3P6-2

Performance Evaluation of Orthogonal Signal Division Multiplexing Schemes with Large Delay and Doppler Spread

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1. Introduction

Underwater acoustic communication technology, which uses ultrasonic waves to send and receive data, is expected to be a means of data transmission for remote control of underwater drones and other applications[1)]. The environment for underwater communication is severe, and it is necessary to overcome the much larger delay spread and Doppler spread in the communication path than in radio wave wireless communication environments.

Delay spread in communication paths causes inter-symbol interference (ISI) and inter-block interference (ISI). Furthermore, inter-carrier interference (ICI) occurs in multi-carrier communications in which signals are assigned to multiple frequencies for transmission.

Therefore, orthogonal signal division multiplexing (OSDM) exists as an underwater acoustic communication method that is robust to delay spread and Doppler spread[2), 3)]. OSDM can measure and equalize the delay and Doppler spread of the communication channel by repeating the data on the time and frequency axes and by adding appropriate gaps between the data in the time-frequency direction.

In OSDM, guard intervals (GI) of length L are placed between signal blocks to prevent IBI, and Q null subcarriers are placed as guard bands (GB) to prevent ICI. It has been confirmed that errors caused by ISI and ICI are small in communication paths where the magnitude of delay spread, and Doppler spread are smaller than the set values. However, since GI and GB are also the cause of lower effective transmission rates, as small a value as possible is desirable. On the other hand, if the delay spread or Doppler spread over the communication channel exceeds the set value, errors due to ISI or ICI may occur.

Therefore, the purpose of this study is to clarify the communication quality of underwater acoustic communication using OSDM when the delay spread, and Doppler spread larger than the values of GI and GB occur in the communication channel by computer simulation.

2. Orthogonal Signal Division Multiplexing (OSDM)

A block diagram of an underwater acoustic communication system using OSDM is shown in **Fig. 1**. where M is the message length, P is the number of messages per group, U is the number of groups, Q is the number of GBs corresponding to the expected maximum Doppler shift, and L is the length of the GI corresponding to the expected maximum delay spread. The transmitter prepares a data matrix Xm represented by an $M \times N$ matrix.

$$\boldsymbol{X}_{\mathrm{m}} = (\boldsymbol{p}^{\mathrm{T}}, \boldsymbol{0}^{\mathrm{T}}_{2Q\times M}, \boldsymbol{x}^{\mathrm{T}}_{\mathrm{t}0,0}, \boldsymbol{x}^{\mathrm{T}}_{\mathrm{t}0,1}, \cdots, \boldsymbol{x}^{\mathrm{T}}_{\mathrm{t}0,P-1}, \boldsymbol{0}^{\mathrm{T}}_{2Q\times M}, \boldsymbol{x}^{\mathrm{T}}_{\mathrm{t}1,0}, \boldsymbol{x}^{\mathrm{T}}_{\mathrm{t}1,1}, \cdots, \boldsymbol{x}^{\mathrm{T}}_{\mathrm{t}1,P-1}, \boldsymbol{0}^{\mathrm{T}}_{2Q\times M}, \cdots, \boldsymbol{0}^{\mathrm{T}}_{2Q\times M}, \boldsymbol{x}^{\mathrm{T}}_{\mathrm{t}U-1,0}, \boldsymbol{x}^{\mathrm{T}}_{\mathrm{t}U-1,1}, \cdots, \boldsymbol{x}^{\mathrm{T}}_{\mathrm{t}U-1,P-1}, \boldsymbol{0}^{\mathrm{T}}_{2Q\times M})^{T}.$$

where $\boldsymbol{p}$ is the pilot signal and $\boldsymbol{x}_{\mathrm{tu,p}}$ is a message vector with M elements, where the elements are complex symbols digitally modulated by QPSK or other means. The transmitter reads $\boldsymbol{X}$m in the row direction and converts it into a row vector $\boldsymbol{x}_{\mathrm{m}}$ of length MN.

$$\boldsymbol{x}_{\mathrm{m}} = (\boldsymbol{p}, \boldsymbol{0}_{1\times 2QM}, \boldsymbol{x}_{\mathrm{t}0}, \boldsymbol{0}_{1\times 2QM}, \boldsymbol{x}_{\mathrm{t}0}, \boldsymbol{0}_{1\times 2QM}, \cdots, \boldsymbol{0}_{1\times 2QM}, \boldsymbol{x}_{\mathrm{t}0}, \boldsymbol{0}_{1\times 2QM}).$$

$$\boldsymbol{x}_{\mathrm{t}u} = (\boldsymbol{x}_{\mathrm{t}u,0}, \boldsymbol{x}_{\mathrm{t}u,1}, \cdots, \boldsymbol{x}_{\mathrm{t}u,P-1}).$$

The transmitter then spreads $\boldsymbol{x}_{\mathrm{m}}$ using the Kronecker product of the inverse DFT matrix $\boldsymbol{F}_N$ of size $N \times N$ and the unit matrix I_M of size $M \times M$, as follows.

$$\boldsymbol{x} = \boldsymbol{x}_{\mathrm{m}}(F_N \otimes I_M).$$

Then, for the obtained vector x, L zero vectors are added to the end of the signal as GI, and the GI-added signal is output to the communication channel.

3.Simulation Environment

In order to investigate the characteristics of the transmitted signal when the delay spread and Doppler spread of the transmitted signal exceed GI and GB in the communication channel, we compared the Output Signal-to-noise ratio (OSNR) and Bit-error rate (BER) of the received signal exceeding GI and GB and the received signal with only Additive white Gaussian noise (AWGN) in the communication channel.

3.1 Simulation of communication with delay spread and doppler spread beyond GI and GB

The communication channel model with independently adjustable maximum delay spread and maximum Doppler spread was constructed by

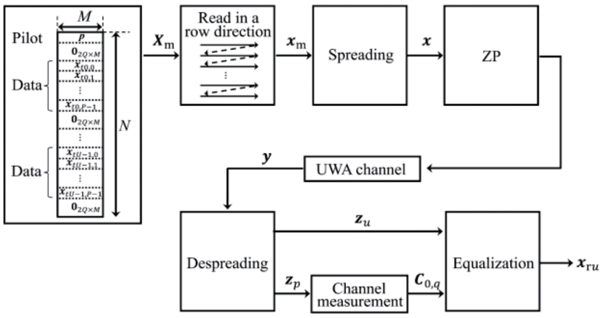

Fig. 1 Block diagram of OSDM at the transmitter and the receiver.

Table. I Parameters used for simulation.

Message Length: M	63
Maximum size of delay: L	63
Total number of message per group: P	1
Total number of groups: U	1
Maximum size of Doppler shift: Q	1
Maximum size of pilot signal and message: N	6
Modulation	QPSK

computer simulation. The Rayleigh fading model was adopted as the communication channel model, with the maximum delay spread *D*m and the maximum Doppler shift f_D of the communication channel as parameters.

The impulse response of the communication channel was assumed to follow a Rayleigh distribution for each sample and to decay exponentially from sample time 0 to *D*m down to -40 dB. The Doppler spread was assumed to have a Bell-type spectrum with a maximum frequency f_D (Hz).

The parameters used in the simulations are listed in **Table Ⅰ**. The GB is 12.70 Hz and the GI at L=63 is 13.16 ms. QPSK was used for message modulation. In this simulation, the maximum delay spread *D*m was varied between 13.33 ms and 60 ms and the maximum Doppler spread f_D between 13 Hz and 50 Hz and the OSNR and BER were measured.

3.2 Simulation of communication channel only with AWGN

we constructed channel model affected only with AWGN. The SNR of each symbol and noise was varied from -30db to 19db and the OSNR and BER were measured.

4.Results and Discussion

Fig. 2 shows that the received signal affected by the delay and Doppler spreading is spread in the positive direction of OSNR when compared to the signal with only AWGN at the same BER. Also, it is found that there is a boundary

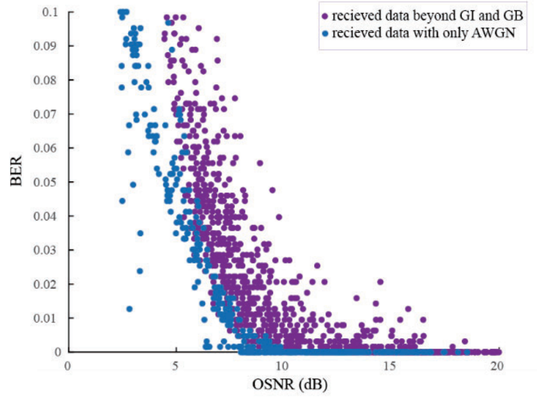

Fig. 2 Scatter plot of received data beyond GI and GB and with only AWGN.

between the received signal with AWGN and the received signal affected by the delay and Doppler spreading.

5.Conclusion

In this study, in order to study their characteristics in an underwater acoustic communication environment where delay and Doppler spread are present, we investigated the relationship between OSNR and BER for communication channels with delay and Doppler spread and with only AWGN.

The results showed that, when compared at the same BER, the received signals beyond GI and GB spread in the positive direction of OSNR, while the received signal with only AWGN spread in the negative direction of OSNR, after a certain boundary.

We expect, by mathematically determining these boundary conditions, it will be possible to separate the effects of noise in the communication channel from those of delay and Doppler spreading, which is expected to further improve communication quality.

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