Adaptive Code with Non-Uniform Modulation on OFDM Subcarriers Modeling for Underwater Acoustic Environment

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***Abstract*— In this paper, an Adaptive Code Non-Uniform Modulation with Orthogonal Frequency Division Multiplexing (OFDM) System was evaluated in the underwater acoustic communication channel. This system was adopted from the Subcarrier arrangement of the OFDM standard of IEEE 802.11a, and improved with some modifications. There are three schemes in the proposed adaptive system. The first is the Hamming code with Binary phase-shift keying (BPSK) modulated, which is mapped for 12-bit subcarrier data. The second is the Bose-Chaudhuri-Hocquenghem (BCH) code with Quadrature phase-shift keying (QPSK) modulation which is for the other 12-bit subcarrier data. And the third is the Reed Solomon code with 16-Quadrature Amplitude Modulation (16-QAM) modulation that is mapped for 24-bit subcarrier data. The system modeling was evaluated in the shallow water acoustic environments. Bit error rate (BER) and signal-to-noise ratio (SNR) were analyzed to evaluate the proposed system performance. The evaluation results showed that the proposed system was able to improve the performance better than the fixed modulation or un-coded Non-uniform modulation. At the same bit error limit which is 0.001, BPSK, QPSK, 16-QAM, un-coded Non-uniform modulation, and the proposed system have its own SNR, i.e.; 24.9 dB, 8.5 dB, 10.3 dB, 7 dB, and 2 dB, respectively. The proposed system requires lower power to achieve an error rate of 0.001. In addition, between the proposed system and un-coded Non-uniform modulation, it has a coding gain of 5dB.**

***Index Terms*— Underwater Acoustic; Adaptive Code; Non-Uniform modulation; OFDM.**

I. INTRODUCTION

Acoustic wave is one of the solutions for underwater wireless transmission because this wave is robust when applied to underwater channels [1]. Recently, the acoustic wave was developed for underwater wireless communication, such as applications in the offshore oil and gas industry, pollution and climate monitoring in environmental systems, sub marine defense system, scientific data recording at submarine stations, and unmanned underwater vehicles [2]. Underwater acoustic (UWA) channel has unpredictable conditions. The source of noise in the underwater channel could be, such as the sound of fish, and other objects that are in the water. In addition, UWA channels have propagation speeds (around 1,500 m/s), limited bandwidth, and multipath [3].

The OFDM emerged as a promising technique for UWA communication system, because of its resistance to long delay spread and frequency selectivity channels [3]. For a certain condition, it is possible for OFDM subcarriers to get different gain from the channel. This problem was presented by the previous researchers in [4] and [5]. In this condition, the underwater acoustic channel varies rapidly, both spatially and temporarily, and has an impact on the inconsistent signal-to-noise ratio (SNR) values. This problem can be overcome by using the adaptive modulation techniques in OFDM systems proposed by [6] and [7]. The Adaptive Modulation and Coding (AMC) is a promising solution for underwater communication, and this technique can be used to overcome problems with underwater communication as mentioned in [8] and [9]. This technique has the capability to improve the system efficiency by matching transmission parameters with channel conditions.

In adaptive modulation, the transmitter determines the type of modulation based on the channel conditions. However, SNR does not increase as the transmission power increases due to impulse noise and the limitations of imperfect channel estimates. Therefore, it affects the system performance. To overcome this problem, the previous research proposed a channel coding technique [10]. By using the Forward Error Correction (FEC), the system was able to increase the performance of OFDM systems [11]. The FEC also reduced the package delays and increased the reliability of high-risk communication system, such as underwater acoustic networks [12]. There are many studies about the utilization of FEC to improve system performance. The FEC techniques used are Hamming code, BCH Code, Cyclic Code, and Reed Solomon Code [11] [12] [13] [14]. The use of FEC has also been done on the Wireless Sensor Network (WSN) for image transmission. In this case the system performance is evaluated through simulations for un-coded and coded systems. In this case, the system evaluation is also carried out in real time. The results show that coded WSN performance is far better than un-coded WSN [15].

This paper will present an evaluation of AMC techniques with adaptive modulation and code modeling for underwater communication in tropical shallow waters. The channel noise is adopted from the measurement results of ambient noise and its characteristics from the underwater acoustic channels in shallow waters located in the bay of Surabaya, Indonesia [16]. The measurement results will be used as the base line in the design of underwater acoustic communication system. In this case, the channel has a noise pattern that has a distribution closed to the Gaussian distribution and has a spectral closed to the white spectral properties. The system will combine the adaptive modulation system with Non-Uniform modulation for the sub-carrier of the OFDM system. The evaluation is carried out by modifying the OFDM subcarrier into several groups according to the type of modulation that will be used.

The modulations are BPSK, QPSK, and 16-QAM. The coding techniques that will be used are Hamming, BCH, and Reed Solomon Code. There are three schemes in this system. First, 12-bit of subcarriers data uses Hamming code and BPSK modulation. Second, another 12 bit of subcarrier data uses BCH code and QPSK modulation. And third, the 24 bit of subcarrier data uses Reed Solomon code and 16-QAM modulation. This modeling is expected to improve performance by improving the error rate value. This study will prove that the proposed system can improve performance by increasing the system's transmission rate as a whole, while maintaining an error rate system of less than 0.001.

II. METHODOLOGY

A. System Description

Modeling Adaptive code with Non-Uniform Modulation in OFDM Subcarriers is illustrated in Figure 1. This system has three main parts: the transmitter, channel, and receiver. The transmission system is evaluated in an underwater acoustic environment.

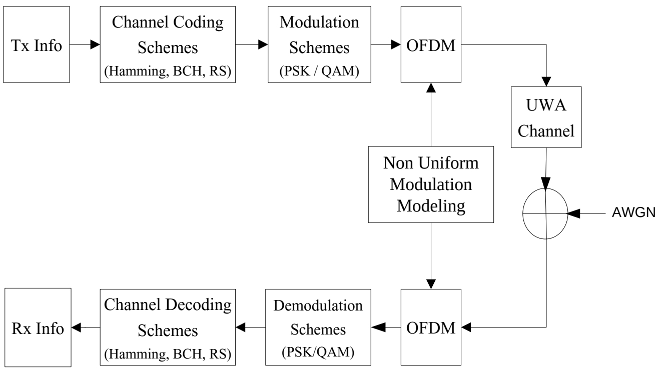

Figure 1: Block diagram of adaptive code with Non-uniform Modulation

Figure 1 shows the Adaptive code modeling with Non-uniform Modulation, which is done by changing the arrangement of subcarriers in OFDM blocks. However, this modeling has been designed starting from the Coding Channel block and Modulation block. This is done by dividing the info bits to be transmitted into three parts, followed by the conduct of the transmission process using three coding and modulation schemes at once. At the transmitter, the binary data input (code bits) is generated, and coded adaptively with non-uniform modulation. Info bits are encoded with coding techniques of Hamming code, BCH code, and Reed Solomon code. The modulation process is then performed, where the info bits encoded with Hamming code are modulated with BPSK modulation. Meanwhile, the info bits are encoded with BCH code modulated with QPSK modulation. Further, the bit info encoded with the Reed Solomon code is modulated with 16QAM modulation. After that it enters the OFDM block.

In OFDM transmitter, Serial to Parallel functions to convert serial data into parallel data, which is adjusted to the number of subcarriers. Non-uniform modulation modeling follows the process. More detailed description will be presented in the Sub Section 2B.

When entering the Inverse Fast Fourier Transform (IFFT) block, zero padding is added to the data row (i.e. giving 0 bits to the data) equal to the IFFT / Fast Fourier Transform (FFT) size. Then, the process is followed with the pilot insertion. After the symbol is added with zero padding, the data is added to the pilot. Furthermore, the IFFT block becomes the core of OFDM multicarrier modulation. The output of one N-point IFFT process will create an OFDM symbol. The Cyclic Prefix is done by copying the end row of the OFDM symbol with a certain period, and put it on the beginning of the symbol.

In the receiver section, the guard intervals are removed and the OFDM symbols are then converted by FFT into complex symbols. The complex symbols are demodulated and decoded adaptively by using Non-uniform Modulation modeling. This model is adopted from the IEEE 802.11a standard, and combined with some modifications. More detailed information of the OFDM system specifications is as shown in Table 1.

Table 1
Specification of OFDM System

Parameter	Specification
Bandwidth, B	12,8 kHz
Channel Coding	Hamming (7,4), BCH (7,4), Reed Solomon (7,3)
Modulation	BPSK, QPSK, 16-QAM
Subcarrier	52
Data Subcarriers	48
Pilot Subcarriers	4
FFT size	64

B. Adaptive Code with Non-uniform Modulation on OFDM Subcarriers

The standard transmission of single channel coding and modulation (PSK / QAM) type is as shown in Figure 2. The model in the simulation is a modification of the IEEE 802.11a standard, as shown in Figure 3. The model is composed of 52 subcarriers, 4 pilots, and 48 bits of data in the transmission process, which are divided into three parts. In this model, some modifications are done by using three types of coding techniques, i.e. Hamming, BCH, and Reed Solomon code, and three types of modulation, i.e. BPSK, QPSK, and 16QAM.

In ideal conditions with high SNR, the 16QAM system will be used. This model uses the Reed Solomon Code coding technique because it will reduce errors very efficiently. When SNR is low, the BPSK system is chosen with the aim of maintaining communication reliability. The coding channel used is the Hamming code. In moderate conditions, QPSK modulation has an error rate greater than BPSK, therefore BCH Code coding techniques are used. This is because the BCH code is able to correct errors better than Hamming code for BPSK and QPSK modulations [11].

Figure 3 illustrates the proposed model. This system has three groups of sub-carriers. The first is Reed Solomon Code and 16-QAM modulation, in which the number of subcarriers used is 24. The second is a group of 12 subcarriers which are encoded with the BCH Code and QPSK modulation. The third is a group of 12 subcarriers with Hamming coded and modulated with the BPSK.

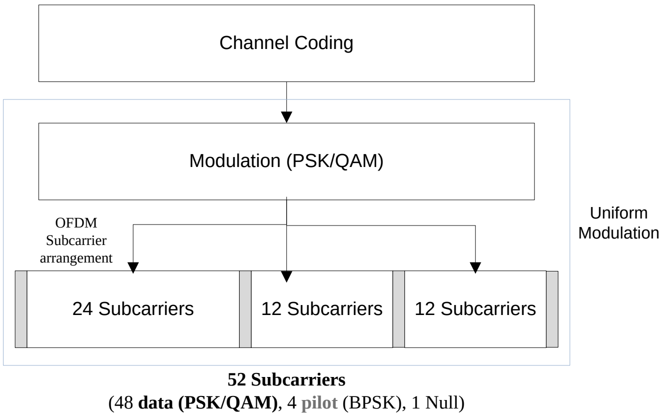

Figure 2: Modeling of the existing standards on OFDM Subcarriers

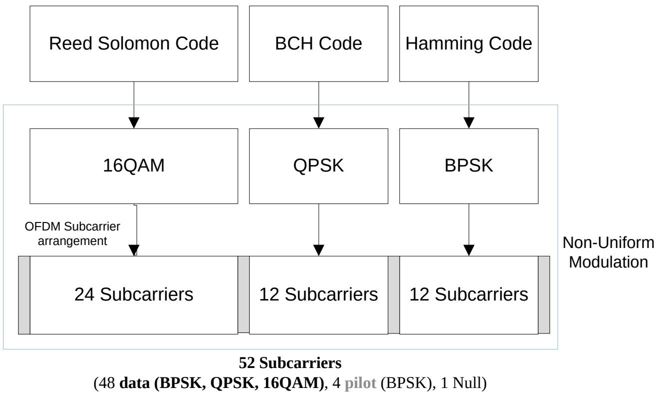

Figure 3: Modeling of the Adaptive Code with Non-Uniform Modulation on OFDM Subcarriers

C. *Ambient Noise from Shallow Waters*

Ambient noise is a background noise that is not desirable at a location within a certain time. Ambient noise is influenced by time, location, and depth of the detected signal. The nature of ambient noise in the ocean is described by spectral, spatial and temporal characteristics. Measurement of these characteristics can provide useful information about the nature of noise [17].

For ergodic stationary stochastic processes $p(t)$ and $u(t)$, the function of the spectrum is [18]:

$$p_k(f,T_k) = \int_0^T p_k(t)e^{-j2\pi ft}\,dt \qquad (1)$$

$$u_{i,k}(f,T_k) = \int_0^T u_{i,k}(t)e^{-j2\pi ft}\,dt \qquad (2)$$

Where T is time, k is the index number and $i = x, y, z$ are points in the cartesian coordinate system. The noise of the underwater environment in shallow sea waters is known to have high variability. Variability can be expressed in fluctuations in the spectrum of each unit of frequency band as a function of frequency. While the cross-spectrum equation is [18]:

$$S_{pui}(f) = \lim_{T\to\infty}\frac{2}{T}\langle p_k{}^*(f,T_k)u_{i,k}(f,T_k)\rangle \qquad (3)$$

The transmission line in this simulation is based on ambient noise measurements that have been carried out on the bay of Surabaya, Indonesia [16]. The results of the ambient noise measurement indicate that the measurement results are very close to the Gaussian distribution pdf function, which means the channel has a white Gaussian noise. Thus, the proposed scheme is tested on the Additive White Gaussian Noise (AWGN) channel.

The ambient noise spectrum in Surabaya bay is shown in Figure 4. The measurement results have a different level of the noise spectrum. In the frequency range of 4 - 7.2 kHz, the power level is high with values between -115 dB ~ -135 dB. In the frequency range of 7.3 - 13.6 kHz, the power level is flat with an average value of -140 dB. While in the frequency range of 13.7 - 17.3 kHz, it has a power noise level that fluctuates between -135 dB ~ -140 dB. From the description of the existing spectrum, non-uniform modulation models can be designed. At a high level of power noise, it will be used for modulation with a low data rate; while at a low power noise level, it will be used for modulation with a high data rate.

We know that BPSK modulation has low error rates, therefore it is used at high power spectrum levels. While 16-QAM modulation systems will be used for the low power spectrum levels. And the middle spectrum level uses QPSK modulation. Based on Figure 3, modeling channel coding types used are, for example Hamming code, BCH code, and Reed Solomon code. Of the three types of coding techniques used, Reed Solomon has the best error correction compared to the BCH code and Hamming code. Therefore, in Scheme 1: The coding technique of the Reed Solomon code will be used in modulation with a large error rate, namely 16QAM modulation. This technique aims to reduce the error rate. While in Scheme 2: QPSK modulation uses coding techniques of BCH code. This scheme was chosen because the BCH code can correct errors better than the Hamming code, while QPSK modulation has a larger error rate than BPSK modulation. Therefore, in Scheme 3: BPSK modulation is used with the coding technique of Hamming code. This modeling is expected to make the system more efficient by matching system parameters with channel characteristics.

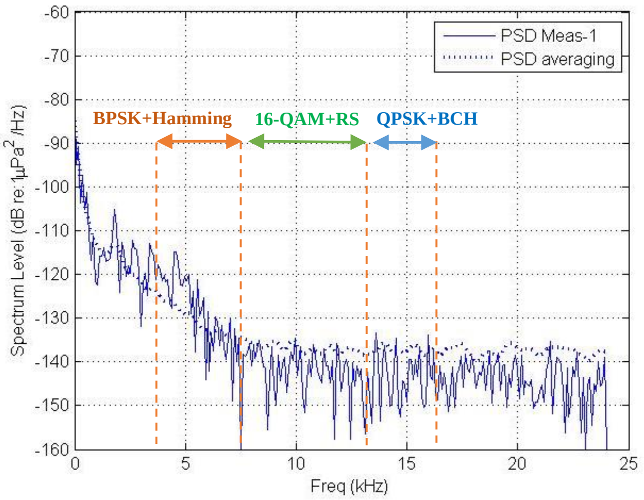

Figure 4: Ambient noise spectrum at Surabaya bay

III. SIMULATION RESULT

The performance of the Adaptive Code system with Non-Uniform Modulation on OFDM Subcarriers that have been designed is tested on the AWGN channel. The first test is done by comparing the un-coded Non-Uniform Modulation with fixed modulation. Furthermore, the un-coded Non-Uniform Modulation will be compared with the proposed system that is the Adaptive Code System with Non-Uniform Modulation.

In the un-coded Non-uniform modulation system, the OFDM Subcarrier modification arrangement is in accordance with Figure 3 but without block coding techniques. 16-QAM modulation will send 24 bits of data, QPSK modulation will send 12 bits of data, and BPSK modulation will send 12 bits of data. After the data is modulated, all data in the modeling will be sent together through the AWGN channel. In this system, it has several SNR values from the simultaneous use of the three types of modulation in the transmission, i.e.; the first SNR obtained from 16-QAM modulation, the second SNR obtained from QPSK modulation, and the third SNR obtained from BPSK modulation. Because they are sent together, the three SNR values will be calculated as the average value. In addition, the use of each modulation has its own error rate, i.e.; error rate 1 (16QAM), error rate 2 (QPSK), and error rate 3 (BPSK).

In Figure 5, the un-coded Non-Uniform Modulation system is compared to its performance with fixed modulation, i.e.; BPSK, QPSK, and 16-QAM. The results show that the un-coded Non-Uniform Modulation has the best performance compared to the fixed modulation. 16-QAM modulation have the largest SNR in comparison to the other modulation. Thus, the data rate is high, although it has the highest error rate. BPSK modulation has a small data rate, but the error rate is the best compared to QPSK and 16-QAM. When using an un-coded Non-Uniform Modulation system, it has a high data rate, but the error rate is better than 16-QAM and QPSK. We can see from SNR -3 dB to 2.2 dB that the error rate of the un-coded Non-uniform modulation system has the same error rate as the BPSK modulation. But with SNR above 2.2 dB, BPSK modulation has a better error rate. Therefore, in the proposed system, a coding process is carried out in the Non-Uniform Modulation to improve system performance by reducing the error rate value.

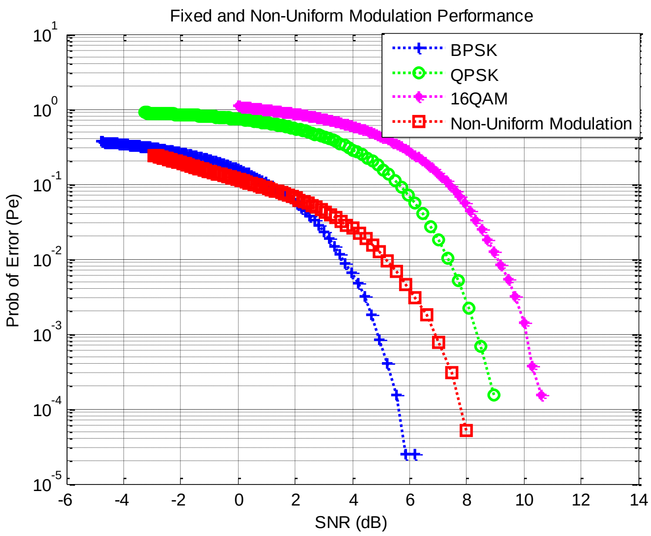

Figure 5: Performance of fixed and Non-uniform modulation

The next test is an adaptive code with the Non-Uniform Modulation compared to the un-coded Non-Uniform Modulation. The proposed adaptive system is as modeled in Figure 3. This is a combination of Non-uniform modulation with added coding techniques. The coding technique used adjusts the type of modulation used. BPSK modulation uses Hamming code, while QPSK modulation uses BCH code, and 16-QAM modulation uses Reed Solomon code. The results in Figure 6 show that the proposed system performance has better performance than the un-coded Non-Uniform Modulation system. The adaptive code system with Non-Uniform Modulation has an error rate better than the un-coded Non-Uniform Modulation. The probability of errors in data blocks with coding is lower than without coding. The use of coding as Error Correction can reduce errors during the transmission process. In underwater communication, there are many sources of noise found in the underwater acoustic channel. An error that might occur is caused by the amount of noise in the water that cannot be predicted by the conditions of the channel. Using the proposed system, this error can be reduced because the system can match according to the characteristics of the underwater acoustic environment.

In addition, channel coding allows the use of lower signal power (smaller SNR) to achieve the same error level without using correction bits because errors can be fixed. This has been proven from the analysis in Figures 5 and 6. With the same bit error rate limitation of 0.001, fixed modulation with BPSK, QPSK, and 16-QAM has each SNR, i.e.; 4.9 dB, 8.5 dB, and 10.3 dB. The un-coded Non-Uniform modulation has an SNR of 7 dB. Whereas the proposed system has an SNR of 2 dB. The results show that the proposed system has the lowest SNR value than the fixed modulation and the un-coded Non-Uniform Modulation. It must be considered that using fixed modulation and un-coded non-uniform modulation requires greater power to achieve a low error rate. However, the proposed system has a low power to achieve an error rate of 0.001.

The results also show that the coding gain between the proposed system with the un-coded Non-Uniform Modulation. Coding Gain is a reduction in SNR (in dB) between the system without the code and the coded system needed to get the same error rate. At the limit of 0.001 error rate, the un-coded Non-uniform Modulation has SNR of 7 dB, while the proposed system is an adaptive code with the Non-Uniform Modulation having SNR of 2 dB. From these results, the modeling proposed with the un-coded Non-Uniform Modulation has a coding gain of 5 dB. The amount of gain from the coding is the result of using three types of coding techniques, namely Hamming code (7.4), BCH code (7.4), and Reed Solomon code (7.3) in the model. Each encoding has a good correction ability; hence, the achievement of the same error level using the three types of coding can have a smaller power. This causes the proposed system to have a large coding gain between systems without coding. Based on the results of the simulations, the uses of this combination of coding techniques cause the use of lower signal strength by the coding gain of 5 dB to achieve the same error rate, which is 0.001. Therefore, the use of the proposed system can produce better performance that is its ability to maintain a low error rate with low power.

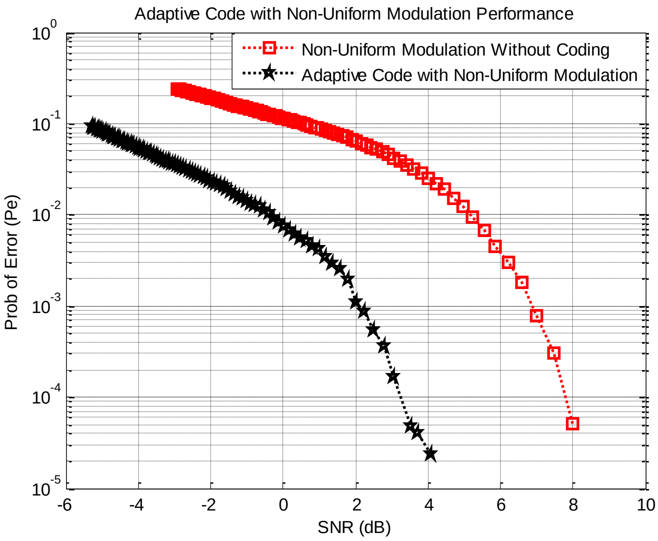

Figure 6: Performance of Adaptive Code with Non-uniform modulation and Non-Uniform Modulation without coding

IV. CONCLUSION

In this paper, a simulation has been carried out on the modeling of adaptive code with Non-Uniform Modulation in OFDM Subcarriers. The system scheme was designed based on the OFDM standard IEEE 802.11a by modifying the subcarrier arrangement in the use of modulation and coding techniques. The proposed system modeling has been analyzed for its performance, in this case of BER and SNR. This paper proves that the use of an adaptive code system with Non-Uniform Modulation in OFDM Subcarriers can improve performance in underwater communication systems. Errors in the process of underwater acoustic communication transmission can be reduced. With the same bit error limit of 0.001, BPSK, QPSK, and 16-QAM modulation, and un-coded Non-Uniform modulation have their respective SNR, i.e.; 4.9 dB, 8.5 dB, 10.3 dB, and 7 dB. Whereas the proposed system has SNR of 2 dB. These results show that fixed modulation and un-coded Non-uniform modulation require greater power. However, the proposed system has a low power to achieve the same error rate, which is 0.001. Therefore, the proposed system has better performance which can maintain low error rates with low power. In addition, in the coding gain analysis, the results show that the un-coded Non-uniform modulation and the proposed system have a coding gain of 5 dB.

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REFERENCES

[1] Y. Labrador, M. Karimi, D. Pan and J. Miller, "Modulation and Error Correction in the Underwater Acoustic Communication Channel," IJCSNS International Journal of computer Science and Network Security, vol. 9, no. 7, pp. 123-130, 2009.

[2] M. Stojanovic, "Underwater acoustic communications," in Proceedings of Electro/International 1995, Boston, 1995.

[3] M. Stojanovic, "Underwater Acoustic Communications: Design Considerations on the Physical Layer," in 2008 Fifth Annual Conference on Wireless on Demand Network Systems and Services, Garmisch-Partenkirchen, 2008.

[4] M. Stojanovic and J. Preisig, "Underwater acoustic communication channels: Propagation models and statistical characterization," IEEE Communications Magazine, vol. 47, no. 1, pp. 84-89, 2009.

[5] M. Badiey, Y. Mu, J. A. Simmen and S. E. Forsythe, "Signal variability in shallow-water sound channels," IEEE Journal of Oceanic Engineering, vol. 25, no. 4, pp. 492-500, 2000.

[6] A. Radosevic, R. Ahmed, T. M. Duman, J. G. Proakis and M. Stojanovic, "Adaptive OFDM Modulation for Underwater Acoustic Communications: Design Considerations and Experimental Results," IEEE Journal of Oceanic Engineering, vol. 39, no. 2, pp. 357-370, 2014.

[7] S. Xiaohong, W. Haiyan, Z. Yuzhi and Z. Ruiqin, "Adaptive Technique for Underwater Acoustic Communication," in Underwater Acoustics, Salah Bourennane, IntechOpen, 2012, pp. 59-74.

[8] S. K. Reddy and Lakshmi, "Adaptive Modulation and Coding with Channel State Information in OFDM for WiMAX," International Journal of Image, Graphics and Signal Processing (IJIGSP), vol. 7, no. 1, pp. 61-69, 2015.

[9] L. Wan, H. Zhou, X. Xu, Y. Huang, S. Zhou, Z. Shiz and J.-H. Cui, "Adaptive Modulation and Coding for Underwater Acoustic OFDM," IEEE Journal of Oceanic Engineering, vol. 40, no. 2, pp. 327-336, 2015.

[10] Nasaruddin, B. Yuhanda, Elizar and Syahrial, "Design and Performance Analysis of Channel Coding Scheme based on Multiplication by Alphabet-9," Journal of Telecommunication, Electronic and Computer Engineering (JTEC), vol. 9, no. 1, pp. 7-13, 2017.

[11] T. B. Santoso, Wirawan and G. Hendrantoro, "Image transmission with OFDM technique in underwater acoustic environment," in 2012 7th International Conference on Telecommunication Systems, Services, and Applications (TSSA), Bali, 2012.

[12] J. Xu, T. Zhang and Z. Dong, "On Forward Error Correction with Hamming Code for multi-path communications," in 012 International Conference on Wireless Communications and Signal Processing (WCSP), Huangshan, 2012.

[13] S. S. Sarnin, N. Kadri, A. M. Mozi, N. A. Wahab and N. F. Naim, "Performance analysis of BPSK and QPSK using error correcting code through AWGN," in 2010 International Conference on Networking and Information Technology, Manila, 2010.

[14] S. P. Choudhari and M. B. Chakole, "Reed solomon code for WiMAX network," in 017 International Conference on Communication and Signal Processing (ICCSP), Chennai, 2017.

[15] D. Andito, F. W. Yap, K. C. Lim, T. Oh and W. K. Yeo, "Forward Error Correction for Image Transmission System using IEEE 802.15.4," Journal of Telecommunication, Electronic and Computer Engineering (JTEC), vol. 3, no. 1, pp. 31-38, 2011.

[16] T. B. Santoso, E. Widjiati, Wirawan and G. Hendrantoro, "Ambient noise measurement and characterization of underwater acoustic channel in Surabaya bay," in 2015 IEEE Asia Pacific Conference on Wireless and Mobile (APWiMob), Bandung, 2015.

[17] P. C. Etter, Underwater Acoustic Modeling and Simulation, London: Spoon Press, 2003.

[18] H. Pengtao, Y. Hongtao, Z. Fusheng and Y. Jianping, "Underwater acoustic noise analysis based on vector phase spectrum," in Proceedings of 2013 2nd International Conference on Measurement, Information and Control, Harbin, 2013.