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Performance Evaluation of Underwater Acoustic Communication Using Orthogonal Signal Division Multiplexing in Suruga Bay
直交信号分割多重を用いる水中音響通信の駿河湾における性能評価

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1. Introduction

Underwater acoustic (UWA) communication is one of the technologies to establish a wireless link over distances in excess of a 100 m in an underwater environment. UWA communication has many potential applications (*e.g.* cooperative underwater exploration) by networking multiple devices. However, UWA communication is still challenging since the UWA channel is characterized by large delay and Doppler spreads. Specifically, an acoustic signal emitted from the transmitter (Tx) propagates toward the receiver (Rx) with numerous reflections along the ocean surface, resulting in a delay spread of several tens of milliseconds. Moreover, a movement of the ocean surface and communication platform make a frequency shift in time, resulting in Doppler spread of several tens of Hz.

To achieve reliable UWA communication, the authors have proposed Doppler-resilient orthogonal signal division multiplexing (D-OSDM) [1]. D-OSDM spreads data symbols in the time domain and frequency domain with guardbands to fully exploit the time and frequency diversity of UWA channels. Simulations and small-scale experimental results in a harbor show that a UWA communication link using D-OSDM will deliver excellent reliability even for channels with large delay and Doppler spreads.

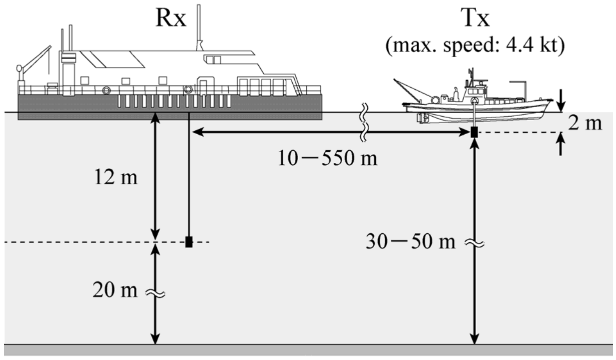
In this paper, we report sea trial results of a UWA communication using D-OSDM. This trial was performed to check the performance of UWA link using D-OSDM in a practical mobile communication environment, where the effect of delay and Doppler spreads are dominant. Section 2 shows the experimental environment. Section3 shows experimental results with some discussions. Section 4 concludes this study.

2. Experimental Environment

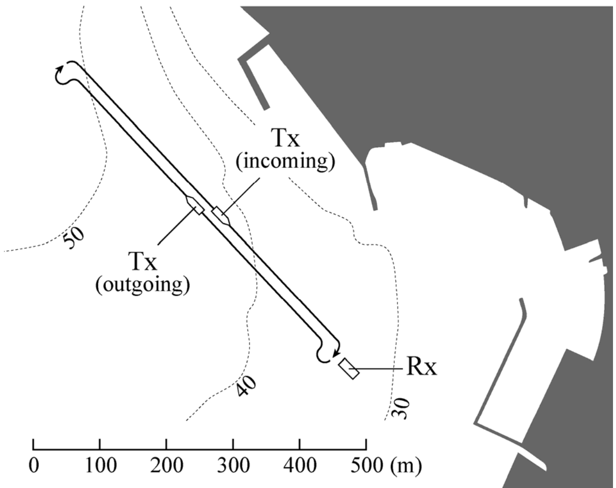
The sea trial was carried out in Suruga Bay (Shizuoka, Japan) on June 22, 2018. **Table I** shows the parameters used for UWA communication. These parameters are designed to cope with maximum delay spread of 26 ms and maximum Doppler shift of 6.8 Hz. Since the combination of signal modulation and channel coding can enhance the communication performance efficiently, we used Turbo bode (code rate of 1/3) as channel coding.

Table I. Parameters used in the experiment

Parameters	Value
Carrier frequency (kHz)	32
Signal bandwidth (kHz)	4.8
Primary modulation	16QAM
Secondly modulation	D-OSDM [1] $\begin{pmatrix} M=127, L=127 \\ P=2, Q=2, U=1 \end{pmatrix}$
Effective data rate (kbps)	3.2 (w/o Turbo code) 1.0 (w/ Turbo code)



(a)



(b)

Fig. 1 Experimental environment (a) side view and (b) top view.

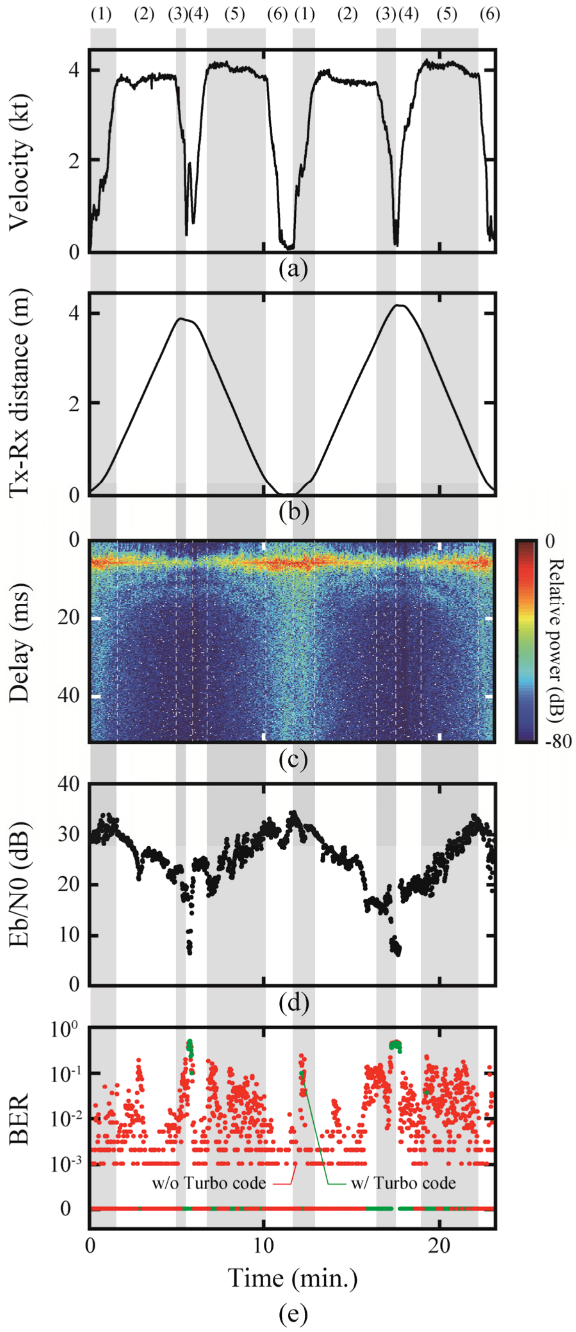


Fig. 2 Experimental results; (a) velocity of Tx, (b) Tx-Rx distance, (c) delay spread of UWA channel, (d) Eb/N0, and (d) BER.

Figure 1 shows the experimental environment. We developed the Tx and Rx by connecting software-defined modem, signal amplifier, and underwater acoustic transducer (OST-2120, OKI SEATEC). The Tx was mounted on a research vessel and the depth of the transducer was set as 2 m below the sea surface. The Rx was mounted on a moored barge and the depth of the transducer was set as 12 m below the sea surface. During the communication test, the research vessel departs the barge towards the outside of the bay and turns back to the barge at Tx-Rx distance of 500 m.

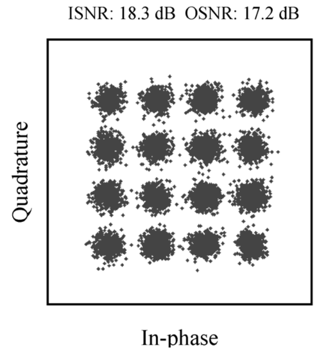


Fig. 3 Received signal (Tx-Rx distance: 500m).

3. Results and Discussions

Figures 2 and 3 show the experimental results. As shown in **Figs. 2(a) and 2(b)**, the Tx (1) departs the Rx with acceleration, (2) keeps the velocity around 4kt for 180 seconds, (3) stops when Tx-Rx distance is about 550m, (4) turns back to the barge with acceleration, (5) keeps the velocity around 4kt for 180 seconds, and (6) stops at the Rx.

Fig. 2(c) shows the delay spread of the UWA channel. As shown in the figure, the delay spread when the Tx locates around the barge becomes 40 ms. However, as the Tx-Rx distance increases, the dominant delay spread becomes within 15 ms. **Fig. 2(d)** shows the energy per bit to the spectral noise density (Eb/N0) of the D-OSDM signal. As shown in the figure, the Eb/N0 value takes 5-32 (dB) and it mainly depends on the Tx-Rx distance.

Figures 2(e) and 3 show the communication performance of D-OSDM. In this experiment, 681/1692 (40%) and 1641/1692 (96%) signal blocks achieved BER of less than 10^{-3} with and without Turbo code, respectively. The obtained results suggest that D-OSDM has high stability in terms of communication even in a real mobile UWA channel.

4. Conclusions

We performed UWA communication using D-OSDM in Suruga Bay and evaluated its performance. From experiments, we found that the D-OSDM achieves excellent communication quality in time-invariant UWA channel. More detailed analysis of the experimental results is one of our future tasks.

Acknowledgement

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References

1. T. Ebihara and G. Leus: IEEE J. Ocean. Eng. **41** (2015) 408.