3J2-2

Multiuser communication with moving targets using adaptive time reversal

Adaptive time reversal による移動体とのマルチユーザ通信

Takuya SHIMURA[1†], Yukihiro KIDA[1], Mitsuyasu DEGUCHI[1] and Yoshitaka WATANABE[1] ([1]JAMSTEC)
志村拓也 [1†]，樹田行弘 [1]，出口充康 [1]，渡邊佳孝 [1] ([1]海洋研究開発機構)

1. Introduction

In underwater acoustic channel, there are difficulties that numerous multipath signals cause a very strong intersymbol interference (ISI) and that the rate of Doppler frequency shift is very large. There difficulties quite different from those in radio communication in air. Thus, it is necessary to choose a method suitable for underwater acoustic channels. In this point, time reversal is an effective method [1,2]. Because time reversal collects multipath signals and rebuilds the original signal with ISI removed.

Recently, there is an increasing demand for multiuser communication to establish multiple AUVs operation. In techniques, e.g., frequency division multiple access (FDMA) or code division multiple access (CDMA), the data transmission rate for each user have to be decreased in proportional to the number of users. In the meantime, in case of spatial division multiplexing (SDM), in which signals from users are transmitted in the same frequency band simultaneously or without timing control, it is possible to achieve multiuser communication without sacrificing the data transmission rate. To realize such SDM, time reversal is also a promising solution because its spatial and temporal focusing makes it possible to separate signals from multiple transmitters. In previous studies [3-5], the performance of adaptive time reversal, which is an enhanced version of time reversal to suppress crosstalk, was investigated.

However, in these studies, the effect of Doppler frequency shift has not been taken into account. Thus, at-sea experiments for multiuser communication including the effect of transmitter movement were carried out.

2. Adaptive Time Reversal Theory

In this study, SDM multiuser communication using adaptive passive time reversal is discussed, that is, communication channel for each user is composed of single-input/multiple-output (SIMO).

In passive time reversal, a probe signal and an information-bearing signal are transmitted consecutively from a transmitter, and received signals are cross-correlated at a receiver array following summation over channels. Assuming that the channel response from the ith transmitter to the jth receiver is $h_{ij}(t)$ and the information-bearing signal transmitted from the ith transmitter is $s_i(t)$, the received signal at the jth receiver is expressed as

$$r_j(t) = h_{ij}(t) * s_i(t) \tag{1}$$

where * indicates the convolution integral. Then, the passive time-reversal process is expressed as

$$\begin{aligned}\sum_j h_{ij}(t) \otimes r_j(t) &= \sum_j h_{ij}(t) \otimes \left(h_{ij}(t) * s_i(t) \right) \\ &= q(t) * s_i(t),\end{aligned} \tag{2}$$

where $\otimes$ indicates the correlation and $q(t)$ is called the q-function.

As far as multiple access interference (MAI) is not so strong, it is possible to achieve SDM communication only with passive reversal. However, for more robust or high rate multiuser communication, a more effective method is desired. Thus, adaptive time reversal [6] is adopted, the probe signal for which is derived as below. Supposing the expression of $h_{ij}(t)$ in the frequency domain is $H_{ij}(f)$, the adaptive time-reversal probe signal expressed in the frequency domain $w_{ij}(f)$ is given by

$$\mathbf{w}_i = \mathbf{R}^{-1}\mathbf{d}_i \big/ \mathbf{d}_i^{\dagger}\mathbf{R}^{-1}\mathbf{d}_i \tag{3}$$

where

$$\mathbf{R} = \sum_k \mathbf{d}_k \mathbf{d}_k^{\dagger} + \sigma^2 \mathbf{I}$$

$$\mathbf{d}_k = \left[H_{k1}(f) \cdots H_{kM}(f) \right]^T$$

$$\mathbf{w}_i = \left[w_{i1}(f) \cdots w_{iM}(f) \right]^T,$$

subject to the constraint that $\mathbf{w}_i^{\dagger}\mathbf{d}_i = 1$. Here, † denotes the complex conjugate transpose, M is the total number of receivers, and $\sigma^2\mathbf{I}$ is a small diagonal loading for a matrix inversion with an identity matrix $\mathbf{I}$. Using adaptive time reversal, the signal from the ith transmitter is preserved while signals from other transmitters are suppressed, that is, null focusing is generated at interfering transmitter points. After adaptive time-reversal processing, a short, single-channel decision feedback equalizer (DFE) is appended to remove residual ISI similarly as in the previous studies.

3. Experiment Set-Up

The experiments were executed in the area of

acoustics237@jamstec.go.jp

1,100 m water depth in Suruga bay, using two transmitters and a twenty channel receiver array. In **Fig. 1**, the arrangements of the transmitters and the receiver array were shown in addition to the bathymetry and the sound velocity profile of the experiment site. As shown in Fig. 1, one of the transmitters was moored at the depth of 870 m at the distance from the receiver array. And the other transmitter was suspended from the research vessel and towed horizontally at the various speed near the moored source. The receiver array aperture was spanned at the depth from 830 to 950 m approximately.

Signals modulated with binary phase shift keying (BPSK) in the frequency band from 450 to 550 Hz were transmitted. In this measurement, the towed transmitter (Tx1) transmitted at every one minute and the moored transmitter (Tx2) transmitted at every two minutes. That is, multi user interfered transmission, and single user transmission, in which only Tx1 transmitted, were repeated. In single user transmission, received signals are modulated with passive time reversal DFE.

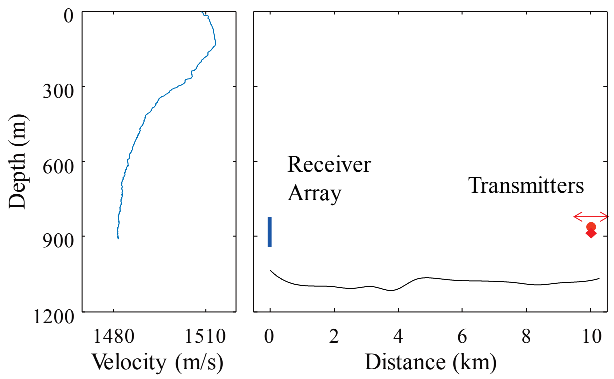

Fig. 1 Transmitters and receiver array arrangements with bathymetry (right panel) and sound velocity profile (left panel) at the experiment site.

4. Results

In **Fig. 2**, demodulated symbols on the constellation map are shown, in cases of single user transmission and multiuser transmission. The towing speed of Tx1 was changed to 0.6, 1.0, and 1.4 kt, approximately. Comparing the results of single transmission (left panels) and multiuser transmission (middle panels) for user1 (Tx1), there is no remarkable degradation. Thus, MAI suppression by adaptive time reversal works well in all the cases. And seeing the results in Figs. 2 (a), (b) and (c), the performance of adaptive time reversal is not deteriorated depending on the moving speed. Additionally, it is shown that the results of user2, (Tx2) is not influence by the result of user 1. Thus, it is demonstrated that adaptive time reversal appended with DFE is still very effective under the effect of moving transmitter.

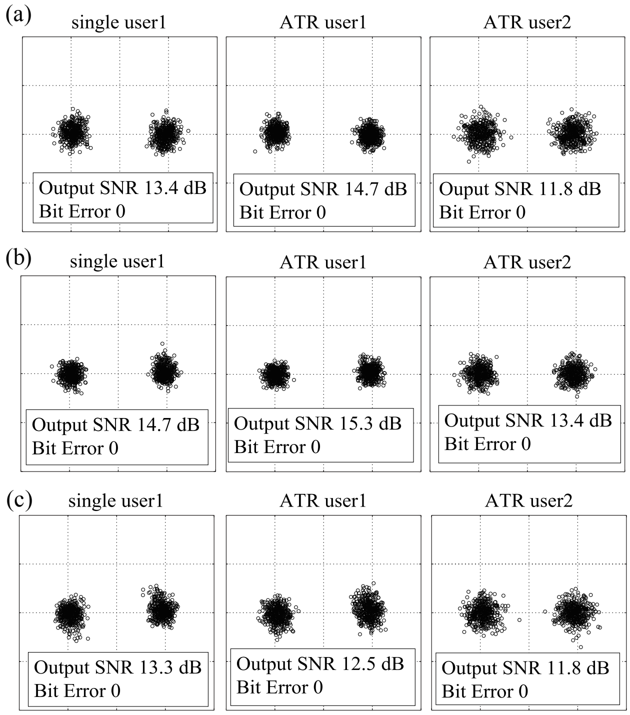

Fig. 2 Demodulated results at the moving speed of (a) 0.6, (b)1.0 and (c) 1.4 kt. Left panels are the results in cases of single user transmission and middle and right panels are the results in cases of multiuser transmission.

5. Summary

In this study, at-sea experiment for multiuser communication including moving effect was carried out. As results, it is demonstrated that adaptive time reversal is still effective even under Doppler effect.

Acknowledgment

This research is partially supported by a 2017 Grant-in-Aid for Scientific Research (C) (Grant No. 17K06977) from the Ministry of Education, Culture, Sports, Science and Technology, Japan.

References

1. T. Shimura, H.C. Song, et al. : J. Acoust. Soc. Am. **132** (2012) EL49.
2. Y. Kida et al. : Jpn. J. Appl. Phys. **56**, (2017) 07JG04.
3. T. Shimura et al. : Jpn. J. Appl. Phys. **56**, (2017) 07JG03.
4. T. Shimura et al. : Jpn. J. Appl. Phys. **54**, (2015) 07HG02.
5. T. Shimura, H. Ochi, and H.C. Song : J. Acoust. Soc. Am. **134** (2013) 3223.
6. J. Kim, H.C. Song, and W.A. Kuperman: J. Acoust. Soc. Am. **109** (2001) 1817.