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Analysis of the relationship between frequency offset and Doppler effect of phase modulation method for wireless communication of underwater vehicles

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1. Introduction

An underwater acoustic channel is a rapid time-varying multipath fading channel.[1)] In underwater multipath channel, the acoustic communication performance of an underwater vehicle is affected by fading by path change and Doppler shift by movement. In these channels, sampling frequency offset (SFO) occurs due to a sampling mismatch between the synchronization signal and the received signal. In addition, carrier frequency offset (CFO) occurs due to multipath and delay spread.

In this paper, we analyzed the characteristics of the frequency offset caused by the movement of an underwater vehicle in underwater acoustic communication using Quadrature Phase Shift Keying (QPSK).

2. Frequency offset and Doppler effect in underwater communication of phase modulation

As shown in **Fig 1**, The transmission signal is received through a multipath with boundary reflection. The movement of these underwater vehicles affects the delay time of the received signal. Also, it causes delay spread, symbol interference, and time-varying homogeneity of the channel band.[2-3)]

Underwater multipath channel and time-varying channel can be expressed as,

$$h(\mathrm{t},\tau) = \sum_{n=0}^{N-1} s_n(t,\tau)\delta(\tau-\tau_n(t)) \tag{1}$$

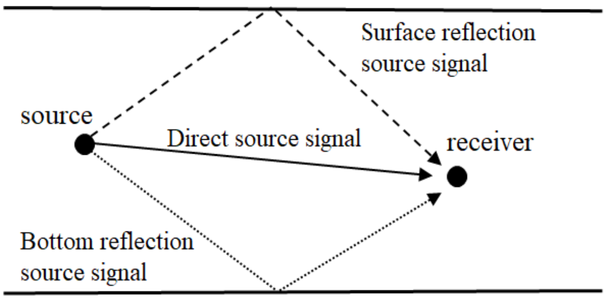

Fig. 1 The underwater multipath channel.

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where, $s(\mathrm{t},\tau)$ and $\delta_N(\tau)$ represent the attenuation coefficient and the path delay of the nth delay, respectively.

Relationship between Doppler effect and frequency offset cause frequency shift in phase modulation. In this relationship, as shown in **Fig. 2** and **Fig. 3**, the sampling frequency offset caused by the sampling pointer fluctuation due to the Doppler shift and the carrier frequency offset generated by the delay spread of the multipath affect the demodulation of the underwater QPSK modulation method.[4-6)]

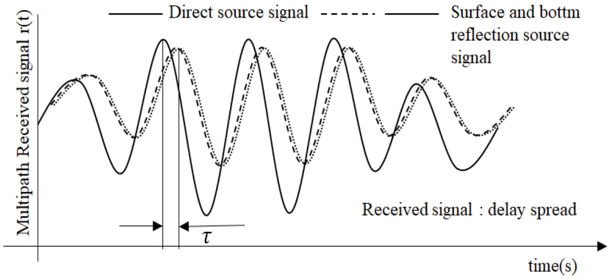

Fig. 2 Received signal characteristics according to multipath delay spread.

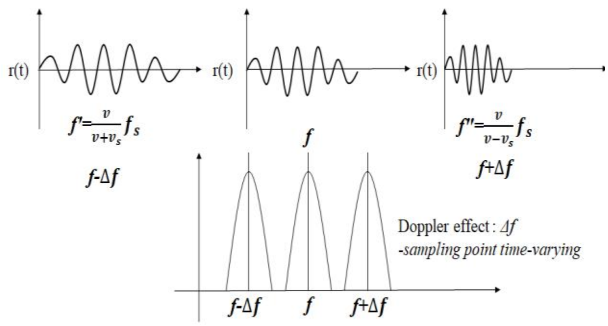

Fig. 3 Doppler effect due to movement of an underwater vehicle.

The relation between Doppler and frequency offset can be expressed as,

$$H_{Dopp.Foff} = \delta\Delta f \tag{2}$$

The received signal of underwater multipath channel can be expressed as,

$$R_n = \sum_{n=0}^{N-1} S_n H_n \cdot e^{-j2\pi(\delta\Delta f)} + \sum_{n=0}^{N-1} S_p H_P \cdot e^{-j2\pi\ (\tau-\tau_n-\delta\Delta f)} \quad (3)$$

where, $S_n H_n$ is frequency Doppler shift of the nth path, and $S_p H_p$ is delay spread of the multipath.

3. Experimental Results

The experimental parameters and configuration are shown in **Table I** and **Fig. 4**, respectively. The source and the receiver are located at depth of 5m and distance 20m, respectively.

Table I. The experimental parameters.

Modulation	QPSK
Carrier frequency	18 kHz
Bit rate	100 sps
Transmission bit	20000 bit
Distance	10 m
Transmitter / receiver depth	2 m, 2 m

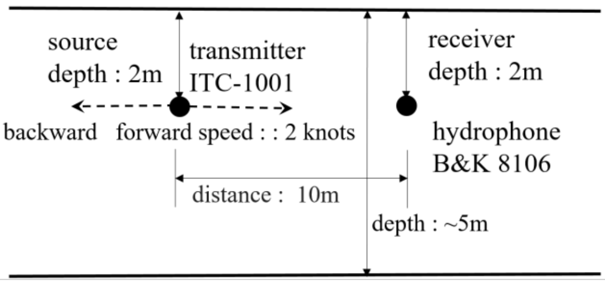

Fig. 4 The experimental configuration.

Figure 5 shows the change of the pointer according to the movement of the underwater vehicle, and has a stable pointer in a relatively stationary state

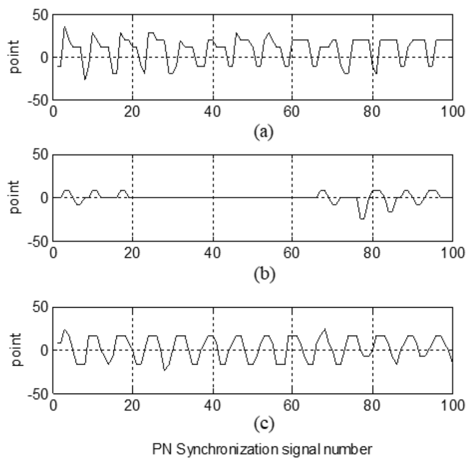

Fig. 5 Change of pointer according to movement of underwater vehicle, (a) forward, (b) stationary, (c) backward.

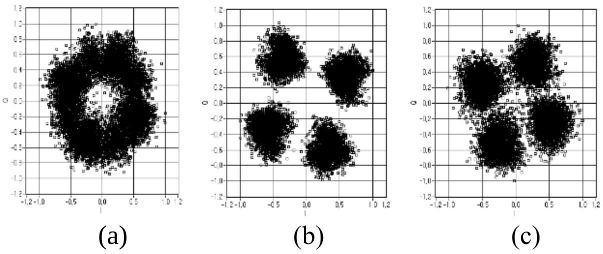

Fig. 6 Change of pointer according to movement of underwater vehicle, (a) forward, (b) stationary, (c) backward.

Figure 6 shows the QPSK constellation showing that the frequency offset is high when approaching an underwater vehicle. In the stationary and backward, the outline of the constellation was clearly shown. It was analyzed that the frequency offset increased due to the influence of Doppler shift relative to the approach and the mismatch of the sync pointer.

4. Conclusions

In this paper, we analyzed the characteristics of the frequency offset caused by the movement of an underwater vehicle in underwater acoustic communication using Quadrature Phase Shift Keying (QPSK). The performance according to the mismatch of the Doppler shift and the synchronization signal according to the movement of the underwater vehicle was analyzed through the constellation diagram. Relatively many errors and frequency offsets occurred when approaching an underwater vehicle. It was analyzed that the pointer change of the synchronization signal according to the Doppler shift affects the phase extraction by the phase modulation method, causing the performance degradation of the underwater communication.

Acknowledgment

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Education)
NO. NRF- 2019R1I1A1A01063575).

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