Underwater Acoustic Communication Channel Model : A Simulation Study of Ibu Kota Nusantara

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***Abstract*— The relocation of the national capital lies at the junction of the Indo-Australian plate, the Pacific plate and the Eurasian plate, which causes frequent tectonic shift activities that have the potential for tsunami disasters. Acoustic underwater wireless sensor networks to monitor and detect tectonic shift activities are often used as a preventive measure. In its implementation, problems often occur in UWSN applications, such as attenuation, delay, and noise. To overcome these problems, this study aims to investigate and analyse acoustic communication of underwater channels to determine the optimum frequency, power required, and the best protocol for the application of UWSN. Through this research, IKN sea characteristics such as salinity, pH, temperature, wind speed in the IKN sea and ship activity constants of 34.31 ppt, 7.82, 4.11 ° C and 6 m/s were obtained. Calculation of the optimum frequency is also carried out in minimizing the attenuation and noise values of the channel and obtaining the optimum frequency required by UWSN for applications at a depth value and transmission range of 500 m, 1 km, 5 km, 50 km, and 100 km respectively are 184.3 kHz, 187 kHz, 210.4 kHz, 790.7 kHz and 3441.5 kHz and 264.5 kHz, 187 kHz, 83.6 kHz, 26.3 kHz, and 18.6 kHz. Analysis of protocol variations was also carried out by comparing the Pure ALOHA, Slotted ALOHA, 1-persistent CSMA/CA, and non-persistent CSMA protocols also carried out, and it was found that non-persistent CSMA/CA protocols had higher throughput values than other variations.**

***Keywords*—Underwater wireless sensor network, acoustic channel, Ibu Kota Nusantara**

I. Introduction

The relocation of the capital of Indonesia from DKI Jakarta to the Capital of the Archipelago (IKN) is a program of the Indonesian government to create equitable development as well as to accelerate Indonesia's economic transformation. In achieving this goal, IKN's infrastructure development planning must consider security factors and public safety. IKN is located at the junction of the Indo-Australian plate, the Pacific plate and the Eurasian plate, which causes frequent tectonic shift activities that have the potential for tsunami disasters [1]. One of the preventive measures of tsunami prevention is to place several wireless sensors, one of which is an acoustic pressure sensor to monitor and detect tectonic shift activities used as an early warning tsunami system [2, 3].

Underwater wireless sensor network (UWSN) is one of the wireless sensor network applications for underwater communication. UWSN consists of sensors that can perform sensing, communication and computing to achieve a specific goal. These sensors are connected to a network and can communicate with each other through *machine-to-machine* protocols or communication between sensors and base stations. One example of an application of UWSN is the Internet of Underwater Things (IoUT). In its implementation, IoUT is deployed through *floating buoys* or *anchor buoys* for data collection such as temperature, salinity, pressure, and light [4–6].

The main problems that occur in the implementation of the UWSN system are attenuation, delay, and noise caused by environmental influences and human activities [7]. To overcome this, low-frequency acoustic waves are used as a substitute for high-frequency radio waves [8]. This is because the characteristics of underwater communication channels are different from terrestrial communication channels. The design and link budget of UWSN must be determined based on the characteristics of the underwater channel. Parameters such as frequency, temperature, salinity, depth distance and pH can affect the power calculation required by UWSN.

Analysis of the characteristics of underwater communication channels plays an important role in determining the design parameters of UWSN devices. In addition, the analysis also plays a role in determining the modulation scheme, protocol, and error correction used. This study aims to investigate and analyze underwater channel communication in IKN waters to create reliable data transmission, reducing energy consumption, and maximizing network life, thereby facilitating successful implementation and operation of UWSN.

The writing of this paper is divided into several sections, namely: 1. Introduction, which explains the background, problem formulation, research objectives, scope, and research systematics; 2. Underwater Acoustic Channel Model, which discusses modeling of the UWSN environment; 3. Methodology, this section describes the research flow, data collection methods and approaches used in analyzing data results; 4. Result and Analysis This section describes the results and discussion of the simulations carried out, which were evaluated on specific parameters; 5. Conclussion, this section contains findings drawn from the results and discussion, considering the research objectives and suggestions for research development.

II. UNDERWATER ACOUSTIC CHANNEL MODEL

The modeling of underwater acoustic channel characteristics is broadly influenced by three components: propagation loss, propagation delay, and noise. The value of each component is influenced by parameters such as operating frequency, transmission distance, depth, salinity, temperature and pH in the underwater environment based on the characteristics of the underwater environment used. Modelling of acoustic channel characteristics aims to calculate the link budget and determine the performance of the UWSN protocol used.

Propagation loss is a large loss experienced when transmitting from one node to another; the loss is caused by absorption caused by magnesium sulphate, boric acid, particle movement and geometrical spreading. $A(d,f)$ is a propagation loss whose value is affected by the distance value d , frequency f with kilohertz units, k is a coefficient spreading and $\alpha(f)$ is a coefficient absorption, that shown in equation (1). The value of k is influenced by geometric spreading for spherical ($k = 2$), for cylindrical ($k = 1.5$), and for practical application ($k = 1.5$) [12].

$$A(d,f) = d^k \alpha(f)^d \tag{1}$$

In modeling the attenuation coefficient, there are several models used, namely Thorp, Fisher & Simons and Ainslie & McColm. The Ainslie & McColm equation has accurate results, because it uses depth, temperature, salinity and pH parameters in its modeling [9]. The equation of Anslie & McColm is shown in equation (2), with temperature in Celsius T, salinity in ppt S, f_1 and f_2 is the frequency of relaxation in kilohertz, and depth in kilometers. D

$$\begin{aligned}
f_1 &= 0.78\sqrt{\frac{S}{35}}e^{\frac{T}{26}} \\
f_2 &= 42e^{\frac{T}{17}} \\
A_1 &= 0.106\frac{f_1 f^2}{f_1^2+f^2}e^{\frac{pH-S}{0.56}} \\
A_2 &= 0.52\left(1+\frac{T}{43}\right)\left(\frac{S}{35}\right)\frac{f_2 f^2}{f_2^2+f^2}e^{\frac{-D}{0.56}} \\
A_3 &= 4.9\times10^{-4} f_2 \cdot e^{\frac{T}{27}+\frac{D}{17}} \\
\alpha(f) &= A_1+A_2+A_3
\end{aligned} \tag{2}$$

Wireless acoustic communication is affected by the medium traversed, which affects the throughput, latency and quality of service of data communication. There are several models used to model the speed of sound for underwater propagation, one of which is the MacKenzie equation shown in equation (3), the MacKenzie equation has more accurate modeling than other models such as Medwin's equation, in modeling depths of more than 1 km [10].

$$\begin{aligned}
A_1 &= 1448.96+4.591\cdot T-5.304\times10^{-2}T^2 \\
A_2 &= 2.374\cdot T^3+1.340\cdot(S-35)+1.630\times10^{-2}\cdot D \\
A_3 &= 1.675\times10^{-7}D^2-1.025\times10^{-2}\cdot T\cdot(S-35) \\
A_4 &= -7.139\times10^{-13}D^3\cdot T \\
v_{uw} &= A_1+A_2+A_3+A_4
\end{aligned} \tag{3}$$

In addition to the speed of sound, large noise also affects the quality of service of acoustic communication. Ambient noise model is a model used in representing the presence of noise underwater, Ambient noise model can be represented into Gaussian form and has continuous power spectral density, with the largest source of noise is turbulence N_T, ship activity N_S, waves formed due to wind movement N_W and thermal influence N_{Th} [11], which is represented in equation (4).

$$\begin{aligned}
N_T(f) &= 17-30\log f \\
N_S(f) &= 40+20(s-0.5)+26\log f - \\
&\quad 60\log(f+0.03) \\
N_W(f) &= 50+7.5w^{\frac{1}{2}}+20\log f-40\log(f+0.4) \\
N_{Th}(f) &= -15+20\log f \\
N_{Total}(f) &= N_T(f)+N_S(f)+N_W(f)+N_{Th}(f)
\end{aligned} \tag{4}$$

In calculating the amount of power transmission and QoS used, the calculation of the link budget is carried out by considering the signal-to-noise-ratio (SNR) whose value is influenced by attenuation and noise with distance and frequency as dependent variables, shown in equation (5).

$$\begin{aligned}
10\log SNR(d,f) = 10\log P_0 - 10\log A(d,f) - \\
10\log N_{Total}(f)
\end{aligned} \tag{5}$$

The throughput of UWSN is affected by the propagation medium which affects the propagation speed. In terrestrial WSN, the propagation speed of data transmission is the speed of light, resulting in a ratio delay between transmission times (ζ) $\tau_{transmission}$ and propagation time $\tau_{propagation}$ approaches to zero. The three components are shown in equation (8)-(10). In UWSN, the propagation speed of the acoustic sensor is affected by the underwater medium shown in equation (3), which causes the delay ratio in UWSN to be significantly greater than that of terrestrial WSN.

$$\tau_{transmission} = \frac{k_c + k_d + k_t}{\mu} \tag{6}$$

$$\tau_{propagation} = \frac{d}{v_{uw}} \tag{7}$$

$$\zeta = \frac{\tau_{transmission}}{\tau_{propagation}} \tag{8}$$

Carrier sense multiple access collision avoidance (CSMA/CA) is a MAC protocol used to manage communication on the same communication channel. In achieving collision avoidance, the CSMA/CA protocol listens to the base station before sending data. If the base station is idle, the device will send data to the base station.

There are several types of CSMA/CA, 1-persistent CSMA, p-persistent CSMA and non-persistent CSMA. Non-persistent CSMA has greater throughput than 1-persistent CSMA and p-persistent CSMA because non-persistent CSMA uses a random backoff technique to check whether a channel is busy based on a random time period [12]. The throughput equation of non-persistent CSMA and 1-persistent CSMA is represented by ρ and shown in equations (9) and (10).

$$\rho = \frac{G \cdot e^{-\zeta \cdot G}}{G(1+2\zeta)+e^{-\zeta \cdot G}} \tag{9}$$

$$\rho = \frac{G\left[1+G+\zeta G\left(1+G+\zeta G/2\right)\right]e^{-G(1+2\zeta)}}{G(1+2\zeta)-\left(1-e^{-\zeta G}\right)+\left(1+\zeta G\right)e^{-G(1+\zeta)}} \tag{10}$$

In ALOHA, data transmission is carried out continuously without waiting for the base station to idle first. There are several types of ALOHA protocol, including Pure ALOHA and Slotted ALOHA. Pure ALOHA is a random-access protocol where multiple devices share the same channel. Random Access allows each device to send data anytime without waiting for simultaneous time slots. Pure ALOHA can perform collision detection. After the device transmits data, it waits for an ACK signal from the base station. If the device does not receive the ACK signal, the device will send data back at a certain random time.

Slotted ALOHA is a development of Pure ALOHA. The protocol divides data into different interval time slots for each device to reduce the potential for collisions. The throughput equations of Pure ALOHA and Slotted ALOHA are shown in equations (11) and (12).

$$\rho = Ge^{-2G} \tag{11}$$

$$\rho = Ge^{-G} \tag{12}$$

III. Methodology

This study aims to investigate and analyze the acoustic communication of underwater channels in IKN waters. In achieving this, quantitative approaches are used through numerical and statistical analysis of the results of simulations and comparisons. The sampling method was carried out experimentally based on computer program simulations through modelling the underwater environment of IKN. In obtaining UWSN environmental characteristics in IKN waters, literature studies and analyses are carried out to obtain salinity, pH, temperature and wind speed values as well as ship activity, which are determining parameters in determining UWSN environmental characteristics, which are dependent variables in equations (1)-(5).

Investigation and analysis of attenuation and noise characteristics of underwater acoustic communication channels were carried out by varying the transmission distance and placement of UWSN devices. The analysis is used to determine the optimum frequency value and the transmission power required to achieve a specific SNR value that minimizes attenuation and noise values in the channel. In throughput analysis, variations of the protocol are carried out to determine the performance of the protocol in the UWSN environment as supporting data for the approach taken.

IV. Result and Discussion

Information on the characteristics of IKN sea waters aims to determine the model of the underwater acoustic channel. The IKN Sea is located in the Makassar Strait area. At a depth of 1 km, the IKN sea has the characteristics of salinity, pH and temperature of 34.31 ppt, 7.82 dan 4.11℃ [13, 14]. Makassar Strait is influenced by the southeast monsoon wind, which causes the upwelling phenomenon with wind speeds of 6 m / s [15]. The development of IKN aims to replace Jakarta's economic development. This triggers increased shipping activity from logistics or trade shipping activities [16]. On this basis, determining the vessel activity constant required at observation (4) is assumed to be 0.8.

In Fig 1, it is shown that the transmission distance influences attenuation. The greater the depth of the device, the smaller the value of the attenuation constant of the channel. In the Ainslie & McColm equation, the attenuation value is caused by absorption, which can be in the form of absorption from the movement of particles that cause viscous drag and absorption caused by chemical reactions. At high frequencies, particle motion caused by sound propagation will cause heat from particle vibrations caused by viscous drag. Conversely, absorption caused by chemical reactions does not significantly affect high frequencies.

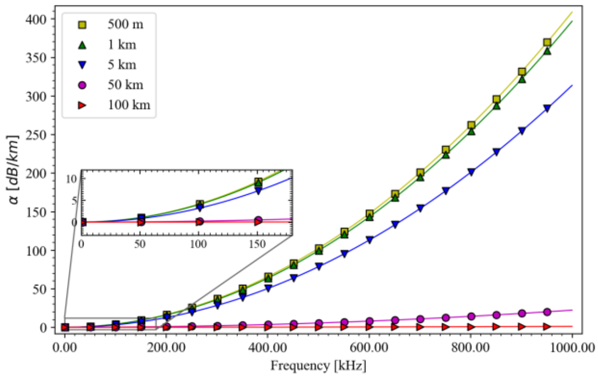


Fig 1. Attenuation characteristics of the IKN marine acoustic underwater channel against different depth variations

Noise is a determining component of the quality of the received signal. The distribution of noise in IKN sea waters in underwater acoustic channel modelling is carried out using equation (4) with the characteristic parameters of IKN waters obtained that the influence of turbulence has a strong influence on the frequency of 0-10 Hz. At a 10-100 Hz frequency, ship activity has a high influence. At frequencies of 100 Hz - 100 kHz, the influence of wind speed has a high influence, and above the frequency of 100 kHz, thermal power has a high influence, as shown in Figure 2.

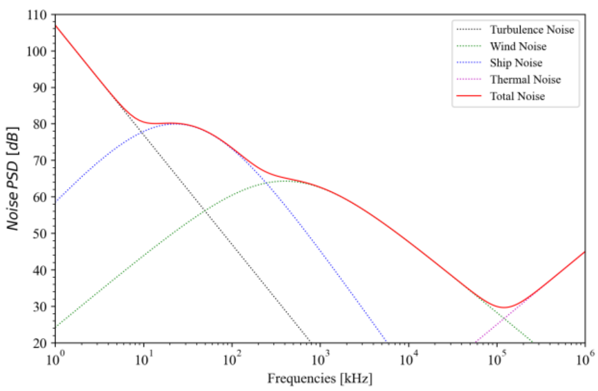
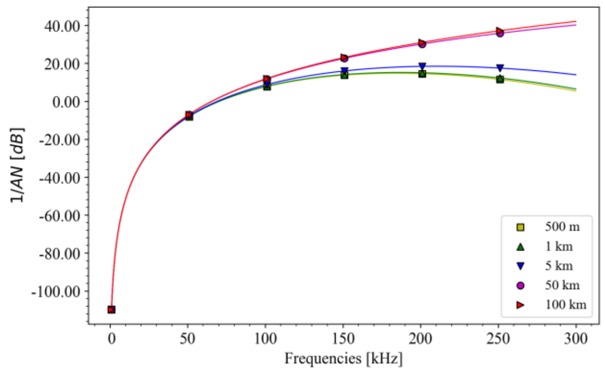


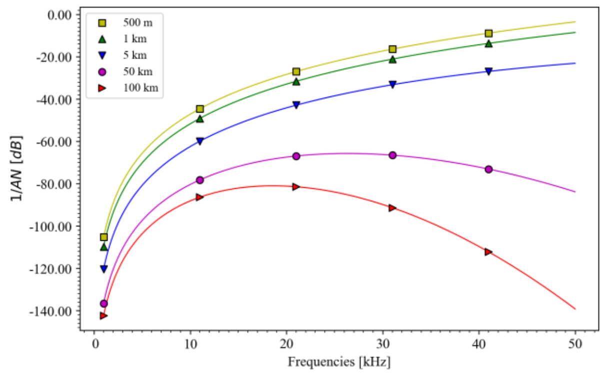
Fig 2. Noise characteristics in IKN's marine acoustic underwater channel

Frequency can be said to be the optimum frequency if it has a minimum SNR value. Equation (5) shows the relationship between SNR and attenuation and noise. Attenuation and noise values are affected by frequency. To minimize the channel's attenuation and noise values by maximizing the SNR value, it is necessary to determine the optimum frequency in understanding the complex relationship between depth, frequency, and transmission distance to SNR values.

It is shown in Fig 3(a) and 3(b) that the magnitude of the depth and distance values influence the SNR values. In Fig 3(a), the greater the depth value of the device, the greater the attenuation value. The smaller the depth value, the higher the optimum frequency required to achieve a high SNR value. However, it differs from the data in Fig 3(b) that the greater the transmission distance, the smaller the attenuation value. The greater the transmission distance value, the lower the optimum frequency required to achieve a high SNR value.



(a)



(b)

Fig 3. Attenuation and noise characteristics in IKN's marine acoustic underwater channel against (a) depth variation, (b) transmission distance variation

The characteristics of the acoustic underwater channel should be based on the objectives and implementation of the UWSN. These characteristics will be the basis for calculating the power and frequency needed for the device's design. It is shown in Table 1., that the optimum frequency value has different values for each transmission depth and distance used. Based on the table, it is known that the optimum frequencies required by UWSN for applications at depth values of 500 m, 1 km, 5 km, 50 km, and 100 km respectively are 184.3 kHz, 187 kHz, 210.4 kHz, 790.7 kHz and 3441.5 kHz at transmission distances of 500 m, 1 km, 5 km, 50 km, and 100 km respectively is 264.5 kHz, respectively, 187 kHz, 83.6 kHz, 26.3 kHz, and 18.6 kHz.

TABLE I. OPTIMUM FREQUENCY AT TRANSMISSION DISTANCE AND DEPTH VARIATIONS

f_{opt} (kHz)	Variations				
	500 m	1 km	5 km	50 km	100 km
Depth	184.3	187	210.4	790.7	3441.5
Distances	264.5	187	83.6	26.3	18.6

Link budget calculation is done to get the minimum power value of P_0 in achieving SNR values of 30 dB. Through calculations at depth of D is 1 km, and the optimum frequency in Table 1 is obtained the power value of P_0 required to achieve the 30 dB SNR shown in Fig 4. The results of these calculations can be used as a basis in determining the transmit power, receive power and idle power of the acoustic sensor on UWSN.

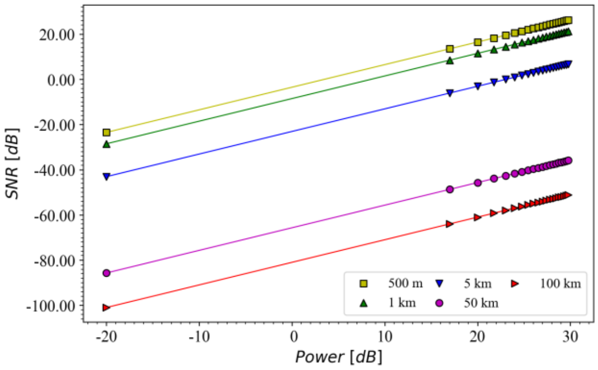


Fig 4. Transmission power to SNR

Delay propagation in underwater acoustic channels affects throughput values. Equations (11) and (12) show the effect of ratio delay, whose value is influenced by the propagation speed. The speed of acoustic propagation underwater at a depth of 1 m is 1630.85 m/s and at a depth of 1 km is 1630.87 m/s. Figure 6 shows the difference between throughput at underwater propagation speed and propagation speed at light speed at a bitrate of 500 bit/s. The figure shows the largest throughput value found in the Non-persistent CSMA protocol; this is because in Non-persistent CSMA, data transmission by the sensor is done by waiting for CH / BS at idle; if CH / BS is busy, then the sensor will wait for random backoff time before sending data back. This will reduce the potential for collisions caused by sensors sending data simultaneously; the results of this study are in line with Zhao et al research, which shows good performance of CSMA protocols underwater [17].

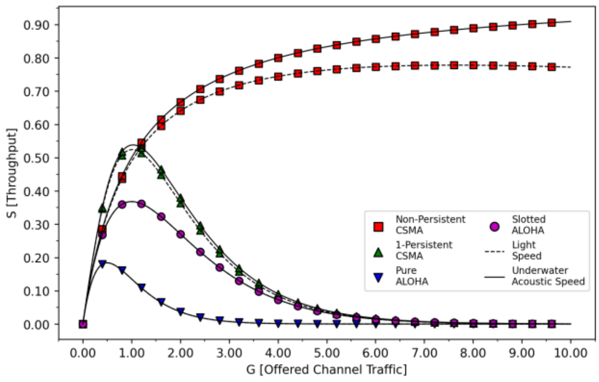


Fig 5. The effect of frequency on noise and attenuation

V. CONCLUSION

This study aims to investigate and analyze the acoustic communication of underwater channels in IKN waters. This study uses a quantitative approach with numerical and statistical analysis of the results of simulations and comparisons. The sampling method was carried out experimentally based on computer program simulations through modelling the underwater environment of IKN. In obtaining UWSN environmental characteristics in IKN waters, literature studies and analyses were carried out to obtain salinity, pH, temperature, wind speed values, and ship activity, which are parameters in determining UWSN environmental characteristics. This research obtained IKN sea characteristics such as salinity, pH, temperature, wind speed in the IKN sea and ship activity constants of 34.31 ppt, 7.82, 4.11°Cand 6 m / s. Calculations of the optimum frequency are also performed in minimizing the attenuation and noise values of the channel and obtain the optimum frequencies required by UWSN for applications at depths of 500 m, 1 km, 5 km, 50 km, and 100 km respectively are 184.3 kHz, 187 kHz, 210.4 kHz, 790.7 kHz and 3441.5 kHz at a transmission distance of 500 m, 1 km, 5 km, 50 km, and 100 km are 264.5 kHz, 187 kHz, 83.6 kHz, 26.3 kHz, and 18.6 kHz, respectively. Analysis of protocol variations was also carried out by comparing the Pure ALOHA, Slotted ALOHA, 1-persistent CSMA/CA, and non-persistent CSMA protocols also carried out to determine the best protocol performance in underwater channel acoustic communication, and it was found that non-persistent CSMA/CA protocols had higher throughput values than other variations. This is because the potential for collision in non-persistent CSMA/CA is smaller than in other protocols. Through this research, it is expected to be a reference and additional literature in improving information in the design and determination of the design of UWSN. In the future, comprehensive experimental-based research needs to be carried out to validate and support the data found in the simulation.

REFERENCES