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Adaptive time reversal multiuser communication in the deep ocean

Adaptive time reversal による深海域におけるマルチユーザ通信

Takuya SHIMURA†[1], Mitsuyasu DEGUCHI, Yukihiro KIDA and Hiroshi OCHI (Marine Technology Department, JAMSTEC)
志村拓也†, 出口充康, 樹田行弘, 越智寛 (海洋技術開発部 海洋研究開発機構)

1. Introduction

Recently, in the field of underwater acoustic communication, demands for multiuser communication has increased. Time reversal is an attractive solution to achieve such communication [1,2]. Spatial and temporal focusing of time reversal can be applied to separate signals from different positions by the same signal processing in the single user case, in addition to removing intersymbol interference (ISI) due to multipath environment. Furthermore, to enhance the performance of cancelling crosstalk, adaptive time reversal has been proposed [3,4].

In this study, supposing communication from multiple sources, e.g. autonomous underwater vehicles (AUVs), the effectiveness of adaptive time reversal for multiuser communication in the deep ocean is discussed with experimental data.

2. Adaptive Time Reversal Theory

The scope of this study is communication from multiple sources to a receiver array. Thus, only single-input-multiple-output (SIMO) multiuser communication is discussed.

Time reversal for SIMO communication is passive time reversal, in which a probe signal is transmitted from a source, followed by an information-bearing signal. The channel response is obtained from the received probe signal, which is cross-correlated with the received information-bearing signal at each channel, and summed over the channels. Thus, by spatial and temporal focusing effect, in addition to removing ISI, signals from sources at different positions can be separated.

To enhance crosstalk mitigation effectiveness additionally, adaptive time reversal is applied in this study, which has been proposed by Kim et al [3,4]. The theory is explained in brief here in case of two users for explanation. Supposing the channel response, $h_j^i(t)$, received at the jth element of the receiver array from the ith user (source), and its expression in the frequency domain, $H_j^i(f)$, a column vector $\mathbf{d}_k$ is defined as

$$\mathbf{d}_k = \left[H_1^k(f) \cdots H_M^k(f) \right]^T \quad (1)$$

where M is the total number of receivers.

$$\mathbf{w}_1 = \frac{\mathbf{R}^{-1}\mathbf{d}_1}{\mathbf{d}_1^\dagger \mathbf{R}^{-1}\mathbf{d}_1} \quad \text{where} \quad \mathbf{R} = \mathbf{d}_1\mathbf{d}_1^\dagger + \mathbf{d}_2\mathbf{d}_2^\dagger + \sigma^2\mathbf{I} \quad (2)$$

subject to the constraint that $\mathbf{w}_1^\dagger \mathbf{d}_1 = 1$. Here, † denotes the complex conjugate transpose and $\sigma^2\mathbf{I}$ is a small diagonal loading for a matrix inversion with an identity matrix **I**. By calculating equation (2) for all frequencies in the bandwidth and converting them to the time domain, the adaptive time-reversal signal can be obtained, which replaces, $h_j^i(t)$, in conventional time reversal.

In this study, after time-reversal combining, a single channel decision feedback equalizer (DFE) is combined to remove residual ISI similarly as in the previous studies [5].

3. Analysis of At-Sea Experiment Results

3.1 Experimental set-up

The experiment was carried out in Suruga-bay as shown in **Fig. 1**, using two sources and a 20-channel receiver array. One of the source (denoted as Tx1) was suspended from the R/V Kaiyo with changing its depth from ~ 300 to ~ 1400 m and the other (denoted as Tx2) was moored at the depth of ~ 600 m, as shown in Fig. 1. The source level was ~ 196 dB and the frequency band was from 450 to 550 Hz. The receiver array was moored at the range of 30 km from the sources. The intervals of

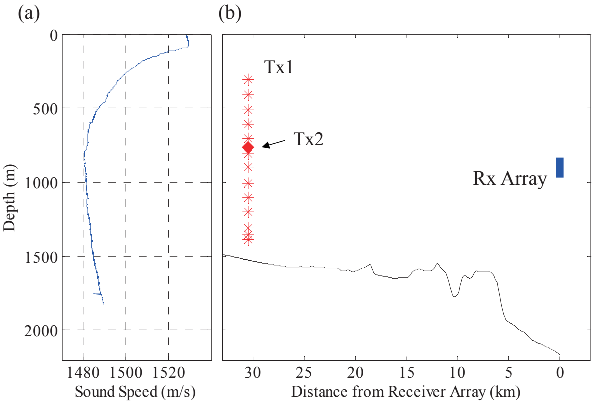

Fig. 1 (a) Sound speed profile at the experimental site and (b) arrangement of sources and receiver array.

[1] acoustic237@jamstec.go.jp

receives were ~ 6 m and the total length of the array was ~ 114 m. The receiver aperture was spanning at the depth from ~ 840 to ~ 950 m. The distance between the sources and the receiver array was 30 km. The sound speed profile at the experiment site is also shown in Fig. 1.

3.2 Multiuser demodulation with real data

The sources, Tx1 and Tx2, transmitted mostly simultaneously signals modulated with binary phase shift keying (BPSK), quadrature phase shift keying (QPSK) and 16QAM (quadrature amplitude modulation). These signals were tried to be demodulated with adaptive time reversal and conventional time reversal. **Fig. 2** shows output SNRs in case of 16QAM during the period when signals from two sources collided, that is, the multiuser interference took place. These results show that enhanced effectiveness by adaptive time reversal for crosstalk suppression is observed in all cases regardless of the relative positions of the two sources.

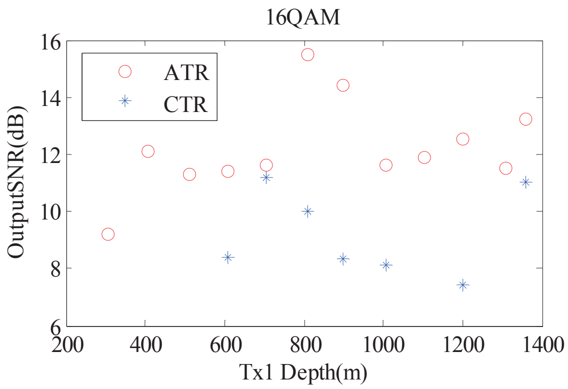

Fig. 2 Experiment result of multiuser demodulation by adaptive time reversal in case of 16 QAM.

3.3 Comparison with multiuser M-DFE

In this section, performance of adaptive time reversal is compared with multiuser multichannel DFE [6]. To apply multiuser M-DFE, it is necessary that differences of travel times from multiple sources are shorter than the length of feedforward taps of DFE. Thus, the signals of Tx1 from different positions were synthesized to create multiuser communication signals including simultaneous collision, which were processed with conventional and adaptive time reversal, and single user and multiuser MDFE. In the cases of conventional time reversal and single user M-DFE, the signal processing is the same as in the case of single user. In all these four methods, a second order digital phase-locked loop (DPLL) is embedded in the DFE [7].

Fig. 3 shows the result in case that the signal of BPSK from the depth of 1202 m (denoted as User1) is synthesized with signals from other depths (denoted as User2). The vertical axis indicates the output SNR of User1 and the horizontal axis indicates the depth of User2. This result shows that adaptive time reversal is better than the other three methods wherever User2 is located to User1. Thus, adaptive time reversal is most effective for crosstalk mitigation. In the meantime, the improvement by multiuser multichannel M-DFE is observed comparing with single user M-DFE, however, both of them are not competitive to conventional and adaptive time reversal.

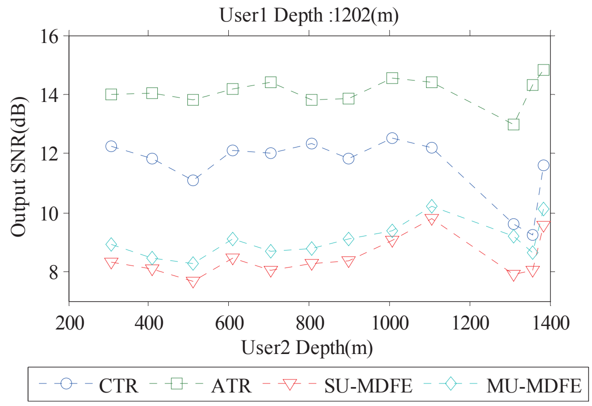

Fig. 3 Comparison with multiuser M-DFE based on synthesized experimental data

4. Summary

Adaptive time reversal was applied to multiuser communication in the deep ocean and its effectiveness of crosstalk cancellation was demonstrated with experimental data. As results, in all cases, it was shown that adaptive time reversal has better performance than other methods.

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