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Performance Evaluation of Chip-Interleaving Method for Acoustic Communication
チップインターリーブを用いる音響通信方式とその性能評価

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1. Introduction

Recently, there has been an increase in the amount of research on underwater acoustic communications especially in improvement of the efficiency and the expansion of the range for searching[1-3]. One of the most difficult problems on underwater communications is to avoid the inter-symbol interference (ISI), that is a kind of signal distortion in which one symbol interferes with subsequent symbols, and caused mainly by the multipath environment and the band-limiting of channels. To avoid the ISI due to the multipath environment, many preceding studies were conducted. The authors have reported that the chip-interleaved multiple access (CIMA) method has good performance for underwater comm- unication, because it enables to transmit both the pilot signal for multipath measuring and the transmit data simultaneously, to communicate by measuring multipath profile in real time, and to reconstruct the transmitted signal from the received signal[4].

This study was aimed to reveal the CIMA performance in the Rayleigh fading channel, which is commonly used for a multipath environment. By using the Rayleigh fading channel model, we investigated the CIMA performance, especially the channel estimation accuracy.

2. Chip-interleaving method

2.1 Signal processing in transmitter

Figure 1 shows signal architecture of the CIMA. We define bit, symbol, and chip as binary digits, encoded bits, and vectorial symbols, respectively. In the CIMA, the transmitter constructs transmit signal $\mathbf{T}^*$ from two chips $\mathbf{C}_1$ and $\mathbf{C}_2$ of length M as

$$\mathbf{T}^* = \sum_{k=1}^{2} \mathbf{C}_k \otimes \mathbf{h}_k \ , \qquad (1)$$

where $\otimes$ means the Kronecker product and $\mathbf{h}_k$ is a row of spreading matrix whose length is N. We make this signal $\mathbf{T}^*$ to pseudo cyclic signal by prefixing guard-interval, in order to avoid the ISI effect due to the multi-path environment. The guard interval is a tail section of the signal $\mathbf{T}^*$, whose length L should be longer than the length of the multipath profile l. The transmit signal $\mathbf{T}$ is then send to the acoustic transducer after modulation process.

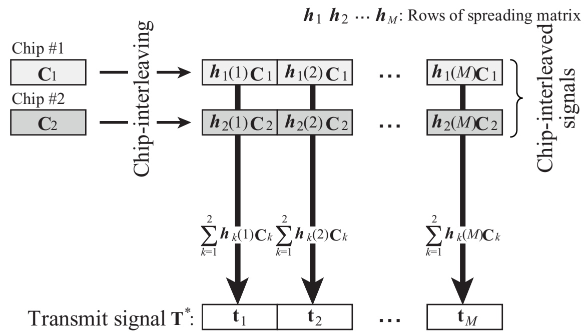

Fig. 1 Signal architecture of the CIMA.

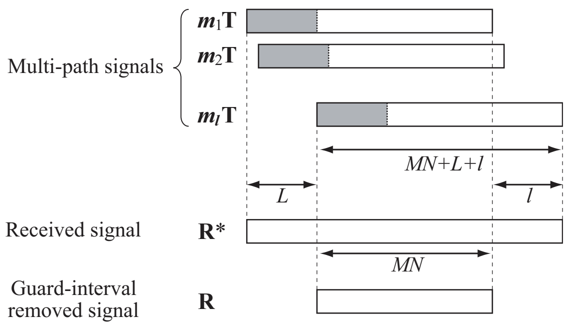

Fig. 2 Relationship between the transmit signal **T**, the received signal $\mathbf{R}^*$, and the guard interval removed signal **R**.

2.2 Signal processing in receiver

We define $m_1, m_2, ..., m_l$ as multipath profile. The received signal $\mathbf{R}^*$ can be expressed as

$$\mathbf{R}^* = \sum_{k=1}^{l} m_k \mathbf{T} S^k \ , \qquad (2)$$

where S is a cyclic shift matrix. Firstly, the receiver removes the carrier by multiplying phase coherent carrier and adopting the low-pass filter. Then, digital sequence $\mathbf{R}^*$ is obtained by the data sampler. The receiver gives the signal $\mathbf{R}$ by removing the guard interval from the received signal $\mathbf{R}^*$. The relationships among the multipath signal $m_i\mathbf{T}$, the received signal $\mathbf{R}^*$, and the guard interval ablated signal $\mathbf{R}$ is shown in **Fig. 2**. The receiver reconstructs transmitted chips $\mathbf{C}_1$ and $\mathbf{C}_2$ by using a matched filter $F_i E_i^{-1}$ and the guard interval removed

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signal **R** as follows:

$$\mathbf{C}_i = \mathbf{R} F_i E_i^{-1}, \quad (3)$$

$$F_i = I \otimes \mathbf{h}_i^{\mathrm{T}}, \quad (4)$$

where i is 1 or 2, I is a 2×2 unit matrix, and $\mathbf{h}_i^{\mathrm{T}}$ means the transposition of $\mathbf{h}_i$. E_i is a channel matrix where

$$E_1 = \begin{pmatrix} m_1 & m_2 & \cdots & m_N \\ m_N & m_1 & \cdots & m_{N-1} \\ \vdots & \vdots & \ddots & \vdots \\ m_2 & m_3 & \cdots & m_1 \end{pmatrix}, \quad (5)$$

$$E_2 = \begin{pmatrix} m_1 & m_2 & \cdots & m_N \\ -m_N & m_1 & \cdots & m_{N-1} \\ \vdots & \vdots & \ddots & \vdots \\ -m_2 & -m_3 & \cdots & m_1 \end{pmatrix}. \quad (6)$$

$$m_i = 0, \text{ when} (l + 1 \le i \le N).$$

These channel matrix elements m_1, m_2, ..., m_l can be obtained from the pilot signal. In the CIMA, we can allocate the pilot signal to one of the chip $\mathbf{C}_1$ and the communication data to the rest of the chip $\mathbf{C}_2$. If the pilot signal allocated chip $\mathbf{C}_1$ is a sequence which has excellent autocorrelation property like maximum length sequence (M-sequence), multipath profile can be obtained by calculating cross correlation between transmitted and received sequences.

3. Experimental results

We evaluated the performance of the CIMA in the Rayleigh fading channel in a simulation. The parameters which is used for a simulation is shown in Table I. The chip length is 127 bits and each chip is modulated in bi-phase shift keying (BPSK). The guard interval length is 30 and we used M-sequence as pilot signal. The channel is assumed as exponential Rayleigh slow fading channel. In this channel, each multi-path profile m_1, m_2, ..., m_l is Rayleigh distributed amplitude and the channel power delay profile decays exponentially.

Figure 3 shows the simulation results. Fig. 3(a) shows a bit-error-rate (BER) of the CIMA method in Rayleigh fading channel. BERs when the multipath profile is ideally given to the receiver and when the profile is measured by the pilot signal from the received signal are indicated in a dotted line and a solid line respectively. Fig. 3(b) shows the relative correlation value (RCV) between the given multipath profile and the measured profile from the pilot signal. If the pilot signal measures the multipath profile accurately, the RCV value reaches to one. From Fig. 3(a), it is revealed that the CIMA method can reconstruct the transmitted signal and communicate in Rayleigh fading channel, and the BER difference when the multipath profile is ideally given or measured is limited up to 5 dB. From Fig. 3(b), the channel estimation accuracy increases as the energy per bit to noise power spectral density ratio (E_b/N_0) increases and it seems sufficient when the E_b/N_0 is larger than 10 dB.

Table I: Parameters which is used for simulation.

Chip length M	127 bits
Modulation	BPSK
Guard-interval length L	30
Pilot signal	M-sequence
Channel property	Exponential Rayleigh slow fading channel
Fade rate	0.5

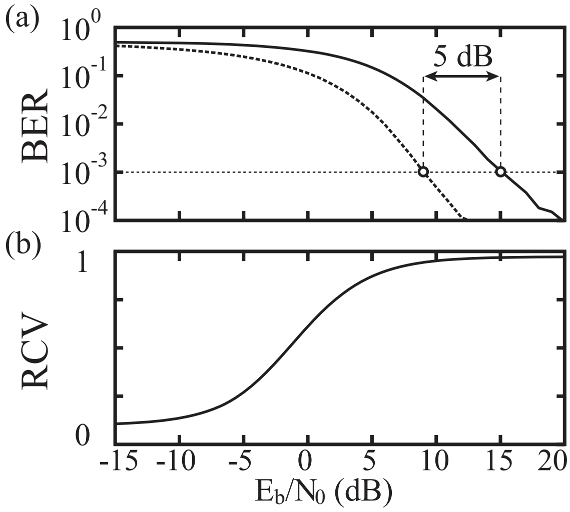

Fig. 3 BER and RCV obtained from experiment.
(a) BER of CIMA method.
(b) RCV between given multi-path profile and measured multi-path profile from pilot signal.

4. Conclusions

We evaluated the CIMA performance in the Rayleigh fading channel, and investigated the multipath profile measurement accuracy. The obtained results suggest that an underwater communication with the CIMA can contribute actively in multipath fading channel.

Acknowledgment

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