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Large Doppler Compensation for Mobile OFDM Based Underwater Acoustic Communication

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Abstract: In this study, large Doppler compensation for Orthogonal Frequency Division Multiplexing (OFDM) suitable for mobile underwater acoustic communication is proposed. The scheme is applicable to underwater acoustic communication between rapidly moving platforms. Considering the structural characteristics of OFDM symbols, re-sampling and time-frequency differential code mapping are used to realize the broadband and narrowband Doppler compensation. The experimental results prove the feasibility of the proposed scheme. In addition, the error performance of this scheme in different Signal-to-Noise Ratio (SNR) and different relative speed is given.

Key words: Orthogonal frequency division multiplexing, time-frequency differential code mapping, Doppler compensation, mobile underwater acoustic communication

INTRODUCTION

Underwater acoustic (UWA) communication is the primary means of underwater comprehensive information perception and information interaction and it has broad application prospects in military and civilian field. With the development of marine resource and the increase of underwater users, underwater transfer information has also greatly increased and high-bit-rate mobile UWA communication has become a hot topic (Zhang *et al*., 2012). Orthogonal Frequency Division Multiplexing (OFDM) has advantages including high spectral efficiency and reliable performance against intersymbol inference caused by multipath propagation, so it attracts more and more attention in high-bit-rate UWA communication (Jingwei, 2011).

In UWA communication, the relative motion between the receiving and sending nodes will generate Doppler shift, which is reflected as signal stretching or compressing in the time domain and carrier frequency offset and broadening of spectrum in the frequency domain. For OFDM, different carrier frequency offsets will destroy the orthogonality between subcarriers and cause Intercarrier Interference (ICI), hence deteriorating the error rate of the system (Schullzel and Luders, 2005; Sliskovic, 2001; Zhang, 2005). To obtain highly reliable communication, effective measures have to be taken to suppress the Doppler frequency offset and intersymbol interference(ISI) caused by multi-path spreading. Zhang (2005) and Wei *et al*. (2005) have provided a method for Doppler compensation via re-sampling, but the compensation is not that accurate due to Doppler estimation bias. Considering that in the OFDM system, the frequency domain differential modulation is not sensitive to small Doppler shift and the time domain differential modulation can effectively restrain ISI resulted from multi-path spreading. Therefore in this study, we apply the time-frequency differential phase shift keying modulation technology to the high-bit-rate mobile OFDM based UWA communication, analyze the re-sampling technology and principle of time-frequency differential modulation technology, provide a design scheme for the mobile OFDM based UWA communication system using time-frequency differential coding and validate the feasibility of the system via simulation.

THE TIME-FREQUENCY DIFFERENTIAL CODING SYSTEM

The design of the time-frequency differential coding for high-bit-rate mobile OFDM based UWA communication system is shown in Fig. 1.

The input signal is first deserialized and then Quadrature Phase Shift Keying (QPSK) modulated using the Gray coding. For the OFDM system, considering the slow time-varying characteristic of UWA channel, the modulated data is further mapped via time-frequency

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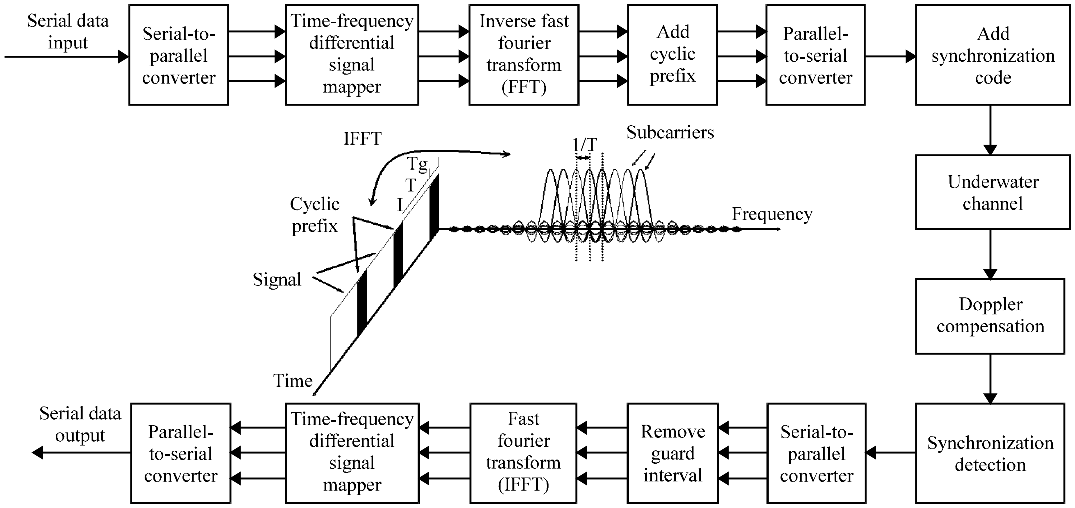

Fig. 1: The system diagram of time-frequency differential OFDM for mobile underwater acoustic communication

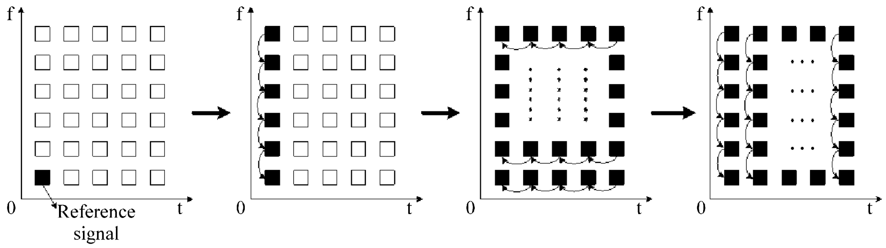

Fig. 2: Flow diagram of time-frequency differential code mapping

hybrid differential code (Fig. 2). The mapped sequence information then goes through Inverse Fast Fourier Transform (IFFT) transformation so as to change the spectrum expression of the data to the time domain and is added cycle prefix to eliminate ISI and ICI caused by multi-path propagation. Linear Frequency Modulation (LFM) signals are added before and after the OFDM frame signal respectively so as to facilitate demodulation of Doppler estimation and Sync-byte detection. The receiving end conducts inverse transformation corresponding to the transmitting end.

PRINCIPLE OF DOPPLER COMPENSATION FOR MOBILE UWA COMMUNICATION

The effects of Doppler shift on OFDM based UWA communication can be divided into broadband Doppler and narrowband Doppler. Broadband Doppler can be seen as changes of sampling frequency at the receiving end, different subcarriers' frequency deviators are different, the losses of Signal to Noise Ratio(SNR)are also not the same; while narrowband Doppler can be regarded as the same frequency deviation for all carriers, the SNR losses are the same(Xu, 2009).

Broadband Doppler compensation: Broadband Doppler, also known as the non-uniform Doppler, refers to different Doppler shifts by different subcarriers, which is caused by the relative motion of both sender and receiver (Xu, 2009). In the time domain, the broadband Doppler is reflected as signal compression or expanding, which is equivalent to increasing or decreasing sampling rate. People can use block Doppler estimation to estimate the Doppler factor and then based on the measured Doppler factor, adopt changeable sampling processing to deal with the signal, thus achieving estimation and compensation of the broadband Doppler (Li *et al*., 2007, 2008).

The expression for sampling frequency variation caused by Doppler shift is:

$$f_s' = f_s \frac{v_s}{c} \quad (1)$$

where, f_s is the sampling frequency at the transmitting terminal, v_s is the relative movement speed between the sender and receiver, c is the propagation speed of acoustic wave in the water.

The length variation of data frame in the time domain, caused by Doppler shift, is shown as in Fig. 3 (Yin *et al*., 2008).

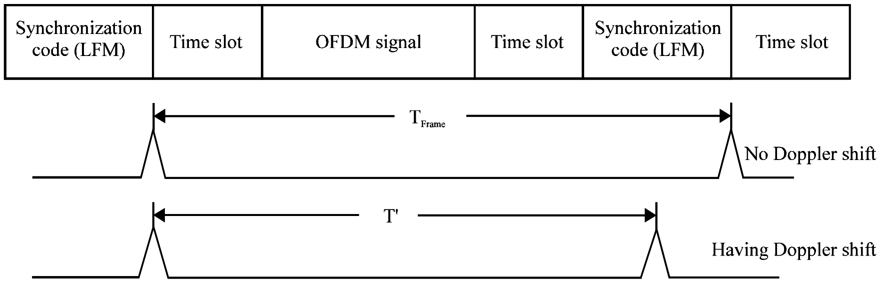

Fig. 3: The length cariation of data frame caused by Doppler shift

Within the Doppler tolerance range of the LFM signal, the sampling frequency at the receiving terminal can be estimated by measuring the time interval between correlation peaks of two adjacent sync codes:

$$f_s' = \frac{T'}{T_{Frame}} f_s \tag{2}$$

Narrowband Doppler compensation: The broadband Doppler compensation cannot completely compensate the Doppler effect because of compensation accuracy, the residual Doppler (quite small) can be modeled as a consistent Doppler frequency offset (Xu, 2009), namely that all subcarriers experience the same carrier offset б and then the signal after broadband Doppler compensation can be expressed as:

$$R_{i,k} = S_{i,k} e^{j\sigma t} \tag{3}$$

The Doppler frequency offset will not only cause phase deflection of the received signal, also will destroy the orthogonality between carriers, causing ICI.

Differential phase shift keying modulation delivers information through the relative phase changes between adjacent subcarriers. For OFDM communication, the time domain differential modulation can effectively correct the phase deflection of the received signal, while the frequency domain differential modulation can inhibit the frequency offset of the received signal; therefore the time-frequency differential modulation is used to suppress the effect of narrowband Doppler on the system performance.

The differential modulation in the frequency domain of the system is mapped by the different phases between neighboring subcarriers in the same number OFDM symbol. The phase of the mapped signal in No. k subcarrier of No. i symbol is:

$$\Delta\phi_{i,k} = \varphi_{i,k} + \Delta\phi_{i,k-1} \tag{4}$$

where, $\varphi_{i,k}$ is the phase information after the time domain differential modulation but before the frequency domain differential modulation, $\Delta\varphi_{i,k}$ is the phase information after the time-frequency hybrid differential modulation.

The sending signal after differential modulation is:

$$S_{i,k} = A_{i,k} e^{j\Delta\phi_{i,k}} \tag{5}$$

After broadband Doppler compensation for the receiving signal, the processed signal is:

$$R_{i,k} = S_{i,k} e^{j\sigma t} = A_{i,k} e^{j(\Delta\phi_{i,k} + \sigma t)} \tag{6}$$

Take the phase information from the signal:

$$\hat{\phi}_{i,k} = \Delta\phi_{i,k} + \sigma t \tag{7}$$

Then demodulate using the frequency domain differential coding:

$$\begin{aligned} \hat{\phi}_{i,k} - \hat{\phi}_{i,k-1} &= (\Delta\phi_{i,k} + \sigma t) - (\Delta\phi_{i,k-1} + \sigma t) \\ &= \Delta\phi_{i,k} - \Delta\phi_{i,k-1} = \varphi_{i,k} \end{aligned} \tag{8}$$

As is shown in Eq. 8, the coincident frequency offset of narrowband Doppler is also compensated.

EXPERIMENTAL RESULTS

In previously published studies, the time domain and the frequency domain differential modulation for mobile OFDM wireless communication in the High Throughput (HT) channel was given respectively and the results showed that the frequency domain differential one has a better performance with the condition of little Doppler (Song *et al*., 2005). Here, experimental simulation is carried out using Matlab, comparing the time-frequency differential modulation with the time domain differential one. The simulation channel is 5-diameter multi-path fading acoustic channel and the noise is band-limited

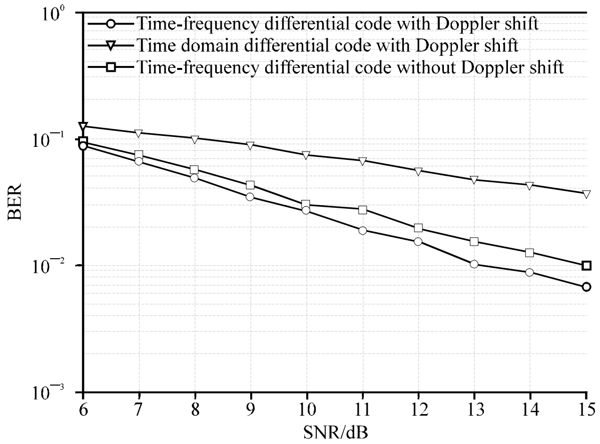

Fig. 4: The performance of QPSK time-frequency differential code

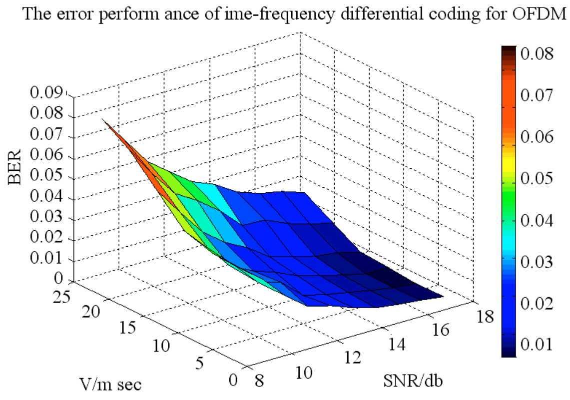

Fig. 5: The error performance of time-frequency differential coding for OFDM

white Gaussian noise. The parameters of mobile OFDM based UWA communication system are: sampling frequency is 48 kHz, frequency range is between 6-9 kHz, FFT modulation points are 4800, the number of subcarriers is 300, cycle prefix length is 25 ms; synchronous signal employs the LFM signal with a starting frequency of 6 kHz, duration of 20 m sec.

The simulation analysis of QPSK time-frequency differential modulation is shown in Fig. 4, the relative motion speed is 10 m sec. The simulation results demonstrate that when adopting the time-frequency differential modulation technology, the system performances are generally consistent under both conditions with and without Doppler shift, this can effectively inhibit Doppler frequency offset; Under the Doppler conditions, its performance is better than that using the time domain differential modulation.

Figure 5 gives the performance of time-frequency differential modulation for mobile OFDM based UWA communication system under different SNR and relative motion speeds. As can be seen from the figure, the bit error rates are all low when SNR is high and the technology can be applied to short-distance high-bit-rate mobile UWA communication. If properly use the channel coding, the bit error rate of the system will be greatly reduced, therefore the system may choose the corresponding parameters according to the actual engineering application.

CONCLUSION

This study presents a new communication scheme of high-bit-rate mobile OFDM based UWA communication system, which can be used to realize broadband and narrowband Doppler compensation in mobile UWA communication through re-sampling the receiving signal and use of the time-frequency differential modulation. Moreover, it gives the error performance of time-frequency differential codes for mobile OFDM based UWA communication system in different SNR and relative motion speeds. The technology will be applied to the short-distance high-bit-rate mobile underwater acoustic communication.

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REFERENCES

Jingwei, Y., 2011. The Theory and Signal Processing Technology of Underwater Acoustic Communication. National Defence Industry Press, Beijing, Pages: 195.

Li, B., S. Zhou, M. Stojanovic, L. Freitag and P.P.K. Willett, 2007. Non-uniform Doppler compensation for zero-padded OFDM over fast-varying underwater acoustic channels. Proceedings of the International Technology Conference and Exhibition on Marine Challenges: Coastline to Deep Sea, June 18-21, 2007, Aberdeen, Scotland, pp: 1-6.

Li, B., S. Zhou, M. Stojanovic, L.E. Freitag and P.P.K. Willett, 2008. Multicarrier communication over underwater acoustic channels with nonuniform Doppler shifts. IEEE J. Oceanic Eng., 33: 198-209.

Schullzel, H. and C. Luders, 2005. Theory and Applications of OFDM and CDMA: Wideband Wireless Communications. John Wiley and Sons Ltd., New York, USA., ISBN-13: 9780470017395, pp: 145-166.

Sliskovic, M., 2001. Sampling frequency offset estimation and correction in OFDM systems. Proceedings of the 8th IEEE International Conference on Electronics, Circuits and Systems, Volume 1, September 2-5, 2001, Malta, pp: 437-440.

Song, L., Y. Tang and S. Li, 2005. Comparison of frequency and time domain differential detection BER performance of OFDM. Chin. J. Radio Sci., 20: 105-109.

Wei, L., C. Qiang and W. Yu, 2005. An efficient Doppler processor for underwater acoustic communication. Tech. Acoustics, 12: 206-209.

Xu, X., 2009. The study of the key technologies for high-speed shallow water acoustic communication based on OFDM. Ph.D. Thesis, Harbin Engineering University, Harbin, China.

Yin, J.W., J.Y. Hui and L.X. Guo, 2008. Study on point-to-point mobile underwater acoustic communication. Acta Physica Sinica, 57: 1753-1758.

Zhang, X., 2005. Simulation research on doppler compensation for underwater acoustic communications. Acta Simulata Systematica Sinica, 5: 1172-1174.

Zhang, Y., C. Wang, J. Yin and X. Sheng, 2012. Research on multilevel differential amplitude and phase-shift keying in convolution-coded orthogonal frequency division multiplexing underwater communication system. J. Acoust. Soc. Am., 132: 2015-2015.