Lan-jun LIU, Jian-fen LI, Lin ZHOU, Peng ZHAI, Hao ZHAO, Jiu-cai JIN, Zhi-chao LV, 2018. An underwater acoustic direct sequence spread spectrum communication system using dual spread spectrum code. *Frontiers of Information Technology & Electronic Engineering*, 19(8):972-983. https://doi.org/10.1631/FITEE.1700746

An underwater acoustic direct sequence spread spectrum communication system using dual spread spectrum code

Key words: Underwater acoustic communication; Direct sequence spread spectrum; Doppler estimation and compensation; Channel estimation and equalization; Gold code; Single carrier; Code division multiple access

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Motivation

1. Single-carrier underwater acoustic (SC-UWA) communication technology with the spread spectrum technique is one of the solutions for long distance stable and reliable communication in a complex environment. Moreover, the direct sequence spread spectrum (DS/SS) scheme is a good approach for implementing code division multiple access (CDMA) based underwater acoustic networks.

2. For DS/SS system, the larger the spread spectrum gain, the better the system bit error rate (BER) performance. However, the larger the spread spectrum gain, the lower the system communication rate. The larger the length of the spreading code used for correlation operations, the better the performance of Doppler estimation, channel estimation, and frame synchronization.

3. Therefore, in terms of spread spectrum code length, the system communication rate is in conflict with the performance of Doppler estimation, channel estimation, and frame synchronization. This problem has not been adequately considered in previous studies.

Main idea

1. We propose a direct sequence spread spectrum based single-carrier underwater acoustic communication system using dual spread spectrum code (SC-UWA/DSSC).

2. To solve the contradiction between the information data rate and the accuracy of Doppler estimation, channel estimation, and frame synchronization, a data frame structure based on dual spread spectrum code is designed.

3. A long spread spectrum code is used as the training sequence that can be used for data frame detection and synchronization, Doppler estimation and compensation, and channel estimation and equalization.

4. A short spread spectrum code is used to modulate the effective information data.

Methods

1. The structure of the proposed SC-UWA/DSSC system

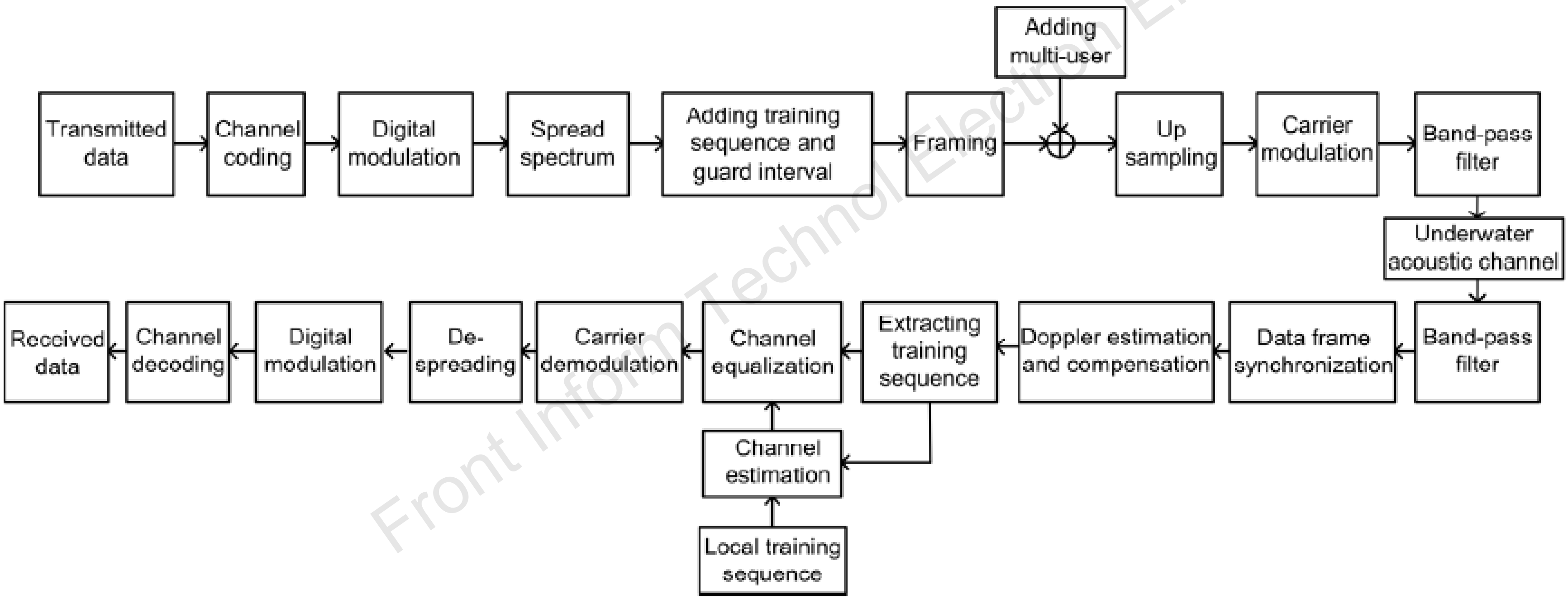

Fig. 1 SC-UWA/DSSC system structure

Methods

2. Data frame structure of the SC-UWA/DSSC system

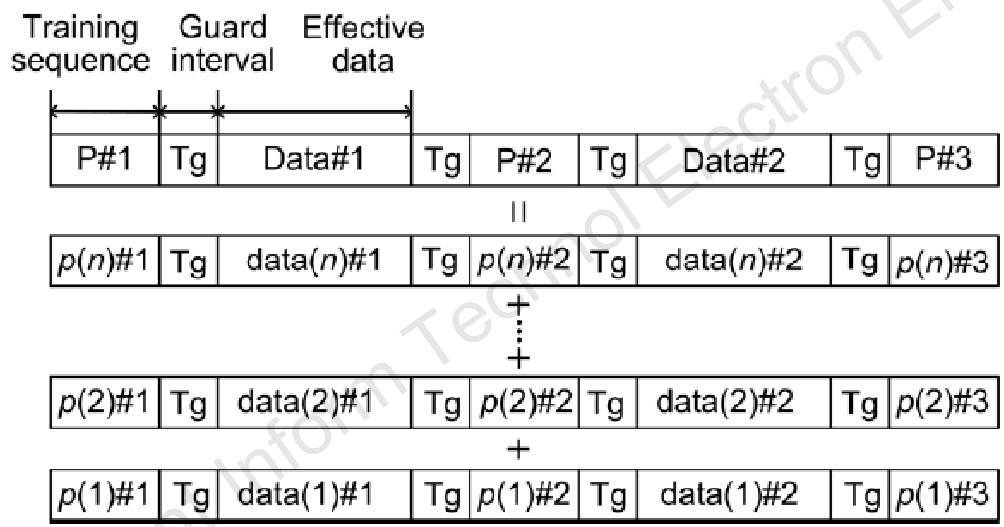

Fig. 3 Data frame structure of the SC-UWA/DSSC system

A long spread spectrum code is used as the training sequence that can be used for data frame detection and synchronization, Doppler estimation and compensation, and channel estimation and equalization.

A short spread spectrum code is used to modulate the effective information data.

Major results

1. The system BER obviously decreases with Doppler estimation and compensation. A similar trend is seen between the fixed velocity and the random velocity.

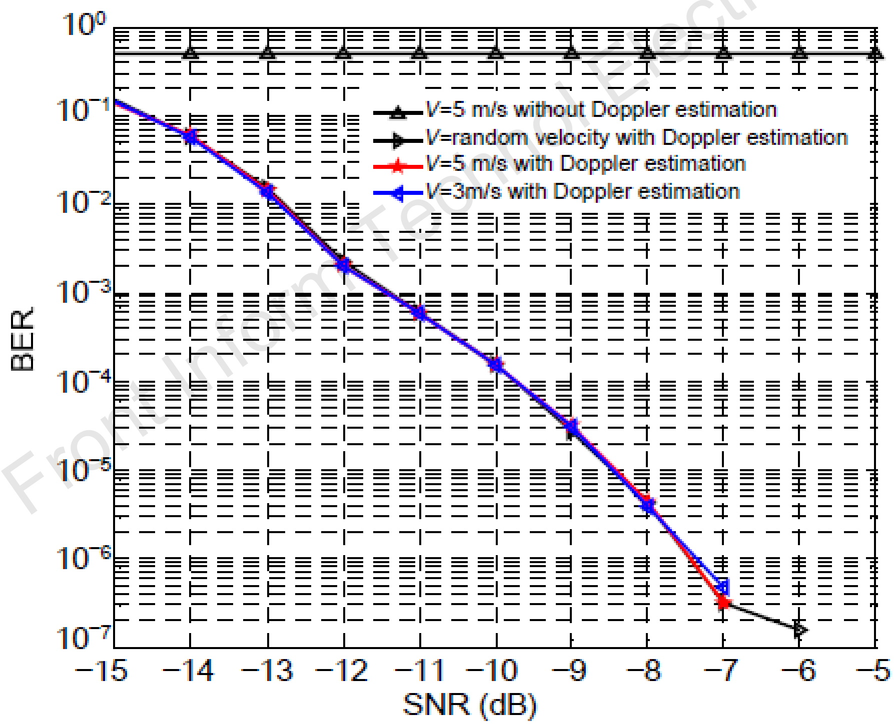

Fig. 7 Simulation results of Doppler estimation and compensation at different velocities

Major results

2. The proposed system could recover the transmitted signal well at both channel 1 and channel 2 with channel estimation and equalization.

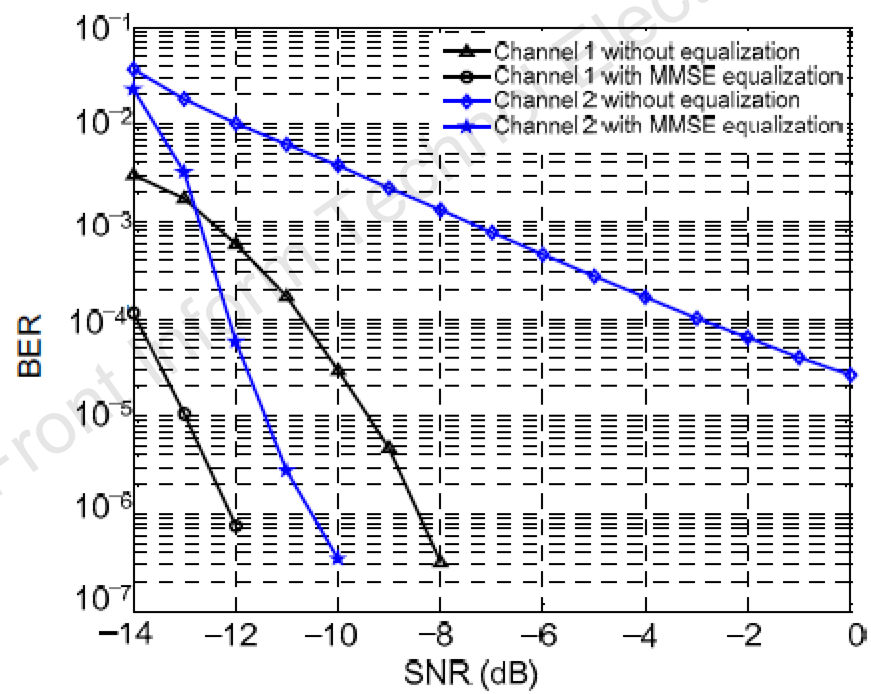

Fig. 8 Simulation results of channel estimation and equalization for different channels

Major results

3. The system BER can be less than 10^{-6} when the SNR is larger than −10 dB in an environment with multipath interference and Doppler frequency shift.

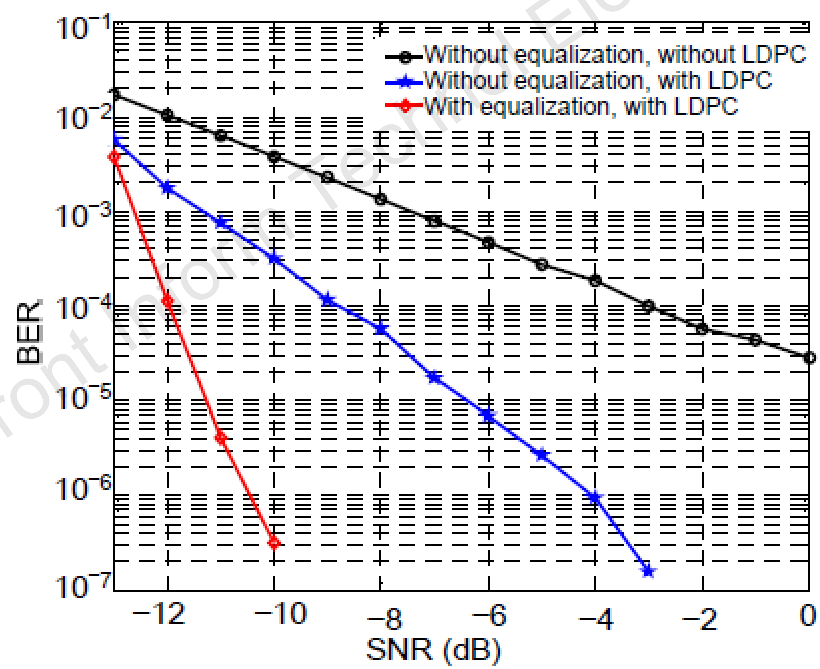

Fig. 10 Point-to-point system performance simulation results when the relative velocity is 5 m/s

Major results

4. The simulation results show that the system has some abilities to support the multiuser communication.

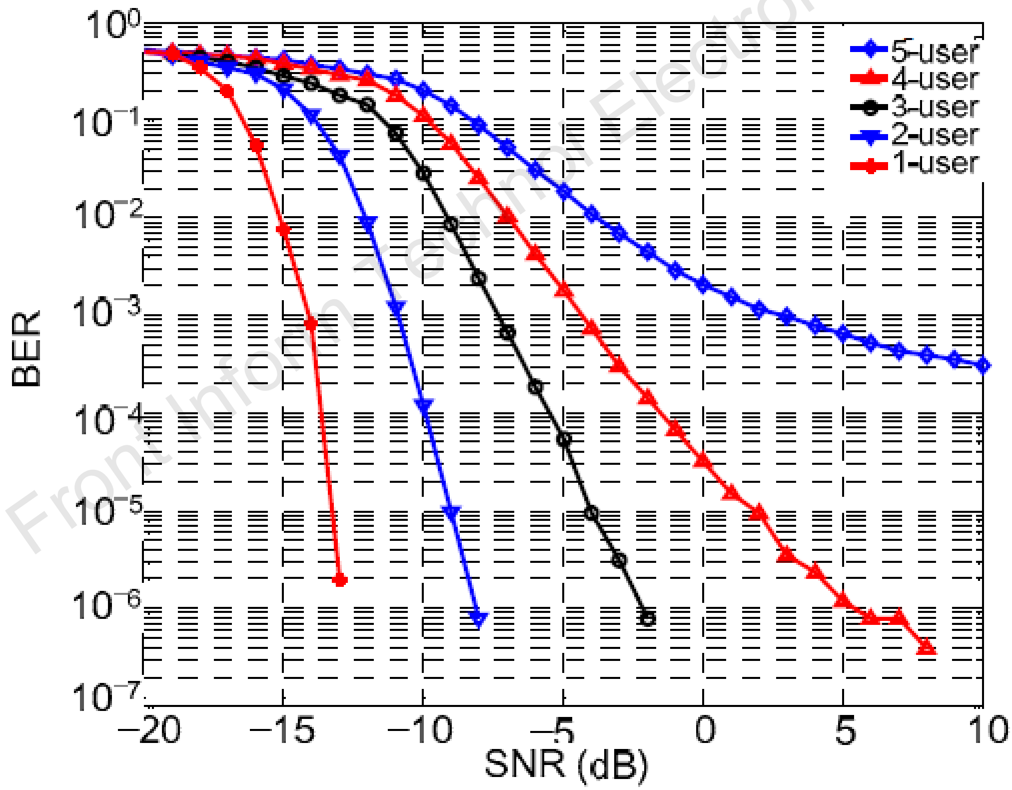

Fig. 11 Multiuser system performance simulation results

Major results

5. SC-UWA/DSSC has a lower system BER with a lower SNR and more multipath interference, and has a relatively high communication rate compared with the other systems, being as high as 355 bits/s.

Table 2 Comparison between the SC-UWA/DSSC system and other systems

Source	Spread code	Code length	Coding	Digital modulation	Band-width (kHz)	Carrier frequency (kHz)	Doppler	Multipath number	BER/SNR (dB)	Data rate (bit/s)
SC-UWA/ DSSC	Gold	31	LDPC	BPSK	6	24	Yes	12	10^{-6}/−10	355
Sozer et al. (1999)	PN	25	–	BPSK	–	12	Yes	3	–	100
Palmese et al. (2007)	Gold	63	–	Chirp	3.5	–	Yes	Several	–	27
Huang and Sang (2007)	m	255/511/ 1023	RS	–	2.25	9	Yes	Several	–	8–35
Liu et al. (2009)	Gold	31	RA	QPSK	–	44	No	4	(10^{-5}–10^{-7})/ −5	473
Yin et al. (2014)	m	63	–	CSK/BPSK/ MFSK	4	6	Yes	5	10^{-2}/−5	317
Tang et al. (2016)	N-H	7/15	–	–	4	–	–	<10	10^{-4}/−5 10^{-4}/−7.5	428.8/ 272.7
Shu et al. (2017)	CMP	127	–	QPSK	–	–	Yes	2	10^{-3}/−5	100

Conclusions

1. A DS/SS based single-carrier underwater acoustic communication system using dual spread spectrum code has been proposed. Moreover, a data frame structure based on dual spread code has been designed. To address the Doppler frequency shift and the multi-path interference, a Doppler estimation and compensation method and a channel estimation and equalization method, both of which are based on a long spread spectrum code, have been introduced.

2. The point-to-point communication simulation results showed that this system can estimate the Doppler factor and compensate for the Doppler effect accurately, and that the channel estimation and equalization algorithm based on training sequences can demodulate the correct signals, even with a strong multi-path interference. The system BER can be smaller than 10^{-6} when the SNR is larger than −10 dB, even if there are as many as 12 paths with multipath interference.

3. The multiuser communication simulation results showed that the proposed scheme can be used in the downlink channel of an underwater CDMA based networking system.