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Evaluation of effects of multipath and co-channel interference on time reversal MIMO in underwater acoustic channel.

水中音響位相共役 MIMO 通信に対するマルチパス干渉とチャンネル間干渉の影響評価

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1. Introduction

Underwater acoustic channel (UAC) is one of the most difficult environment for remote communicaitons because of multipath interference, limited frequency band, and etc. In spite of these difficulties, recent advances in underwater measurements require high data rate for remote communication techniques. To speed up the very band-limited communication in UAC, multiple -input/multiple-output (MIMO) communication technique has attracted attensions.

In MIMO, multiple transmitters send the signal simultaneously to the receivers, therefore the received signals contain co-channel interference (CCI). To remove the CCI, it is nessesary to decompose the channel impulse response (CIR) of each acoustic path, and this point is the most significant difference between single-input/ multi-output (SIMO) and MIMO. From the point of view of interferences in underwater acoustic MIMO communication, the multipath and CCI are most important problems to deal with.

Time reversal (TR) acoustic communication techniques have been studied as an alternative solution for the multi-channel equalizer in highly coherent UAC[1]. Using the reciprocity of the acoustic wave propagation, TR produces the highly resolved spatial and temporal focusing. It is considered that the temporal focusing of TR is very effective for heavy multipath environment of underwater acoustic as a preprocissing of a decision feedback equalizer (DFE)[2]. Additionally, the spatial forcusing of TR has exploited the possibility of space division multiplexing for MIMO/multi-user communications[3].

There have already been some practical studies for TR-MIMO communication technique, however the quantitative investigation is still in short to discuss the efficiency. In this study, we investigate the relation among the multipath interference, CCI and output SNR (OSNR) of demodulation result using a TR-MIMO technique using synthetic dataset of UAC in shallow sea environment.

2. Adaptive Time Reversal

In this study, application of passive TR (PTR) to MIMO communication is discussed. In PTR, the back propagation process is realized vertually by the cross-correlation of the signals and CIR as follows:

$$\begin{aligned}\sum_j h_{ij}(t) * r_j(-t) &= \left(\sum_j h_{ij}(t) * h_{ij}(-t) \right) * s_i(t) \qquad (1) \\ &= q(t) * s_i(t)\end{aligned}$$

where * denotes the convolution, $h_{ij}(t)$ is the CIR from the *i*th transmitter to the *j*th receiver, $r_j(t)$ is the received signal at *j*th receiver, $s_i(t)$ is the signal transmitted from the *i*th transmitter, and $q(t)$ is so called q-function. Practically, a probe signal to measure the CIR such as chirp signals is used for the cross correlation.

In MIMO communication, different signals in the same frequency band are sent simultaneously from each transmitter. Conventional PTR is efficient for MIMO communication in moderate multipath conditions, however there are still room for improvement. To enhance the spatial resolution of PTR, an adaptive weighting proposed by Kim et al[4] is applied. Supposing the expression of CIR in frequency domain as $H_{ij}(f)$, the probe signal of adaptive time reversal (ATR) expressed in frequency domain w_{ij} is given by as follows:

$$\mathbf{w}_i = \mathbf{R}^{-1}\mathbf{d}_i / \mathbf{d}_i^T \mathbf{R}^{-1} \mathbf{d}_i \qquad (2)$$

subject to constraint that $\mathbf{w}_i^T \mathbf{d}_i = 1$, where

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

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

$$\mathbf{w}_i = [w_{i1}(f) \cdots w_{iM}(f)]$$

R is a synthesized cross spectral density matrix exploiting knowledge of CIR, σ^2 is small diagonal loading for L_2 regularization and $\mathbf{I}$ is the identity matrix. Note that a typical value used for diagonal loading is 1% of the trace of the matrix. Using this weighting scheme, the probe signal for TR processing is optimized to suppress the CCI from other transmitters. In this study, we use this ATR scheme for preprocessing of a recursive least square based single channel DFE.

3. Synthetic dataset

The ATR scheme is applied to the synthetic dataset of shallow sea acoustic channel shown in **Fig.1**. The CIR is calculated by the normal mode equation method[5] and the time-series data at each receiver is acquired by convoluting its CIR and communication signals.

Dataset is generated for various SNR and signal to interference ratio (SIR) to investigate the effectiveness of the method for multipath environment. The white Gaussian noise is added to the dataset to control the SNR. SIR is varied by adjusting the number of modes calculated by the normal mode equation method for CIR computation. In this environment, lower modes correspond to the direct wave from transmitter to receiver array. Then, as including higher modes, the number and incident angle of multipath is gradually increasing.

4. Results

Fig.2 shows the relation between the number of modes for CIR computation and OSNR using dataset of SNR=40dB. The blue, red and orange lines show the result of 2x40, 3x40 and 5x40 MIMO, respectively. The results are averaged among all transmission channels. Green line indicates the result of SIMO communication using PTR in the same environment. As shown in **Fig.2**, all MIMO results fall below the result from SIMO communication, especially in the data of lower number of modes. As the data including higher mode number, the OSNR of MIMO results slightly improve, and they moderately decrease and converge subsequently. In addition, the difference with SIMO is getting smaller. This implies that ATR-MIMO requires the diversity derived from the multipath. It is also found that there is little difference among the MIMO results and the difference between SIMO and MIMO converges to only about 2dB.

Fig.3 shows the relation between total input energy and OSNR. Here, total input energy is evaluated by summation of signals including multipath-to-noise ratio and array gain. The total input energy and OSNR should be equal in ideal Gaussian environment and this bound is the theoretical limitation. **Fig.3** shows that OSNR of MIMO results are nearly completely equivalent to the total input energy. As long as following this equivalent relation, it means that ATR-MIMO utilize all the energy including energy of multipath. In high SNR dataset, the improvement of OSNR is gradually declining and converges to a typical value.

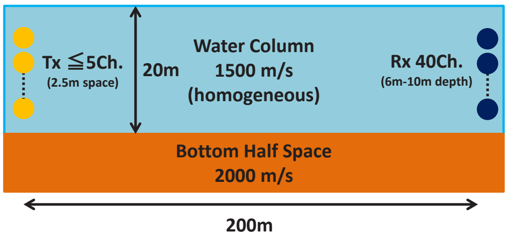

Fig. 1 Acoustic model for synthetic dataset

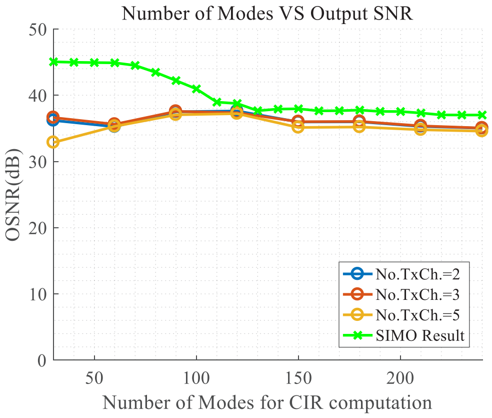

Fig. 2 Number of Modes VS Output SNR

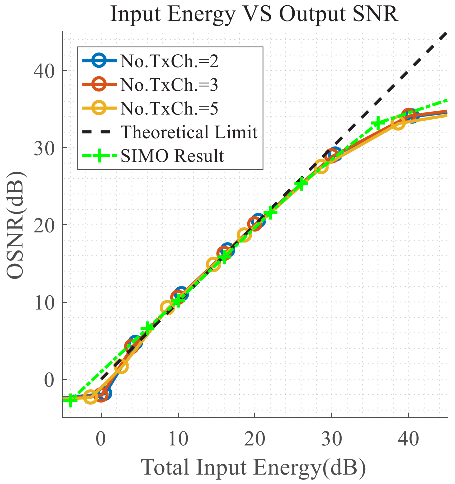

Fig. 3 Total Input Energy VS Output SNR

4. Conclusion

The effectiveness of ATR to MIMO communication in multipath rich UAC environment is investigated. As a result, ATR utilizes energy of the multipath nearly completely. It is also found that the difference of OSNR among various transmitting channel is insignificant, in other words, ATR removes most of CCI. ATR could be considered as one of the promising solutions for MIMO in UAC.

References

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