Multipath Selection Method for Maximum Ratio Combining in Underwater Acoustic Channels

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Abstract— This paper proposes a multipath selection method for maximum ratio combining to improve bit error rate (BER) performance in code division multiple access (CDMA) experiencing underwater long multi-path channels. To select optimum paths, BERs are calculated for each multipath and the optimum multipaths that exhibit the minimum BER are selected. Computer simulation shown that the proposed method has better BER performance than a conventional threshold generalized selective combining (T-GSC).

Keywords — Maximum Ratio Combining, ISI, Underwater communication

I. Introduction

Underwater acoustic communications mainly use acoustic waves since electromagnetic fields may not be effectively traveled through conductive materials such as water [1]. In underwater, acoustic waves are radiated from a transmitter and reflected by sea surfaces and bottoms. A low speed of sound, e.g., 1500m/sec, causes long propagation delay profiles at the receiver, and inter symbol interference (ISI) plays an important role in increasing receiver bit error rate (BER) performance.

Code division multiple access (CDMA) is one of solutions to mitigate the ISI [2]. Spreading code of CDMA reduces the ISI since each multipath can be eliminated by using orthogonality among different spreading codes [3-4]. To increase BER performance of CDMA, receiver needs to collect transmitted information contained in multipaths. The combining process of multipaths is performed by maximum ratio combining (MRC), generalized selective combining (GSC), etc [5-6]. The fact that combining all multipath provides the best BER performance of MRC is known. When noise is large, however, all multipaths may not be helpful due to channel estimation errors. Therefore, paths with preserving information need to be selected and utilized for combining. In general, it is difficult to determine which paths provide the optimum performance.

To overcome this issue, this paper proposes a selection method of multipath combining to increase BER performance by using calculating BER based on spread pilots. Every pilot is spread with orthogonal codes and multipaths obtained from the pilot are tested to calculate BER of pilots by adding every multipath. Then, the optimum multipaths are selected. The selected multipaths are varying by time, and better BER performance is kept.

The composition of this paper is as follows. In Sec. 2, the proposed method is described. In Sec. 3, the performance of the proposed method is compared with the conventional GSC method and analyzed using computer simulation. Sec. 4 concludes this paper.

II. Proposed Method

Fig. 1 denotes a block diagram for the symbol-level combining Rake receiver. The conventional path selection method in Fig. 1 utilizes a threshold generalized selective combining (T-GSC). T-GSC combines only paths whose amplitudes are greater from a certain threshold of the estimated channel level. When the background noise is large, a channel estimation error occurs and some selected paths from the estimation may not contain signal information. Thus, it is difficult to find an optimum selection rule. To solve this problem, this paper proposes an optimum multipath selection method by using spread pilot.

In general, pilot is generated by pseudo random noise (PN) sequence. However, the proposed method utilizes the spread pilot. Using the spread pilot, not only the underwater acoustic channel can be estimated, but also each path of the multipath channel can be analyzed individually. This paper proposes a path selection method that minimizes BER by using the spread pilot.

The transmitter generates pilot signals based on spread symbols. The receiver estimates the channel using received pilots and delay times of multipaths. The signals at every multipath location are de-spread by the spreading code, and compensated by channel equalizer, and combined to recover the received signals. Thus, SNR of the combined signal increases and BER decreases. This combining method is called a Rake receiver. However, in practice, the estimated multipath channel has a channel estimation error and noise. To reduce the BER, only multipaths which include signal information should be selected and combined.

The proposed method provides a multipath selection method to minimize BER of the pilot signals. The proposed method utilizes the spread pilot as transmitted symbols. Since the spread pilot is the same as pseudo random sequence,

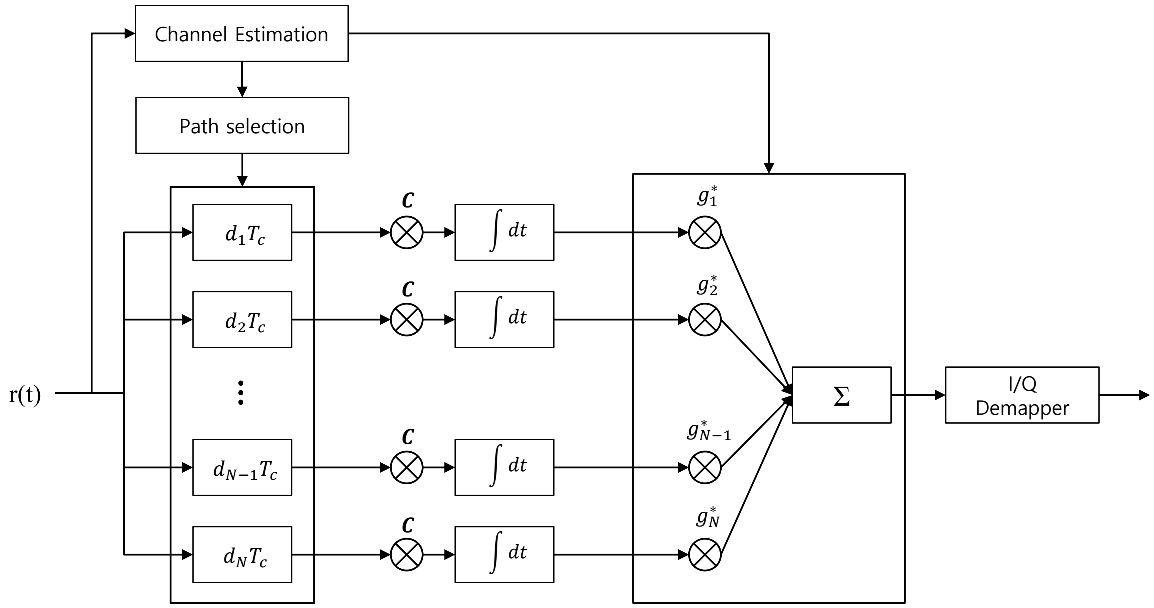

Fig. 1. Symbol level Combining of Rake receiver

channel estimation can be performed by chip level. The pilot is added at every slot or frame, and BERs for the pilots show local BER performance by time varying channels.

In order to select optimum multipaths that provide a minimum BER among N multipaths at a given pilot, after channel estimation, all multipaths are sorted by amplitude descending order, and every multipath is combined sequentially by its order. Then, BERs are calculated whenever each path is combined. If an additional path increases BER, the multipath is excluded for combining, and the next path is tested for combining and BER is calculated. When the nth multipath is combined, assume that the combined signal and BER are denoted as $\mathbf{Z}_n$ and e_n, respectively. The additional combining rule is given as

$$\mathbf{Z}_{n+1} = \begin{cases} \mathbf{Z}_n + g_{n+1}^* \mathbf{D}_{n+1}, & \text{if } e_{n+1} \le e_n \\ \mathbf{Z}_n, & \text{otherwise} \end{cases} \quad (1)$$

where g_n and $\mathbf{D}_n$ denote the channel coefficient and the de-spread pilot symbols of the nth path. Assume that a set of all multipaths is denoted as P, and a set of selected multipaths is denoted as P_{opt}, which contains multipaths minimizing BER among P. Then, following equation can be determined,

$$P_{opt} = \{ n \in P \mid e_n \le e_{n-1} \} \quad (2)$$

Since the proposed method provides the local BER optimum, the proposed method always keeps the lowest BER for the time slot for time varying channel.

III. SIMULATION

Computer simulations were conducted to analyze and compare the performance of the proposed method with T-GSC. Underwater acoustic channels used in simulations were generated based on BELLHOP, and are shown in Fig. 2 and Fig. 3. The channels in Fig. 2 and 3 have three and two strong multipaths and maximum delays are about 6 msec and 3 msec, respectively. Other simulation parameters are summarized in Table 1. The thresholds of T-GSC are set at 50% and 70% of the maximum path gain.

The simulation results of the proposed method and T-GSC are shown in Fig. 4 and Fig. 5. Fig. 4 demonstrates BER performance of the proposed method and T-GSC for the channel given in Fig. 2. Fig. 5 exhibits BER performance for the channel shown in Fig. 3. A black circle and a blue square denote BERs of T-GSC with a threshold 70% and 50%, respectively, and a red triangle denotes BER results of the proposed method. In Fig. 4, the proposed method shows 14dB and 3.5dB SNR gains compared with T-GSC by a threshold 70% and 50% at 10^{-2}BER, respectively. In Fig. 5, the proposed method improves SNR gain by 12dB compared with T-GSC with a threshold 50% at 10^{-3} BER.

Based on the simulation results, the conventional T-GSC combines all paths without considering whether the multipath contains signal information or not, while the proposed method selects and combines the optimum local multipaths. Thus, the proposed method attains better time diversity gain and BER performance of the proposed method is always better than that of T-GSC.

TABLE I. SIMULATION CONDITIONS

Channel model	the number of chips		spreading factor	
	pilot	*data*	*pilot*	*data*
Rician	200	600	10	20

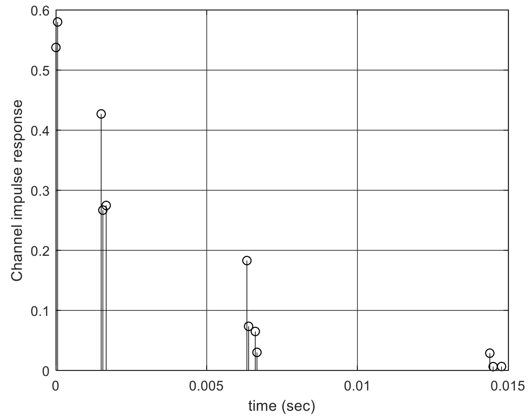

Fig. 2. Underwater acoustic channel 1

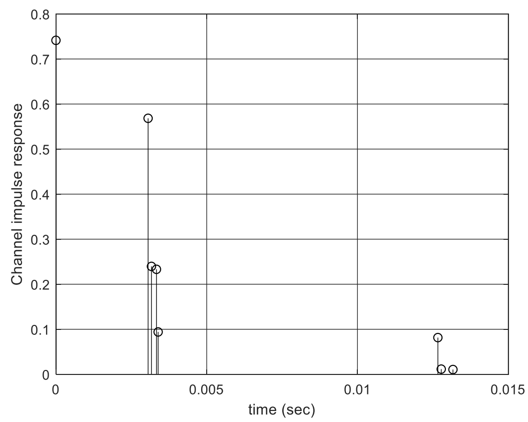

Fig. 3. Underwater acoustic channel 2

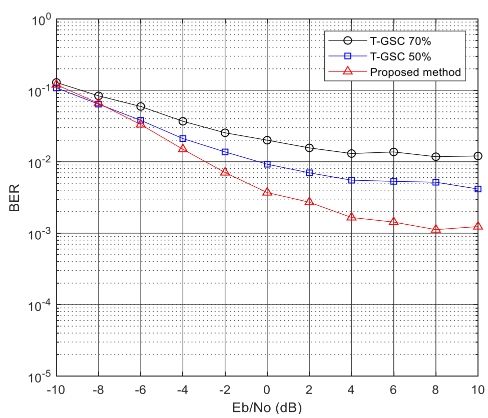

Fig. 4. Simulation result for channel 1

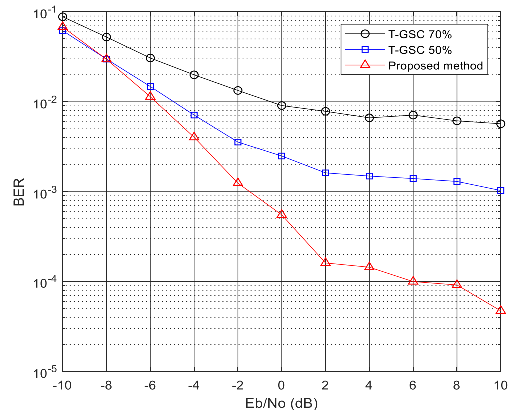

Fig. 5. Simulation result for channel 2

IV. CONCLUSION

This paper proposes a multipath selection method using BER of spread pilot. The proposed method utilizes pilots to measure the local BER performance and selected paths for combining are determined based on the BER. Computer simulation demonstrates that BER performance of the proposed method is better than that of the conventional T-GSC for the two underwater acoustic channels. The proposed method demonstrates 14dB and 5dB SNR gains compared with T-GSC with a threshold 70% on channel 1 and 2 at 10^{-2} BER, respectively.

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