Bidirectional Equalization for Long-Range Underwater Acoustic Communication in BLAC18

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Abstract**—** The bidirectional equalization is an effective method for demodulating communication signals with weak strength since it improves the signal-to-noise ratio by obtaining additional diversity as well as temporal and spatial diversity when used in combination with the time reversal technique. In this paper, we will demodulate the communication signals acquired from biomimetic long-range acoustic communication experiment 2018 (BLAC18) conducted in East Sea of Korea in October 2018 using time reversal and bidirectional equalization techniques. It is shown that the bidirectional equalization including decision direct equalizer has the best error performance.

Keywords—underwater acoustic communications; time reversal combining; channel compensation; long-range communication; bidirectional equalization

I. Introduction

Long-range underwater acoustic (UWA) communications have been researched in order to transmit the information to a remote location without relaying. Particularly, the signal transmission using a sound channel formed at the minimum sound velocity layer between the thermocline and the deep sea has attracted attention because acoustic wave can propagate far away with low energy loss [1]. Since the acoustic waves in the water tend to be refracted toward the sound channel, the acoustic waves propagating to the sound channel have less energy loss because they propagate without reflection loss on the sea surface or bottom [2]. However, acoustic wave must suffer transmission loss such as expansion or absorption loss even if there is no reflection. Therefore, the intensity of the signal propagated far away is very weak and the reliability of the communication link is degraded. In order to improve the error performance of the long-range communication system, multi-channel time reversal (TR) combining followed by a single channel equalizer has been proposed [3]. Multi-channel TR combining method enhances the signal-to-noise ratio of the received signal by obtaining temporal and spatial diversity from TR combining of the communication signals received from several hydrophones. A subsequent single channel equalizer reduces the error rate by eliminating the residual inter-symbol interference (ISI). A bidirectional equalization for UWA communications has been proposed to further improve the error performance of the TR technique [4]. The bidirectional equalization technique obtains the diversity gain and reduces the error rate by combining the forward and backward equalized signals.

In this paper, we utilize the bidirectional equalization technique to recover the communication signal acquired from the long-range underwater acoustic communication experiment conducted in East Sea of Korea. The error performance of the conventional TR and the bidirectional technique are compared, and the error rate according to the presence and type of the equalizer is also analyzed. The analysis results show that the bidirectional equalization including the decision-direct equalizer minimizes the error rate.

II. Bidirectional Equalization

Fig. 1 illustrates the receiver structure of the bidirectional equalization system. The received signal is split into two streams, each of which is signal processed and then recombined. One stream is equalized after TR combining as in the conventional TR technique. The equalizer used in the receiver can be either a decision direct or a decision feedback equalizer. Another stream is flipped in time domain, processed by TR-combining and equalization, and then flipped in time domain again. Two soft outputs have different values because they estimate the different channels and calculate the different equalizer coefficients according to the starting point of the channel compensation. Therefore, combining two signals produces additional diversity, although additional training sequence should be inserted at the end of the transmission frame for backward channel estimation and compensation. Finally, the decision device detects the symbol from the combined signal.

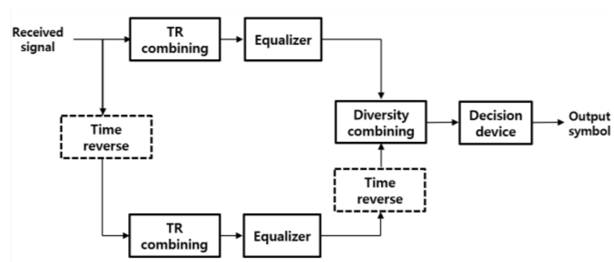

Fig. 1. The receiver structure of the bidirectional equalization system.

III. LONG-RANGE COMMUNICATION EXPERIMENT

In this section, we analyze experimental data with conventional TR and bidirectional techniques. Biomimetic long-range acoustic communication experiment 2018 (BLAC18) was conducted in October 2018. As shown in Fig. 2, single acoustic source as a transmitter was deployed, and vertical line array (VLA), as a receiver, composed of 16 hydrophones spaced 2.8 meters was installed about 90 kilometers away. The source depth was 200 meters, and the nominal depth of the top hydrophone of VLA was 179 meters.

Fig. 3 shows the frame structure for bidirectional equalization. Communication signals were composed of 2816 symbols with a center frequency of 2.5 kHz and a bandwidth of 1024 Hz with binary phase shift keying modulation. The initial and last 176 symbols were used as training sequences for synchronization and channel estimation, respectively, and the remaining 2464 were used as information. Since root raised-cosine pulse with 1 of roll-off factor was applied, the effective data rate was 448 bits per second. A total of 12 transmissions were made.

Fig. 4 shows bit error rate (BER) by each received frame. The bidirectional equalization scheme including the decision-direct equalizer has low BER as a whole while the conventional TR techniques have high BER. The bidirectional technique including the decision feedback equalizer has the lowest BER in some frames, but often shows very high error rates. It can be seen that the error rate of the decision feedback equalizer, which is vulnerable to error propagation, is increased due to erroneous feedback.

Table I shows average BER by each receiver type. The bidirectional technique including the decision direct equalizer has BER of 0.0184 as the best performance. The conventional TR without equalization has the highest BER of 0.1965. The conventional TR with the decision direct equalizer has the BER of 0.0445 and shows better performance than the bidirectional equalization with the decision feedback equalizer. The conventional TR and the bidirectional technique including the decision feedback equalizer have BER of 0.1136 and 0.0824, respectively. These BERs are higher than that of decision direct case because error propagation occurred in the decision feedback equalizer.

IV. CONCLUSION

In this paper, we present the demodulation results for the communication signals acquired from biomimetic long-range acoustic communication experiment 2018 (BLAC18) conducted in East Sea of Korea in October 2018 using time reversal and bidirectional equalization techniques. The analysis results show that the bidirectional technique including the decision direct equalizer has the best error performance.

ACKNOWLEDGMENT

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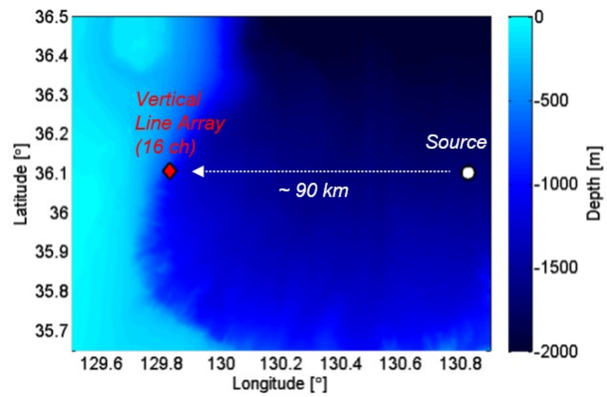

Fig. 2. Experiment site.

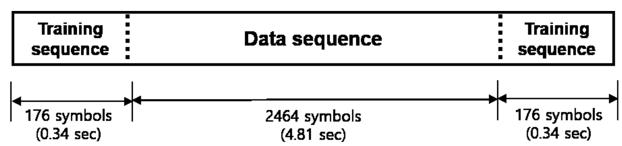

Fig. 3. Frame structure for bidirectional equalization.

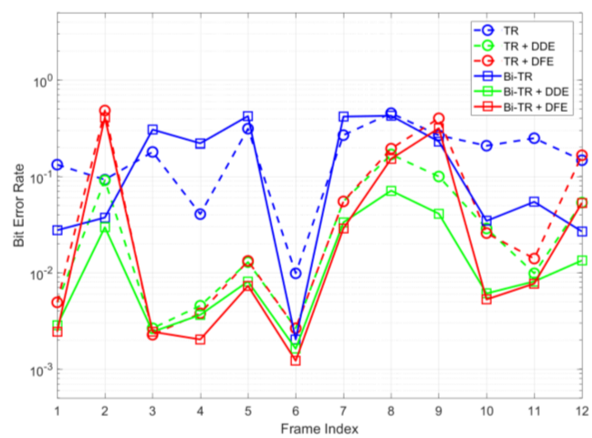

Fig. 4. Bit error rate for each frame.

TABLE I. BIT ERROR RATE ACCORDING TO RECEIVER TYPE

Receiver Type	*TR*	*TR +DDE*	*TR +DFE*	*Bi-TR*	*Bi-TR +DDE*	*Bi-TR +DFE*
BER	0.1965	0.0445	0.1136	0.1836	0.0184	0.0824