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Experimental Study on Doppler Shift Compensation for Underwater Acoustic Communication Using Orthogonal Signal Division Multiplexing

ドップラーシフト環境における直交信号分割多重を用いる水中音響通信の実証実験

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1. Introduction

Limited bandwidth, multipath-induced signal fading, and motion-induced Doppler effect makes underwater acoustic (UWA) communication still an ongoing challenge. Among numerous interesting researches on UWA communication, the application of orthogonal signal division multiplexing (OSDM) has been proposed by authors. In our previous work, it was found that the UWA communication with OSDM achieves high-quality data transmission in heavy multipath channels compared to the exiting UWA communication with DFE. However, it was also found that the UWA communication with OSDM is more sensitive to the Doppler shift compared to the existing UWA communication [1)].

To achieve communication under Doppler shift environment, Doppler shift compensation, proposed by Sandell, was considered and evaluated in simulation [2)]. The obtained results suggest that OSDM can achieve communication under Doppler shift environment by applying the compensation [3)]. In this paper, we experimentally evaluated the UWA communication with OSDM applying Doppler shift compensation to confirm the simulation results.

2. Overview of UWA Communication with Orthogonal Signal Division Multiplexing

Figure 1 shows the signal processing flow of UWA communication with OSDM. The transmitter multiplexes a pilot signal, $\boldsymbol{a}$, and messages, $\boldsymbol{m}_1,\ldots,\boldsymbol{m}_{N\text{-}1}$ into a sequence, $\boldsymbol{p}_\mathrm{s}$ using N-by-N IDFT matrix. After prepending guard interval (GI), modulated signal, $p_\mathrm{p}(t)$ is transmitted into the UWA channel. The receiver demodulates the receiving signal, $q_\mathrm{p}(t)$, and de-multiplexes sampled sequences, $\boldsymbol{q}_\mathrm{b}$ using N matched filters (MFs). Because OSDM can separate the channel-affected pilot signal, $\boldsymbol{q}_0$, from $\boldsymbol{q}_\mathrm{b}$ without any interferences, the receiver can obtain a channel profile by calculating cross-correlation between $\boldsymbol{a}$ and $\boldsymbol{q}_0$. By using the obtained profile, $\boldsymbol{h}$, the receiver applies inverse filters (IFs) on de-multiplexed sequences, $\boldsymbol{q}_1,\ldots,\boldsymbol{q}_{N\text{-}1}$, and successfully obtains the receiving message.

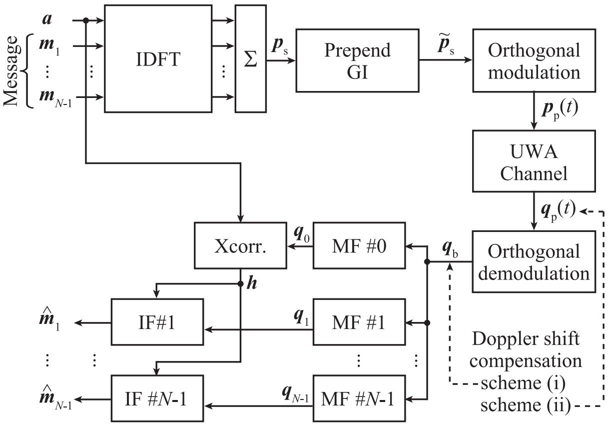

Fig. 1 Signal processing flow of UWA communication with OSDM.

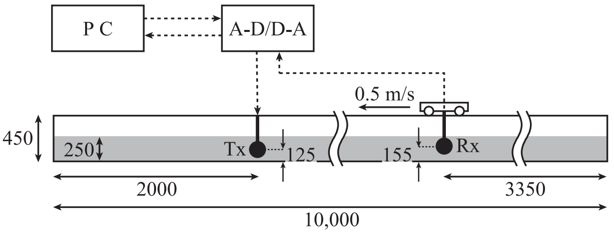

Fig. 2 Trial environment in experimental channel.

However, under Doppler shift environment, there are interferences among $\boldsymbol{q}_0$, $\boldsymbol{q}_1,\ldots,\boldsymbol{q}_{N\text{-}1}$. To detect and correct the Doppler effect, correlation-based method proposed by Sandell is applied as scheme (i) and (ii) on the receiver. In scheme (i), the receiver calculates $\lambda(\theta)$, which is a correlation function between the last part of the frame and GI, and Doppler effect on $\boldsymbol{q}_\mathrm{b}$ is measured as phase angle of the peak of $\lambda(\theta)$. In scheme (ii), scheme (i) is applied on receiving signal, $q_\mathrm{p}(t)$, and Doppler effect on $q_\mathrm{p}(t)$ is measured by calculating two-dimensional correlation function between the last part of the frame and GI. Combination of scheme (i) and (ii) enables to correct large Doppler shifts. More details about these techniques are described in Ref. 3.

3. Experiments and Results

We implemented signal processor for UWA communication with OSDM on software (Lab-

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VIEW 2009; National Instruments) and performed data transmission using an experimental channel, whose volume is 450×10,000×200 (mm^3). **Figure 2** shows the trial environment. Two hydrophones (H1a; Aquarian), work as acoustic transmitter (Tx) and receiver (Rx) are connected to the A-D/D-A converter (U2531A; Agilent). Tx is fixed in the experimental channel of length 10 m, and Rx is suspended on the moving platform, which moves toward the Tx at a constant speed of 0.5 m/s. In this environment, we tested two cases by using parameters as shown in **Table 1**. In this testing environment, the averaged link SNR is 36 dB.

Through the experiment, Doppler shift compensation is successfully achieved by two schemes. **Figure 3** and **4** show the signals used in scheme (i) and constellation points obtained in the experiment, respectively. In scheme (i), the Doppler shift can be estimated as phase angle of the peak of λ (θ). As a result, the constellation points in Fig. 4 converge to the QPSK constellation diagram, and achieve BER of 0.018 and 0.067 in Case #1 and #2, respectively. If Doppler compensation schemes are not applied, the BER become 0.229 and 0.419 in each case. However, different from the simulation results, the convergence of constellation points, especially shown in Fig. 4(b), is not enough to achieve high-quality communication. One of the reasons is considered due to the existence of Doppler spread. The difference in real environment and an assumption for applied scheme, which deals the Doppler shift as uniform for all paths, is considered to make the difference between simulation and experimental results.

4. Conclusions

In this paper, we evaluated the Doppler shift compensation for UWA communication with OSDM. The obtained results suggest that we can confirm that the Doppler shift compensation schemes work well and OSDM can be conducted as one of the UWA communication tools. Considering the effect on Doppler spread is one of our future works.

Acknowledgment

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References

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Table 1 Parameters for trial test.

	Case #1	Case #2
Multiplicity, N	2	4
Message length, M (symbols)	127	
Guard interval, L (symbols)	50	
Data modulation	QPSK	
Carrier frequency, f_c (kHz)	20	
Signal bandwidth (kHz)	4	
Effective data transfer rate (kbps)	3.3	5.4

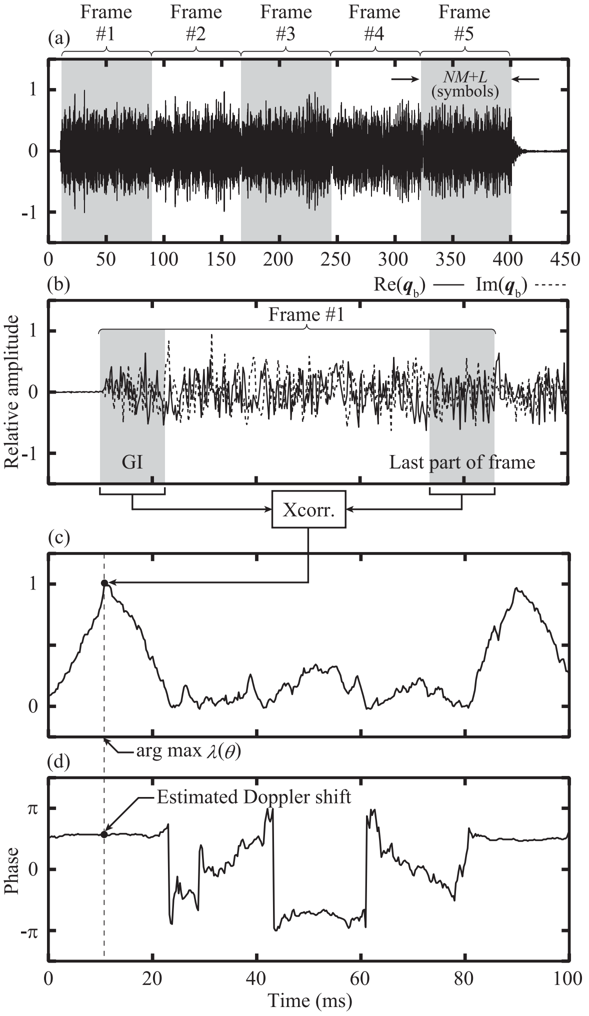

Fig. 3 Signals used in Case #1; (a) Receiving signal, $q_p(t)$, (b) Demodulated and sampled sequence, $\boldsymbol{q}_b$, (c) Correlation function between the last part of the frame and GI, λ (θ), and (d) Phase angle of λ, γ (θ).

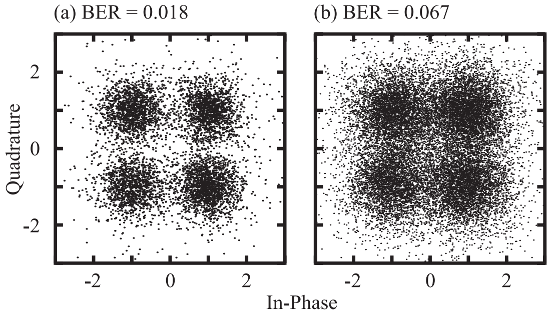

Fig. 4 Constellation points obtained from experiment; (a) Case #1 and (b) Case #2.