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Analysis of effects of multipath signal with nonuniform Doppler shift on vertical underwater acoustic communication

非定常ドップラーシフトを伴ったマルチパス信号の水中音響通信に対する影響解析

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1. Introduction

Recently, orthogonal freuquency domain multiplexing (OFDM) communication has been pursued for underwater acoustic (UWA) communication. In OFDM communication, each data symbol is assigned to the corresponding frequency component which is called a subcarrier. Whil the OFDM communication has an advantage of a low calculation cost, it also has a disadvantage of sensitivity to the Doppler shift in principle. Particularly, it is difficult to suppress effects of the Doppler shifts of multipath signals, because they differs from the Doppler shift of the direct signal generally. While many techniques was proposed to deal with the Doppler shift of only the direct signal, few papers proposed techniques against that of the multipath.[1)] Furthermore, they are thought to be unable to work validly on a condition of the nonuniform Doppler shift of the multipath.[2)]

In this study, it was investigated on simulation that a multipath signal with the Doppler shift has an effect on OFDM demodulation in vertical UWA communication. The Doppler shift of the multipath was set to be nonuniform and different from that of a direct signal.

2. Doppler Shift and Inter Carrier Interference

In OFDM communication, a received signal of the *k*th subcarrier Y_k is represented in the frequency domain as

$$Y_k = \sum_m H_{k.m} X_m, \qquad (1)$$

where $H_{k,m}$ denotes the (*k*,*m*) element of a channel response matrix, and a transmitted signal of the *m*th subcarrier is written as X_m. Without the Doppler shift, the matrix has only diagonal components, namely $H_{k,m} = H_{k,k}\delta_{k,m}$ where $\delta_{k,m}$ is the kronecker delta. On the other hand, the Doppler shift results in the non-diagonal components of the matrix.

At OFDM demodulation, a frequency domain equalizer (FDE) is utilized to compensate for the diagonal components generally. However, it cannot compensate for the non-diagonal components and may compensate for the diagonal components incorrectly according to wrong responses affected by the non-diagonal components. Removal of the effects of the Doppler shift demands an accurate structure of the matrix.[3)] However, if the Doppler shift vary temporally, that is the nonuniform Doppler shift, the structure of the matrix is too complex to be even estimated. The effects of the non-diagonal components of the channel matrix on demodulation is called inter carrier interference (ICI), and it can degrade the demodulation performance seriously.

3. Simulation Description

In this study, two simulations of UWA communication between a moored source and a surface vehicle with a pitch motion were carried out: the simulations with a multipath signal and without it. To focus on effects of the Doppler shift, both simulations include no attenuation mechanisms. Furthermore, media are assumed to be uniform and time invariant.

In the time domain, the received signals $y(t)$ is written as

$$y(t) = \sum_m a_m x(\tau_m) + v(t), \qquad (2)$$

$$\tau_m(t) = t - l_m(t)/c, \qquad (3)$$

where x , c, and v denote a transmitted signal, a sound speed, and a noise component, respectively. Furthermore, a_m, τ_m, and l_m mean the channel response, the transmitted time, and the path length of the *m*th multipath. The direct path is defined as the 0th multipath.

On the simulations, only the signal which reflected on the sea surface was assumed to come to the receiver as a multipath signal. Moreover, a noise component $v(t)$ was set to 0. To calculate a received signal, a digitalized form of the transmitted signal x_d was calculated at a sampling rate F_s. In addition, the path lengths at a sampled time $l_m(n/F_s)$ was calculated according to the positions of the source and the receiver. Following it, $x(n/F_s - l_m(n/F_s)/c)$ was derived by the interpolation of x_d, and then a digitalized form of the received signal $y_d(n) = y(n/F_s)$ was derived

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by Eqs. (2) and (3).

The pitch motion of the surface vehicle is assumed as a simple harmonic motion on *x*-*z* plane with a pitch angle $\theta_p = \theta_{max} \sin(2\pi f_p t)$, where θ_{max} and f_p were set to 20 degrees and 0.3Hz, respectively. **Fig. 1** shows the conditions of the simulations.

A configuration of the transmitted signal is depicted in **Fig. 2**. Known data symbols, which are called pilot signals, were assigned at every three subcarriers. They were utilized to estimate channel responses of other subcarriers which the FDE demanded. **Table 1** describes the parameters of the simulations.

At demodulation, for the evaluation of the simulations, off line filtering was utilized to estimate a received time of each down sampled point of the direct signal. First, the received signal converted to the down sampled signal tentatively. Following it, a phase shift of the direct signal at each down sampled time was estimated with the filter according to an error from a down sampled point of the transmitted signals x_d. Finally, the phase shift yielded an estimated down sampled time and a modified down sampled signal with resampling processing. The obtained down sampled signal was demodulated with FFT operation and a zero-forcing equalizer.

4. Simulation Results and Discussion

Fig. 3 shows constellations of both simulations. It indicates that adjustment of each down sampled time suppresses the effect of the nonuniform Doppler shift of the direct signal sufficiently, when there were no multipath signals. On the other hand, it is found that it cannot suppress the effect of the non-uniform Doppler shift of the multipath, when there was a multipath signal from the sea surface.

Since the direction of the multipath differs from the direction of the direct signal in this geometry, the multipath has the different Doppler shift from that of the direct signal certainly. The adjustment of each down sampled time suppresses the nonuniform Doppler shift of only the direct signal, hence the down sampled signal is still affected by that of the multipath. Because the equalizer utilizes the estimated channel response affected by ICIs which the Doppler shift of the multipath signal causes, it cannot work effectively. As a result, it degrades OFDM demodulation.

4. Summary

In this study, it was investigated on simulation that the nonuniform Doppler shift of a multipath signal has an effect on OFDM demodulation. Consequently, it is found that the nonuniform Doppler shift of the multipath signals degrades OFDM demodulation, even if the nonuniform Doppler shift of the direct signal can be suppressed sufficiently.

References

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Table 1 Parameters of simulations

parameters	description	value
c	the sound speed	1500 m/s
F_s	The sampling rate	400 kHz
a_0	the channel response of the direct signal	1
a_1	the channel response of the multipath signal	0.3 or 0
N	the number of subcarriers	2048
F_{BW}	the band width	8 kHz
F_c	the central frequency	20 kHz

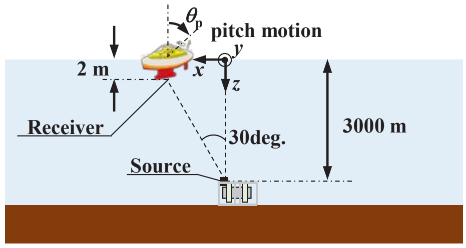

Fig. 1 Simulation conditions.

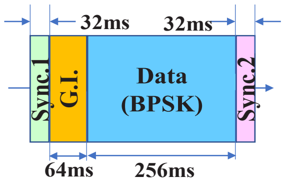

Fig. 2 Configuration of a used signal.

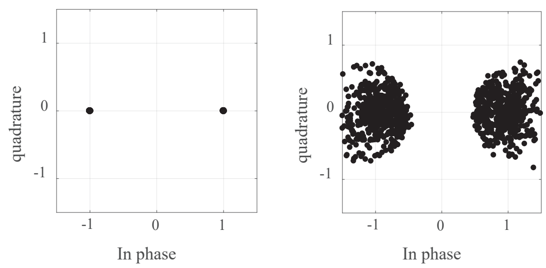

Fig.3 Constellations as simulation results. A left panel shows a result in case of not including a multipath signal, and a right panel shows a result in case of including a multipath signal.