Adaptive Modulation and Coding for Underwater Acoustic Communication

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***Abstract*— In UWAC (Underwater Acoustic Communications), underwater acoustic channels change rapidly due to various environment condition. AMC (Adaptive Modulation and Coding) technique is efficient method for improving the system efficiency by changing transmission parameters according to channel conditions in underwater acoustic channels. In this paper, we propose four modes and three threshold detection algorithms to determine the transmission mode in AMC technique. In transceiver model, convolutional coding is used to free the size of the information bits and turbo equalization is applied to improve the performance. In addition, the relationship between the modes and the threshold is analyzed through underwater experiments.**

Keywords*— *UWAC(Underwater Acoustic Communication), AMC(Adaptive Modulation and coding), Threshold, Convolutional code, Turbo Equalization

I. Introduction

Underwater acoustic channels fast varying according to environment condition such as propagation loss according to the distance of acoustic signals, interference signal caused by multi-path propagation, background noise and Doppler effects that is related to a moving sound source or sea surface roughness [1-2]. The AMC (Adaptive Modulation and Coding) technique is attractive method for acoustic communication to improve the system efficiency by varying transmission parameters according to channel conditions. Furthermore, in communicating with multi-node networks, each node has different channel characteristics. In communicating with nodes, to get LPD (Low Probability of Detection) in military underwater communication environment, we assume there are no feedback information in order to select which transmission mode is used. In this paper, we construct four transmission modes with different data rates and modulation methods. Four different modes for same source data are transmitted in packet, on the receiver side, one critical component of AMC system is to find which mode has best performance. In this paper, we also present threshold detection algorithm to decide appropriate mode. AMC experiment was conducted in the Mun-Kyeong Lake in May 2018 for different distance. We analyzed the performance of four modes based on threshold detection algorithm.

II. AMC Model and Threshold Detection Method

A. AMC Transceiver Model

In the underwater AMC system, we adopted convolutional coding to freely design the size of information bits [3]. Four modes are multiplexed and packetized. Each mode consisted of mode index field, preamble data field and coded modulation field. Preamble data field is used for acquiring synchronization and mode index field indicate which scheme is used for each mode. At the receiver side, after received packet, we analyze mode which is best performance by using threshold detection algorithm.

Figure 1 shows the structure of the AMC transceiver model. In others, as shown in Figure 1, to achieve low error performance, we resort to powerful BCJR decoding algorithms of convolutional codes for different modes [4]. We also employ an iterative turbo equalization method, equalizer and decoder are connected through the interleaving and de-interleaving functions that update each other's information recursively [5]. The interleaved output is canceled a posteriori from the proceeding received signal. The extrinsic information of the decoder is correction factor in order to compensate for the errors. As the number of iteration of turbo equalization increased, the updated error correction approached the original signal, which was to be transmitted, thereby improving the BER performance. Different transmit rates are produced by varying modulation scheme (BPSK/QPSK), convolutional code rate (1/3, 1/2), and the number of transmit element as shown in Table 1. The interleaver length is fixed on 120 and 240 using random interleaver.

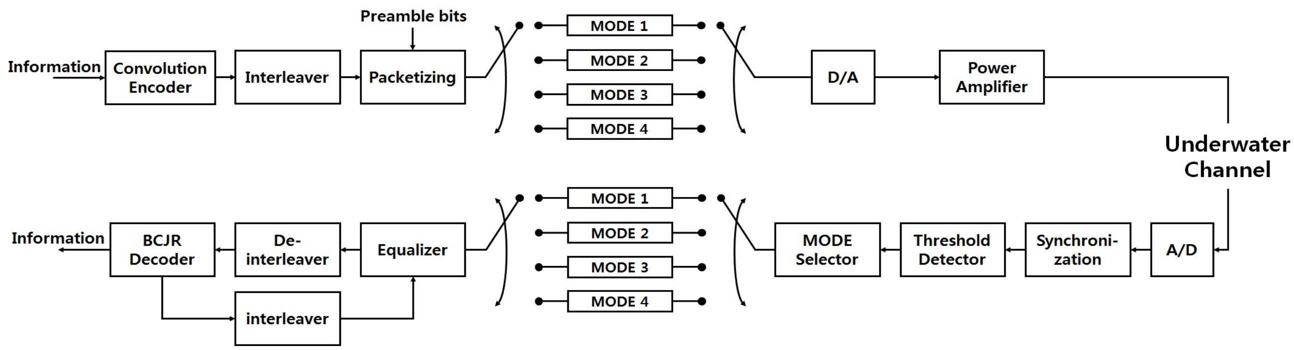

Fig. 1. The structure of AMC Tranceiver Model

TABLE I. PARAMETERS OF AMC MODES

Mode	Input K [bit]	Coding rate	Modulation	Symbols [symbol]
1	80	1/3	BPSK	240
2	120	1/2	BPSK	240
3	80	1/3	QPSK	120
4	120	1/2	QPSK	120

B. Threshold Detection Algorithm

Threshold detection parameters are very important part to decide which mode has best performance. This paper considered three kinds of method.

- First, PSNR (Pilot SNR) method is calculated SNR after channel estimation using the pilot signal or preamble symbols.
- Second, PES (Post Equalization SNR) method [6] is calculated from loot mean square errors from LMS (Least Mean Square) or RLS (Recursive Least Square) equalizer [7].
- Lastly, preamble error rate is used for deciding the packets are consisted of PN sequence and data field.

Using the uncoded PN sequence, the frequency and phase offset are estimated with Doppler and phase estimation algorithm. Estimated frequency and phase offset are fed to coded data field to compensate Doppler and phase offset. Usually PN sequence is utilized for acquiring synchronization information, the other hand the bit error rate of uncoded PN sequence predict performance of coded data field.

III. EXPERIMENTAL RESULTS

We evaluate the performance of the AMC in real underwater environments. The experiment was conducted on a lake of Mun-Kyeong city, Korea, in May 2018. The water depth was approximately 43[m]. Figure 2 shows depiction of lake trial. The source signal has 16 [kHz] center frequency and 1 [kbps] data rate. The hydrophone was equipped at 20 [m] lake bottom. The received signal was sampled at 192 [kHz] sampling frequency. Four modes AMC test was done at different locations. Data were collected at three sites at distance 100 [m], 250 [m], and 400 [m].

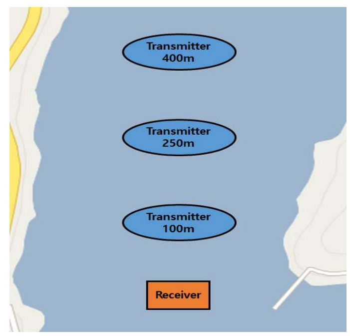

Fig. 2. Depiction of lake trial

The packet structure of AMC test with four modes is as shown in Figure 3.

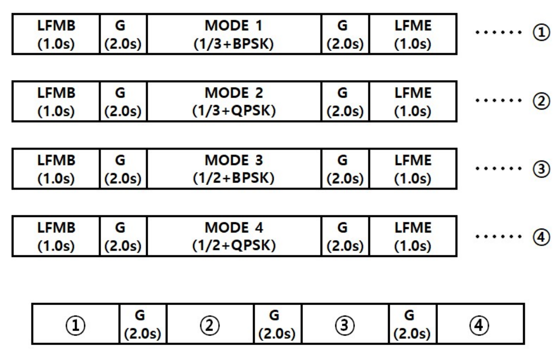

Fig. 3. The packet structure of AMC signal

In Figure 3, each packet is preceded by a LFM (Linear Frequency Modulation) signal. The LFM followed by gap, training symbol and data package. At the front of the data package, a block of training symbols is used for timing synchronization and initial channel estimation. The whole packet is ended by another LFM signal, which was separated from the data package with a gap. During transmission, gaps that were sufficiently long were introduced among packets for avoiding inter-packet interference. The timing synchronization

TABLE II. THE BER(BIT ERROR RATE) PERFORMANCE FOR FOUR MODES AT DIFFERENT DISTANCE

Distance	100 [m]				250 [m]				400 [m]			
	RSNR (dB)	***PES***	***PN BER***	***Data BER***	***RSNR (dB)***	***PES***	***PN BER***	***Data BER***	***RSNR (dB)***	***PES***	***PN BER***	***Data BER***
Mode 1	16.3550	0.2091	$10^{-1.262}$	0	7.4847	0.3692	$10^{-0.876}$	0	0.7156	0.3169	$10^{-0.851}$	0
Mode 2	16.2951	0.2551	$10^{-1.028}$	0	7.8540	0.2956	$10^{-0.851}$	0	0.6990	0.3292	$10^{-0.784}$	$10^{-0.522}$
Mode 3	17.1989	0.2427	$10^{-0.961}$	0	7.8655	0.3743	$10^{-0.608}$	$10^{-1.903}$	1.8588	0.3934	$10^{-0.652}$	$10^{-0.861}$
Mode 4	17.7909	0.1975	$10^{-0.660}$	0	8.0104	0.4513	$10^{-0.463}$	$10^{-0.389}$	2.1470	0.4229	$10^{-0.595}$	$10^{-0.407}$

was carried out by the training symbol, which was an m-sequence of 128 [symbol]. Table 2 shows the RSNR (Received SNR), PES, PN BER and data BER at different distance. RSNR is measured by equation (1).

$$\mathrm{RSNR} = 10\log_{10}\left(\frac{\sigma_{S+N}^2-\sigma_N^2}{\sigma_N^2}\right) \qquad (1)$$

In equation (1), σ_{S+N} and σ_N represent received signal and noise of silence interval, respectively, as shown in Figure 4.

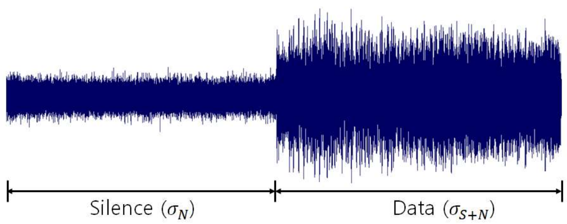

Fig. 4. Received signal

Experimental results in Table 2, error was corrected perfectly the data BER is 0 for all modes at 100 [m] and data BER is 0 for mode 1 and mode 2 at 250 [m]. Mode 3 and Mode 4 show performance of $10^{-1.903}$ and $10^{-0.389}$ respectively. In the case of 400 [m], only mode 1 has a data BER of 0, and mode 2, 3 and 4 show performance of $10^{-0.522}$, $10^{-0.861}$ and $10^{-0.407}$ respectively. At this time, it is understood that the performance is excellent in the order of modes 1, 2, 3 and 4.

In terms of RSNR, mode 1 shows that data BER is 0 when RSNR is 0.7156 [dB]. Mode 2 shows that data BER is 0 when RSNR is 7.8540 [dB] or lower and 0.6990 [dB] higher. Mode 3 shows that data BER is 0 when RSNR is 17.1989 [dB] or lower and 7.8655 [dB] higher. Also, mode 4 show that data BER is 0 when RSNR is 17.7909 [dB] or lower and 8.0104 [dB] higher.

In terms of PES, mode 1 shows that data BER is 0 when PES is 0.3692. Mode 2 shows that data BER is 0 when PES is 0.2956 or higher and 0.3292 lower. Mode 3 shows that data BER is 0 when PES is 0.2427 or higher and 0.3743 lower. Mode 4 shows that data BER is 0 when PES is 0.1975 or higher and 0.4229 lower.

In terms of PN BER, mode 1 shows that data BER is 0 when PN BER is $10^{-0.851}$. Mode 2 shows that data BER is 0 when PES is $10^{-0.851}$ or higher and $10^{-0.784}$ lower. Mode 3 shows that data BER is 0 when PES is $10^{-0.961}$ or higher and $10^{-0.608}$ lower. Mode 4 shows that data BER is 0 when PES is $10^{-0.660}$ or higher and $10^{-0.595}$ lower.

IV. CONCLUSION

AMC technique is an attractive method for acoustic communication that improves system efficiency by changing transmission parameters according to channel conditions in rapidly changing underwater acoustic channel. In AMC technique, it is very important to select the transmission mode according to the channel environment. In this paper, four modes are constructed through convolutional code (1/2, 1/3) and modulation method (BPSK, QPSK). Also, we propose the three threshold detection algorithm to determine the transmission mode. We analyzed the relationship between four modes and three threshold algorithms through underwater experiment. We analyzed the optimal thresholds for each mode according to the RSNR, PES and PN BER. As a result, we estimated approximate thresholds in terms of RSNR, PES and PN BER for four modes. Based on these result, it is considered that more accurate threshold value can be determined by comprehensively considering the threshold values of RSNR, PES and PN BER.

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