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Dependence of Demodulation Performance on Symbol Rate for Underwater Acoustic Communication with Nonuniform Doppler Shift

非定常ドップラーシフトを伴った水中音響通信における復調性能のシンボルレート依存性の研究

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1. Introduction

Recently, demand to survey a sea bed with an autonomous underwater vehicle (AUV) and a small surface vehicle has increased. In this survey system, it has been reported that the nonuniform Doppler shift can degrade a demodulation performance of underwater acoustic (UWA) communication via a multipath signal.[1)] Meanwhile, demand to operate multiple AUVs also has grown, and multiuser UWA communication has been studied intensively.[2)]

The simplest way to establish multiuser UWA communication is frequency division multiple access (FDMA). In the FDMA scheme, each user can utilize only the assigned part of a total bandwidth. Although a symbol rate for each user becomes low due to the narrow usable band width, the FDMA scheme yields reliable communication without interference between signals of users.

However, the nonuniform Doppler shift can affect a demodulation performance at a low symbol rate more severely than that at a higher symbol rate, because channel responses are estimated and compensated at the symbol rate. In this study, dependence of a demodulation performance in UWA communication on a symbol rate with the nonuniform Doppler shift is investigated by simulation.

2. Decision feedback equalizer

In communication with single-carrier modulation signals, a decision feedback equalizer (DFE) is utilized on demodulation.[1-3)] **Fig. 1** shows a block diagram of the DFE. It consists of a feedforward filter, a feedback filter and a digital phase lock loop (DPLL). The feedforward filter and the DPLL compensate for a channel response of the direct signal, and the feedback filter compensates for responses of multipath signals. The DFE can track temporal changes of channel responses, because taps of both filters and a compensation phase of the DPLL are updated adaptively.[1, 3)] The

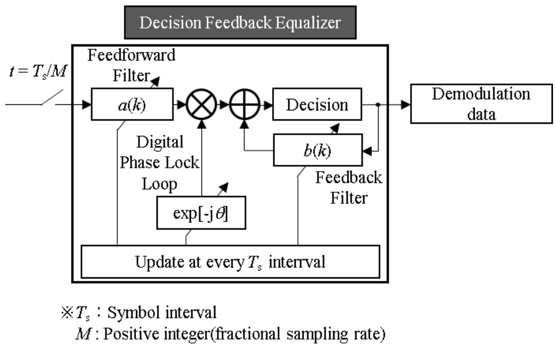

Fig. 1 Typical block diagram of DFE.

tracking performance of the DFE depends on the symbol rate, because the updating rate of the filters and the DPLL equals the symbol rate.

3. Simulation description

In this study, simulations of UWA communication between a moored source and a receiver of a surface vehicle with a roll motion were carried out. The source was fixed at a depth of 3000m, and the roll motion of the vehicle was assumed as a simple harmonic motion (SHM) with a roll angle $\theta_r = \theta_{max} \sin(2\pi f_r t + \phi)$, where θ_{max}, f_r and ϕ denote the maximum of the angle, a roll frequency and an initial phase of the SHM. The simulation condition is depicted in **Fig.2**.

To focus on the nonuniform Doppler shift of the direct signal, no multipath signal was assumed in this study. In propagation simulation, a propagation time of the direct signal at each discrete time was calculated according to the ray theory. Received signals were derived by the propagation time. This method of propagation simulation has an advantage of setting conditions of signals through various paths in a time-varying environment individually with a lot of flexibility.[1)]

A configuration of a transmitted signal is depicted in **Fig. 3**. Simulations in cases of various symbol rates were carried out. In addition, durations of transmitted signals were set as 1 s commonly in this study so that the common nonuniform Doppler

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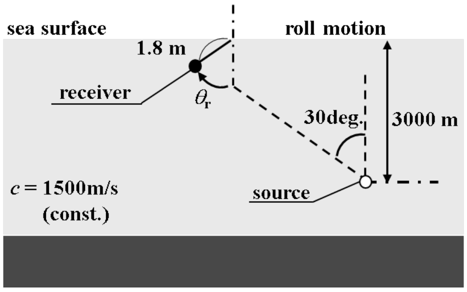

Fig. 2 Simulation condition.

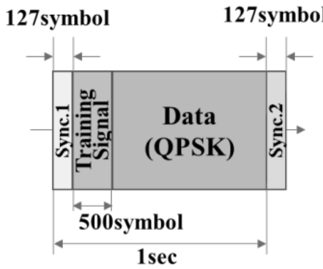

Fig. 3 Signal configuration.

shift affected received signals in all simulations.

An input sampling interval of the DFE was set to $T_s/4$, which means M = 4 in **Fig. 1**. The taps and the compensation phase were updated by the least mean square (LMS) algorithm. In addition, an output signal-to-noise ratio (SNR) was utilized to evaluate demodulation performances.[1-3] The simulation parameters are listed in **Table 1**.

4. Results and discussion

Fig.4 shows output SNRs and the most frequent value at each symbol rate. In **Fig. 4**, output SNRs at each symbol rate are distributed widely, because the nonuniform Doppler shift within the received duration is determined by not only the roll frequency f_r but also the initial phase of the SHM ϕ. Therefore, the most frequent value was utilized to evaluate the demodulation performance at each symbol rate without the dependence on ϕ.[1)] In **Fig. 4**, the most frequent value at the symbol rate of 1kHz is less than the others clearly, which indicates that the demodulation performances depend on the symbol rates.

Constellations and residual phase errors after the DFE are depicted in **Fig. 5**. The results at the symbol rate of 1 kHz indicates clearly that the DFE cannot suppress the effect of phase shift caused by the nonuniform Doppler shift. On the other hand, the results at the symbol rate of 3 kHz indicate that the effect of the phase shift are suppressed sufficiently by the DFE. The results show dependence of the demodulation performance on the symbol rate via the tracking performance of the DFE.

5. Summary

In this study, dependence of a demodulation performance on a symbol rate was investigated by simulation. Consequently, it is found that a performance of the DFE to track a temporal change of a phase shift depends on a symbol rate and a low symbol rate can degrade a demodulation performance. It means that the nonuniform Doppler shift can affect a demodulation performance more severely when a band width for each user becomes narrower in case of FDMA communication.

Acknowledgment

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References

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Table 1 simulation parameters

parameters	description	value
c	Sound speed	1500 m/s
F_s	Sampling rate	400 kHz
θ_{max}	Maximum of θ_r	30 °
f_r	Roll frequency	0.3 Hz
ϕ	Initial phase of SHM	0° to 355° at every 5 °
R_{sym}	Symbol rate	1 kHz to 10kHz
F_c	Center frequency	20 kHz

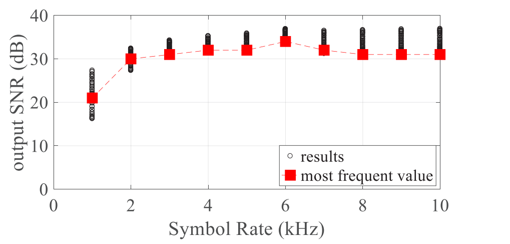

Fig. 4 output SNR for every symbol rate and the most frequent values.

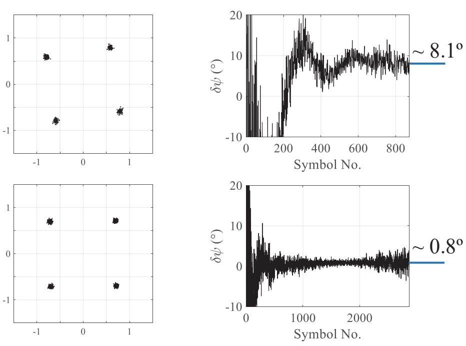

Fig. 5 (left panels) constellations and (right panels) residual phase errors after the DFEs in case of ϕ = 0° and symbol rates of (upper panels) 1kHz and (lower panels) 3kHz.