Underwater Communication with Spatio-Temporal Diversity in a Deep-Water Environment

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***Abstract*—** Inter symbol interference (ISI) reduces the performance of underwater acoustic communication (UAComm). This paper shows that the performance of UAComm can be improved through the spatio-temporal diversity method that is the combination of spatial diversity and temporal diversity methods. By using spatio-temporal diversity considering focal size, the array aperture was reduced to increase the efficiency of the UAComm system. The hypothesis was also verified using the experimental data of Biomimetic Long Range Acoustic Combat 18 (BLAC18) conducted in October 2018.

Keywords—communication;diversity;time reversal;deep water

I. Introduction

The performance of underwater acoustic communication (UAComm) is affected by fading caused by multipath propagation. Fading occurs when sound waves received along multiple paths are perturbed by different amplitudes, phases, and , resulting in an irregularly fluctuating signal. Inter symbol interference (ISI) also reduces the performance of underwater acoustic communication.

Diversity methods solve the fading problem by combining signals received over multiple channels with independent fading. Depending on how the signals are received, as the method is classified as temporal diversity method, spatial diversity method, or beam diversity method. In this study, temporal diversity and spatial diversity methods are used.

When signals are back propagated and re-focused in time and space, the coherence is quantified by the focal size. Therefore, in this study, it is proposed that the optimal array improves communication performance by receiving less coherent signals. In the proposed optimal array, the communication performance can be improved using the time diversity method, proving that spatio-temporal diversity method is an economical and efficient way of improving communication performance. This hypothesis is verified using experimental data from Biomimetic Long Range Acoustic Combination 18 (BLAC18) conducted in October 2018.

II. BLAC18 Experiment

A. Experimental Setup

An underwater acoustic communication experiment, Biomimetic Long-Range Acoustic Communication 2018 (BLAC18), was carried out in the East Sea of Korea in October 2018 for transmitting long-distance communication signals, biometric signals, and communication signals using LPD/LPI techniques. The location of BLAC18 is as shown in Fig. 1. The sound speed profile and the experimental setup are shown in Fig. 2 and 3, respectively.

A transmitter was placed at a depth of 200 m and a receiver was placed in 16 channels at regular intervals of 2.8 m from a depth of 176 m to 218 m. The range between the transmitter and receiver was 30 km, and the depth of the water was 1000 m to 1200 m. The transmitter and receiver were stationary.

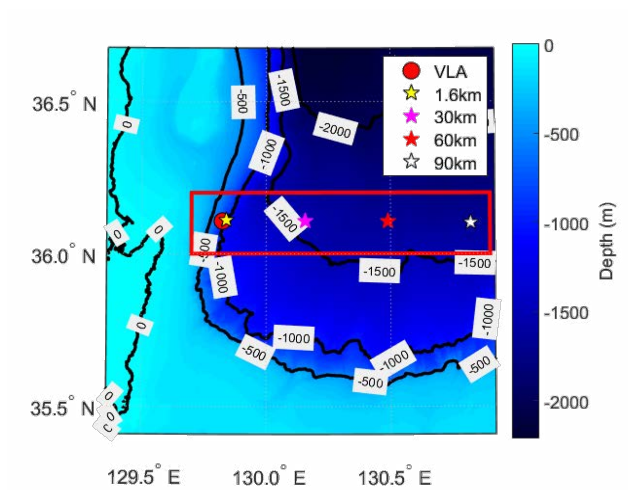

Fig.1. Location of BLAC18

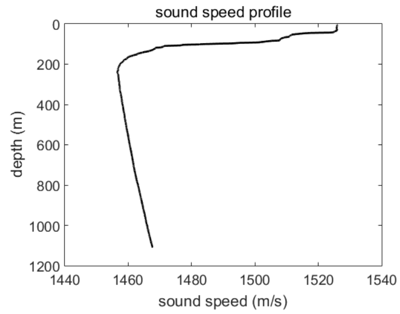

Fig.2. Sound speed profile

Fig.3. Experimental setup

B. *Transmitted Signal Packet Structure*

Fig. 4 shows the packet composition for a transmission signal, which comprises a chirp signal as the probe signal and a data packet. The data signal used binary phase shift keying modulation. To reduce ISI, the root-raised-cosine filter with a roll-off factor of 0.25 was used as a matched filter during modulation and demodulation. The data signal comprised a preamble with 510 bits and a payload of 1000 bits. The transmission rate of the data signal was 1024 bps, the length of the chirp signal was 0.3 s, and the length of the data signal was 9.47 s. Signal transmission was repeated 3 times at 3 min intervals and 3 times at 3 min intervals after 1 h. Therefore, the same signal was transmitted nine times in total.

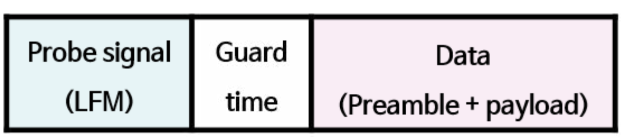

Fig.4. Transmitted signal packet structure

III. Diversity

A. *Spatial Diversity*

Spatial diversity can be implemented by obtaining incoming signals from multiple locations at the same time. Thus, a large number of receivers are required to implement spatial diversity. The systems required to implement these conditions have the disadvantages of costly production, installation and operation. To improve communication performance, an arrangement of optimized locations to obtain signals that are less correlated, can be a solution to address these shortcomings [1].

Time reversal processing was performed to quantify and compare the correlation of the received signals. The received signal re-focused from Fig. 5 was concentrated at the first transmitted position, i.e., the position of the sound source. [2] The focal size shown in Fig. 6 indicates coherence. The vertical focal size with a value of -3 dB was 3.3 m. Therefore, when analyzing the communication performance using the two received signals, the receiver shall have a clearance of at least 3.3 m. Fig. 7 shows the analysis results of communication performance using only spatial diversity of the sixteen signals received over a spatial difference. Fig. 8 presents the maximum, minimum, and average BER for each combination of Fig. 7. The section where the average BER varies greatly according to the array application is between 0 and 8.4 meters and 11.2 to 16.8 meters. It shows that the received signal has a low correlation at array aperture above the focal size, increasing the spatial diversity, which improves communication performance [3,4].

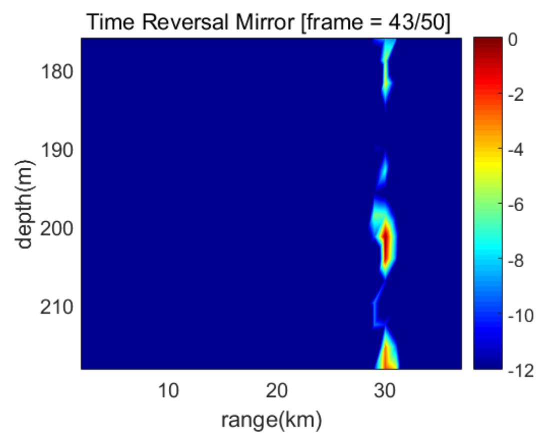

Fig.5. Measured time reversal foci

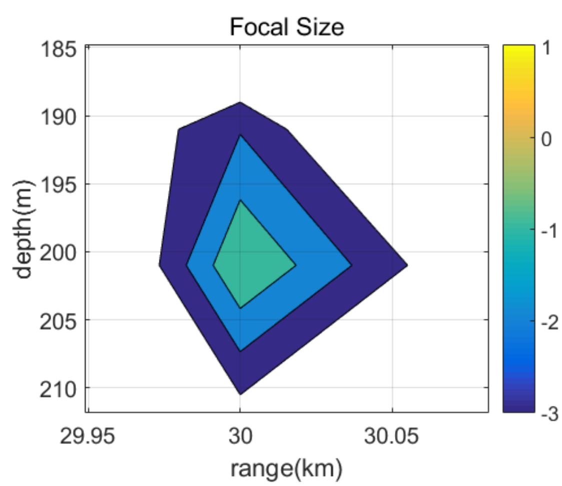

Fig.6. Vertical focal size

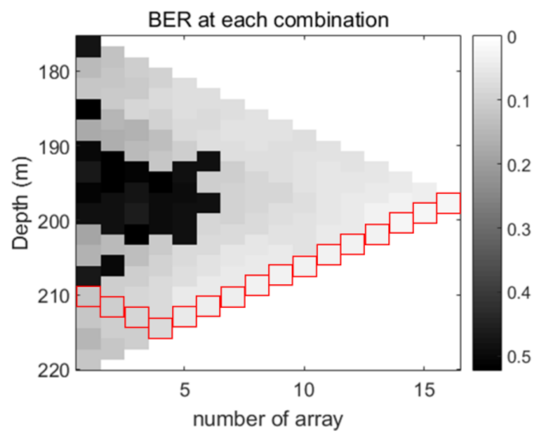

Fig.7. Results of the time-reversal communication performance using spatial diversity

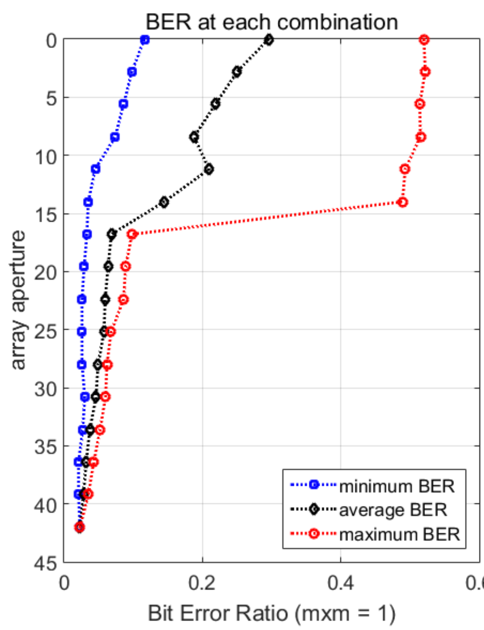

Fig.8. The maximum, minimum, and average BER for each combination using spatial diversity

B. *Temporal Diversity*

Temporal diversity can be implemented by repeatedly transmitting signals at the same location with a time difference and then receiving them. Temporal diversity can be used to improve the communication performance when spatial diversity is limited. Fig. 9 shows the analysis results of communication performance using only temporal diversity, rather than spatial diversity, of the nine signals received over a time difference. Fig. 10 presents the maximum, minimum, and average BER for each combination of Fig. 9. Fig. 10 shows that the number of signals meets a certain number of signals has no greater impact on communication performance than that. In addition, in sections where the difference between the maximum and minimum BER values is greater, it can be seen that other factors than the number of combinations primarily affect the communication performance [5].

Temporal diversity has the disadvantage that, if the time difference is small, changes in the marine environment over time may not be large, resulting in a highly correlated signal. If such a signal is obtained, the degradation of communication performance due to fading cannot be addressed. These results are Fig. 10 state that if the number of combinations is small, the large variation in communication performance is due to correlation.

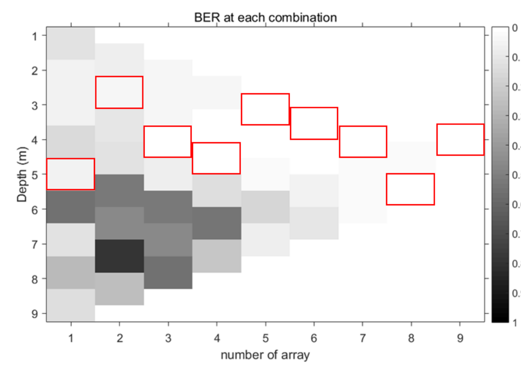

Fig.9. Results of the time-reversal communication performance using temporal diversity

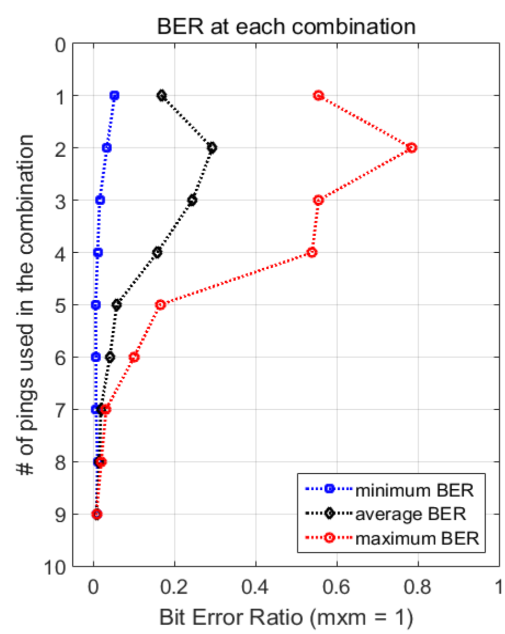

Fig.10. The maximum, minimum, and average BER for each combination using temporal diversity

C. Spatio-Temporal Diversity

Based on the results derived from Section A and B, the performance of spatio-temporal diversity is analyzed using 9 signals received from 2 receivers at 5.6 m intervals. The results are shown in Fig. 11. In Fig. 11, the communication performance of temporal diversity, and spatio-temporal diversity are compared. If two techniques were used in combination, rather than when spatial and semantic universities were used respectively, the lowering of BER would indicate smoothing mitigation. This shows that the Spatio-temporal diversity is effective in improving communication performance[1,5].

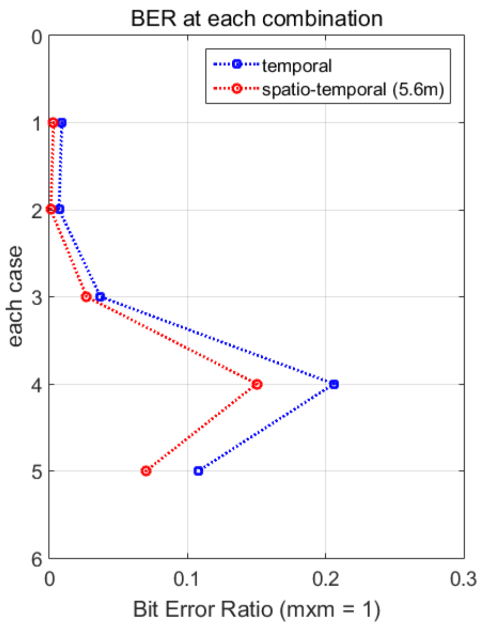

Fig.11. comparison with result of temporal diversity and result of spatio-temporal diversity

IV. Conclusions

The optimal deployment of receivers in the field of underwater communication, including submarines, is important in economic terms. Based on spatio-temporal University, an underwater communication system can be built efficiently if proper receiver application is determined and the communication performance is improved.

Acknowledgment

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References

[1] Hafeth Hourani , "An Overview of Diversity Techniques in Wireless Communication Systems ," S-72.333 Postgraduate course in radio communication,2004

[2] S. Kim, G. F. Edelmann, W. A. Kuperman, W. S. Hodgkiss, H. C.Song, and T. Akal, "Spatial resolution of time-reversal arrays in shallow water," J. Acoust. Soc. Amer., vol. 110, pp. 820–829, 2001.

[3] Takuya Shimura, Yoshitaka Watanabe, Hiroshi Ochi, and H. C. Song, "Long-range time reversal communication in deep water: Experimental results," J. Acoust. Soc. Amer., Vol. 132, No. 1, pp.EL49-EL53, 2012.

[4] H. C. Song, W. S. Hodgkiss, W. A. Kuperman, W. J. Higley, K. Raghukumar, T.Akal, and M. Stevenson, "Spatial diversity in passive time reversal communications,"J. Acoust. Soc. Amer., Vol. 120, No. 4, 2067-2076, 2006.

[5] SALMAN I. SIDDIQUI , HEFENG DONG, "Time Diversity Passive Time Reversal for Underwater Acoustic Communications,IEEE Access, Vol. 7, 24258-24266, 2019.