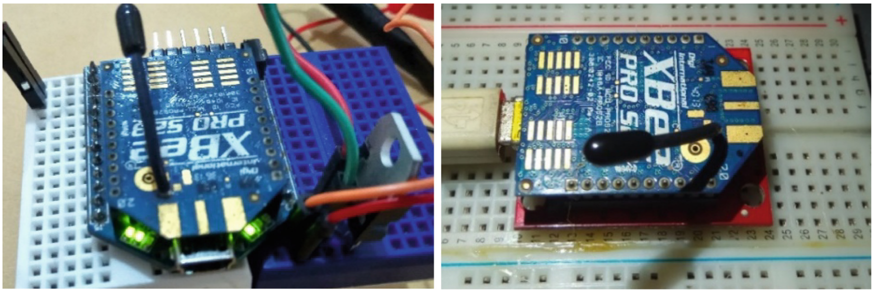


Fig. 6. Test location (map view).



(a) Developed remote module (b). Developed local module

Fig. 7. XBee Communication module.

Figure 8 is a configuration in the XCTU application which is utilized to determine the status of each module. In this case, the Zigbee coordinator served as a local module as demonstrated in Fig. 3(b), while the Zigbee router functioned as a remote module as illustrated in Fig. 3(a).

The three tests were conducted in the offshore area about 1000 m from the coast with salinity of 25%, and the ambient temperature of the test location was 32.6 °C. During the test, wind rate and underwater flow rate were ignored. Figure 9, 10 and 11 demonstrate the results of the system testing which was repeated for 3 times. It can be inferred the character of the test results are not much different since the strength of the signal changes along with the increase of distance between the remote module and the local module.

The findings suggest that the wireless communication quality of XbeePro S2B module from the sea to the open air (water surface) is inversely proportional to the depth of the water where the remote module was sunk. Table 2 is the tabulation of communication test for several target variables in this research.

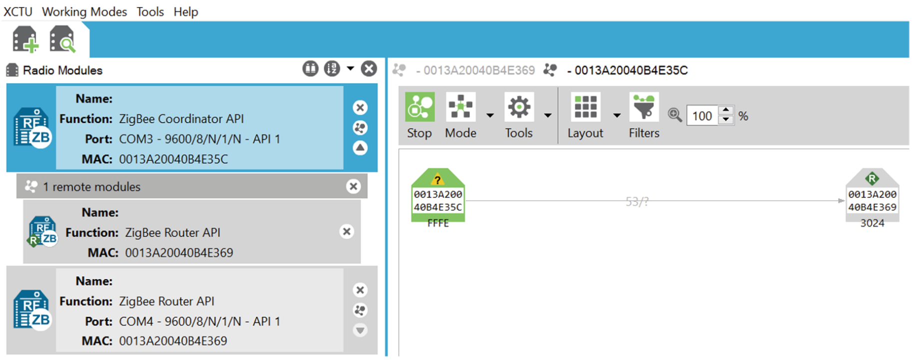


Fig. 8. Configuration of XCTU to determine the status of the remote module and local module.

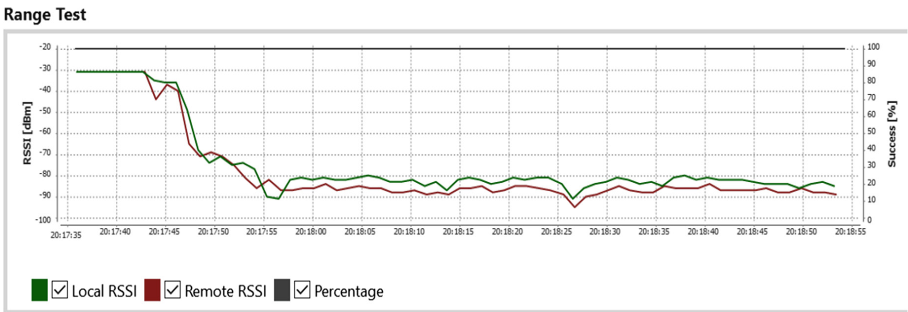


Fig. 9. The range result of the 1st test by using XCTU application at a depth of 0–5 m.

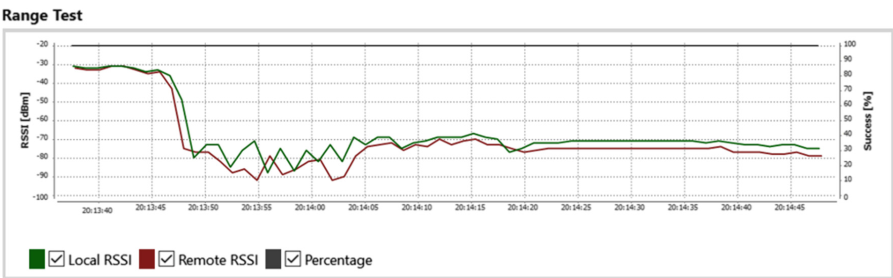


Fig. 10. The range result of the 2nd test using XCTU application at a depth of 0–5 m.

At a depth of 0 m–5 m, the local module seemed to produce a variative RSSI of -40 dBm to -76 dBm, while the RSSI on the remote module started varying between -30dBm at a depth of 0 m and then -88dBm at a depth of 5 m (Fig. 12).

It means that although XbeePro S2B has a good reputation for open air communications [13], the result is different when the wireless communication takes place between the water and the water surface. At a depth of 20 cm, there was a significant

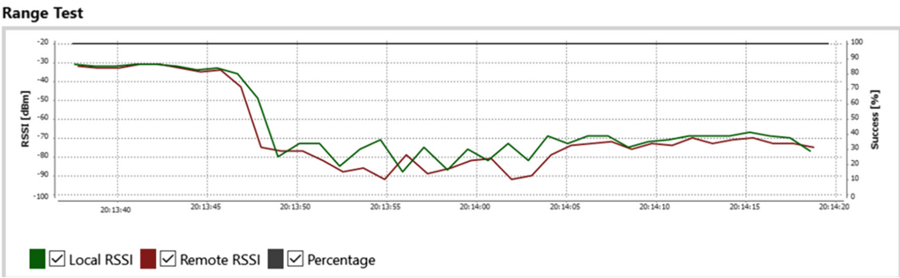


Fig. 11. The range result of the 3rd test using XCTU applications at a depth of 0-5 m.

Table 2. Results of xbee Pro S2B point to point wireless communication performance

Depth (meter)	RSSI local modules (dBm)	RSSI remote modules (dBm)	Packets sent	Error packet sent	Packets received	Error packets received	Level of success (%)
0.0	–30	–30	100	0	100	0	100
0.2	–43	–40	100	11	89	0	29.0
0.5	–39	–37	100	31	83	0	13.9
1.0	–40	–48	100	57	70	0	8.06
1.5	–50	–52	100	73	75	0	6.41
2.0	–60	–61	100	90	64	0	5.26
2.5	–67	–65	100	95	55	0	5.00
3.0	–71	–70	100	52	48	0	4.32
4.0	–73	–83	100	48	30	0	8.47
5.0	–76	–88	100	43	28	0	6.17

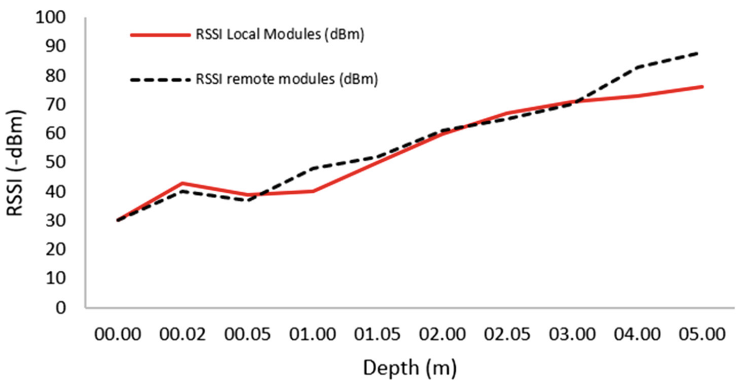


Fig. 12. Characteristic of signal (RSSI) to depth of seawater in communication test.

failure of 89%, while according to [6] Zigbee can perform a communication until a depth of 40 mm in freshwater and seawater. According to the XCTU application, there was no error of data packets received during the test which means that the data was received completely and data defect did not occur.

The decrease in the value of RSSI had caused a transmission error. Through XCTU, the data, which was sent from the local module to the remote module, was set to 100 data per depth (Fig. 13). Out of the 100 data sent, the error occurred is directly proportional with the depth of water in which the remote module was sunk. At a depth of 3 m, the error of data transmission was smaller than at 2.5 m depth. It is due to the possibility that the remote module was carried along by the seawater current so that the remote module approaches the surface. The results of this study are in accordance with what has been done by [3, 6, 10].

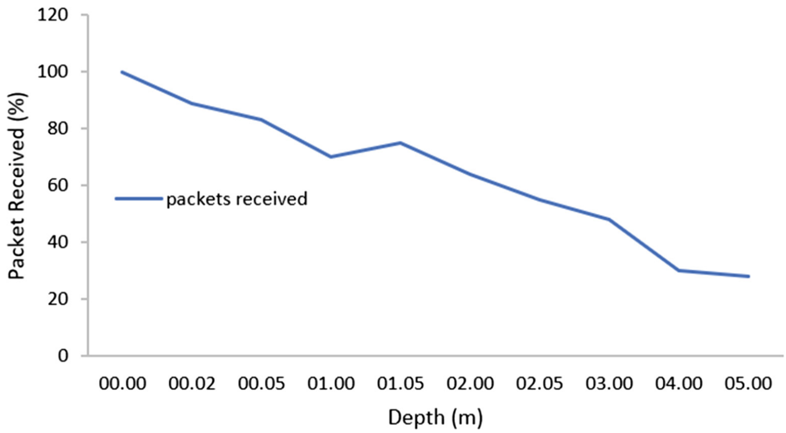


Fig. 13. Decreased levels of success received data to the sea depths.

4 Conclusion

After three tests, it can be concluded that the zigbeePro S2B communication is directly proportional to the depth of the water with the optimal distance is only 20 cm. Although it had been tested to a depth of 500 cm, it seemed that the communication had already failed even at a distance after 20 cm.

The communication by using the IEEE 802.15.4 protocol with the xbee Pro S2B module does not provide satisfactory results on wireless communication techniques in seawater. In addition, the Xbee pro S2B module also requires more energy when it is used in seawater, especially starting from a depth of 20 cm. Therefore, in the use of xbee Pro S2B, it is necessary to consider energy management on communication module that will be placed in the sea. To conclude, since the research themes regarding WSN or UWSN become an interesting topic to be studied, energy management for sensor in seawater also emerges to be an interesting research theme to be studied further.

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