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

直交信号分割多重を用いる水中音響通信における ドップラーシフト補償

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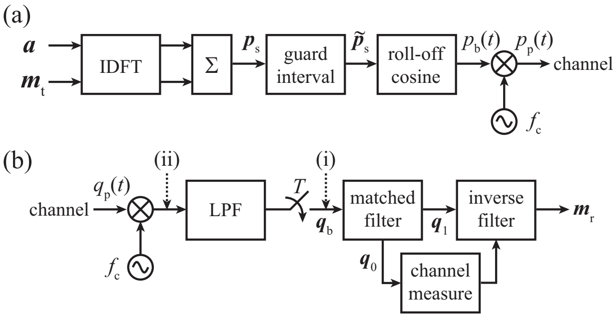
1. Introduction

Underwater acoustic (UWA) communication in shallow water is an ongoing challenge due to multipath-induced signal fading and motion-induced Doppler shift [1)]. To achieve a UWA communication in shallow water, the application of orthogonal signal division multiplexing (OSDM) has been proposed by authors [2)]. UWA communication with OSDM scheme has been confirmed to be robust to heavy inter-symbol interference compared to existing UWA communication with decision feedback equalizer [3)]. However, it has also clarified that OSDM is more sensitive to the Doppler shift compared with the existing communication system, and there is the necessity of applying Doppler shift compensation.

In this paper, we apply Doppler shift compensations for UWA communication with OSDM and evaluate its performance. As Doppler shift compensation, we focus on a synchronization scheme which has been proposed for orthogonal frequency division multplexing (OFDM) by Sandell [4)]. The performance of compensation techniques are evaluated in simulation.

2. UWA Communication with OSDM Scheme and Doppler Shift Compensation

Figure 1(a) and **(b)** show a modulator and demodulator with OSDM scheme, respectively. The modulator calculates sequence, $\boldsymbol{p}_{\mathrm{s}}$, by multiplexing two sequences of length M; pilot sequence for channel measurement, $\boldsymbol{a}$, and transmission message, $\boldsymbol{m}_{\mathrm{t}}$. Then, a guard interval, which is the last part of $\boldsymbol{p}_{\mathrm{s}}$ of length L, is placed at the beginning of $\boldsymbol{p}_{\mathrm{s}}$ (**Fig. 2**). The orthogonality between $\boldsymbol{a}$ and $\boldsymbol{m}_{\mathrm{t}}$ is maintained completely even a modulated signal, $p_{\mathrm{p}}(t)$, passes through a multipath channel. The receiver de-multiplexes the receiving signal, $q_{\mathrm{p}}(t)$ by adopting a matched filter, measures a channel response using pilot sequence, and calculates a receiving message, $\boldsymbol{m}_{\mathrm{r}}$, by adopting an channel inverse filter to the de-multiplexed sequence, q_1.



(a) modulation, and (b) demodulation scheme.

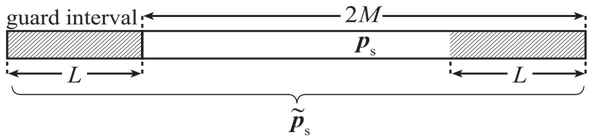


Fig. 2 Structure of OSDM-modulated sequence, $\tilde{\boldsymbol{p}}_{\mathrm{s}}$.

However, OSDM is sensitive to a motion-induced Doppler shift, because it causes interference between $\boldsymbol{a}$ and $\boldsymbol{m}_{\mathrm{t}}$ [3)]. To overcome this problem, we apply Doppler shift compensation schemes which measured Doppler shift by exploiting the guard interval; (i) scheme based on sampled sequence[4)] and (ii) scheme based on receiving signal, as shown in **Fig. 3** and **Fig. 4**, respectively. In scheme (i), the Doppler shift, $f_{\mathrm{d}}^{\mathrm{i}}$, is measured as

$$f_{\mathrm{d}}^{\mathrm{i}} = \frac{-1}{2\pi \cdot 2MT}\gamma(\theta), \quad \theta = \arg\max \lambda(\theta), \quad (1)$$

where

$$\gamma(\theta) = \angle\left(\sum_{k=\theta}^{\theta+L-1} q_b(k) q_b^*(k+2M)\right), \quad (2)$$

$$\lambda(\theta) = 2\left|\sum_{k=\theta}^{\theta+L-1} q_{\mathrm{b}}(k) q_{\mathrm{b}}^*(k+2M)\right| - \rho \sum_{k=\theta}^{\theta+L-1}\left(\left|q_{\mathrm{b}}(k)\right|^2 + \left|q_{\mathrm{b}}(k+2M)\right|^2\right), \quad (3)$$

and ρ is the energy ratio between transmitting and receiving sequences.

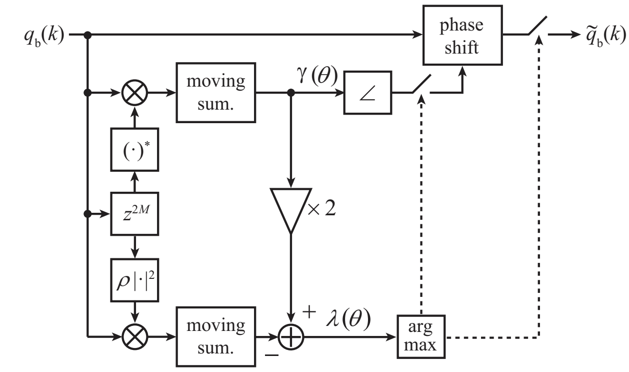


Fig. 3 Doppler shift compensation scheme (i), based on sampled sequence, $\boldsymbol{q}_b$. (in Ref. 4)

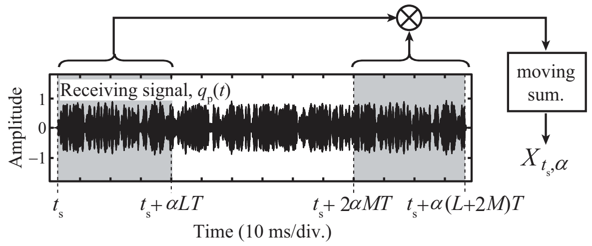


Fig. 4 Doppler shift compensation scheme (ii), based on receiving signal, $q_p(t)$.

In scheme (ii), the Doppler shift, f_d^{ii}, is measured as

$$f_d^{ii} = \frac{1-\alpha}{\alpha} f_c, \quad \alpha = \arg\max X_{\alpha,t_s}, \tag{4}$$

where

$$X_{\alpha,t_s} = \int_{t_s}^{t_s+\alpha LT} q_p(t) q_p(t + 2\alpha MT) dt, \tag{5}$$

$$\alpha = f_c / \left(f_c + f_d^{'}\right). \tag{6}$$

The measured Doppler shifts, f_d^{i} and f_d^{ii}, correct the receiving signal by phase shifting and resampling, respectively. Note that the scheme (ii) works as coarse Doppler shift estimator and (i) works as fine estimator, and scheme (i) cannot work in heavy Doppler shift because it depends on sampled sequence.

3. Performance Evaluation and Discussion

We evaluated the performance of Doppler shift compensations in simulation. The evaluation is performed by calculating the Doppler effect on $q_p(t)$, and demodulate the affected signal. We consider the case that the Doppler shift, f_d, is coherent throughout the packet, and do not consider the signal fading. Parameters, M and L are set as 127 and 60, $1/T$, f_c, and sampling frequency, f_s, are set as 2, 20, and 400 (kHz), respectively. Normalized Doppler shift, f_dT, changes from -0.05 to 0.05. The scheme (ii) searches Doppler shift by changing $f_d^{'}T$ from -0.0515 to 0.0515 every 1.5×10^{-3}. Figure 5 shows the simulation results. In Fig. 5, output signal-to-noise ratio (SNR) expresses the variance of the

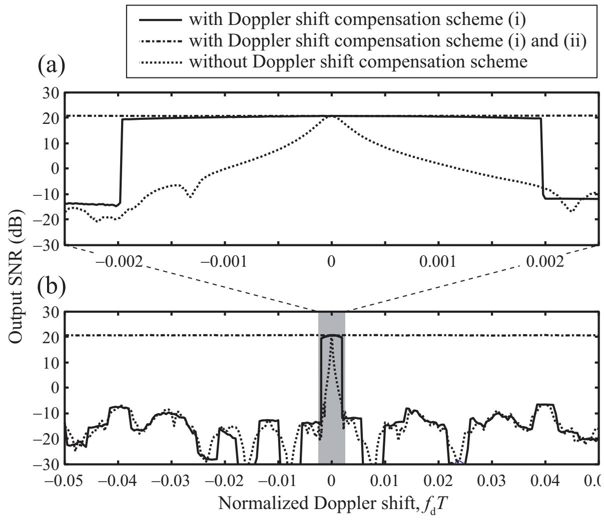


Fig. 5 Relationships between output SNRs and normalized Doppler shifts, f_dT, in OSDM communication with Doppler shift compensation scheme (i), (ii), and without any compensation.

receiving message. By applying Doppler shift compensation schemes, the output SNR values are retained around 20 dB, while that without Doppler shift compensation falls down as Doppler shift occurs. In underwater acoustic communication, Doppler shift, f_d, can reach a magnitude of 10 Hz which corresponds to f_dT around 0.005. OSDM communication with scheme (i) and (ii) can measure f_d and correct the receiving signal under large Doppler shifts, while there is a limitation in OSDM communication with scheme (i) only.

4. Conclusions

We applied Doppler shift compensations for UWA communication with OSDM and evaluate its performance. We focus on two compensations, which base on sampled sequence and receiving signal. The obtained results suggest that OSDM communication with scheme (i) and (ii) can measure f_d under usual Doppler shift and retain communication quality. Performance evaluation in Doppler shift and multi- path environment is one of our future works.

References

1. R. S. H. Istepanian and M. Stojanovic: *Underwater Acoustic Digital Signal Processing and Communication Systems* (Kluwer Academic Publishers, Dordrecht, 2002) pp. 3-7.
2. T. Ebihara, K. Mizutani, and N. Wakatsuki: Jpn. J. Appl. Phys. **48** (2009) 114505.
3. T. Ebihara, K. Mizutani, and N. Wakatsuki: Jpn. J. Appl. Phys. **49** (2010) 07HG09.
4. M. Sandell, J. V. D. Beek, P. O. Börjesson: Int. Symp. Synchronization, 1995, pp.16-19.