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A Multi-hop OFDM Frame Structure for Short-Range Underwater Acoustic Communication Networks

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ABSTRACT

In this paper, for the purpose of providing high data rate services, the multi-hop frame structure is designed for the underwater acoustic (UWA) short-range system which is proposed as a part of ocean surveillance and tracking network (OSTN). Under the measured underwater channel environment, the link-level system performance are also evaluated. Simulation results show not only the packet error rate (PER) comparisons, but the optimal modulation and coding scheme (MCS) levels for the orthogonal frequency division multiplexing (OFDM) based short-range UWA communications network.

Key Words : Multi-hop frame structure, Underwater acoustic communications, OFDM, Modulation and coding scheme selection

Ⅰ. Introduction

The interest in underwater acoustic communications keeps growing in recent decades, because it enables many marine applications of science, environment, and military. Various researches have resulted in improved system performance compared with conventional UWA communications systems. However, due to the severe underwater (UW) channel environment, frame structure has barely discussed for UWA systems. Therefore, it is quite valuable to design the frame structure to provide high data rate services.

In this paper, we design the multi-hop frame structure for the short-range UWA communications network, and evaluate the system performance by the link-level simulation results.

Ⅱ. System Model and Parameters

The underwater environment differs greatly from the terrestrial wireless world. Therefore, existing wireless models can not be used for underwater network test directly. It should be also noted that the underwater channel environment varies greatly with communication distance. In order to model the underwater channel accurately, we categorized the UWA communications into short, medium, and long range systems[1]. In this paper, we focus on the short-range system.

2.1 Short-range UW Channel Model

The UWA short-range system within 1 km is introduced in [1]. To simulate the UWA channel environment, the channel model over 500 meters is adopted from [2], where the model was estimated by using the measured data. Fig. 1 shows the channel impulse response.

2.2 OFDM System Parameters

Based on the information provided by Fig. 1, OFDM system parameters are calculated and presented in Table 1. The guard interval (GI) of the OFDM symbol should be set larger than the maximum multipath delay (τ_{max}=7.7 ms) to overcome the selective fading. GI which causes energy loss (0.97 dB in this paper) should be kept minimum, but considering the application of windowing and to guarantee the no ISI even in the worst case of delay spread, we select the value of 10 ms as GI value which also makes frame structure design easier.

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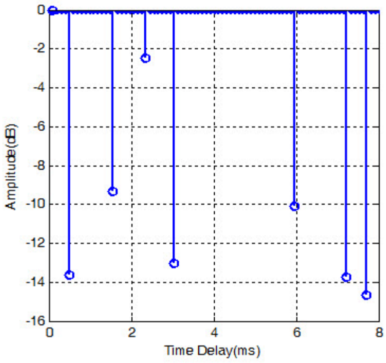

Fig. 1. UWA channel impulse response.

Table 1. OFDM system parameters.

Center Freq. (fc)	32 kHz		
Bandwidth (B)	10 kHz		
Oversampling Freq.	12.8 kHz		
Active Subcarriers	358		
Null Subcarriers	154		
RMS Delay (τrms)	4.5 ms		
Guard Interval (Tg)	10 ms		
Symbol Duration (Ts)	50 ms		
Maximum Data Rate (kbps)	$\frac{1}{3}BPSK$	$\frac{1}{2}BPSK$	
	0.94	1.415	
	$\frac{1}{3}QPSK$	$\frac{1}{2}QPSK$	$\frac{1}{3}16QAM$
	1.885	2.825	3.765

Ⅲ. Multi-hop OFDM Frame Structure Design

In the proposed short-range UWA communications system, the ad-hoc self-organizing TDMA (ASO-TDMA)[3], which is a novel multiple access scheme based on TDMA, is adopted. The proposed frame structure is completely compatible with the ASO-TDMA scheme.

3.1 Frame Configuration

In the proposed short-range UWA network, we allow up to 4 hops and assume the number of nodes decreases from the first to fourth hop[1]. Fig. 2 demonstrates the designed multi-hop frame structure. According to this figure, there are total 4 sub-frames allocated in a frame, and the first sub-frame serves the nodes located in the first hop, so as for the other sub-frames. There are total 155 time slots in a frame, where one slot is the minimum unit of resource management.

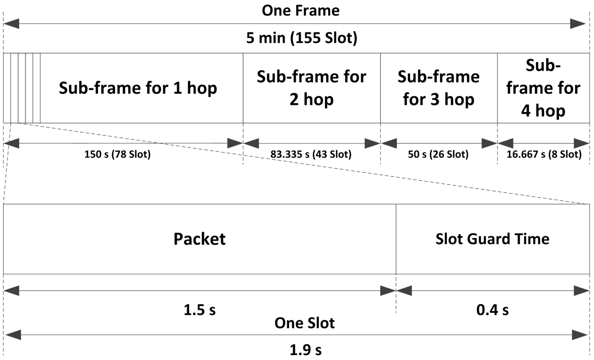

Fig. 2. Proposed frame structure for the short-range UWA communications network.

3.2 Slot Configuration

For the purpose to avoid the inter-slot interference, slot guard time (SGT) for each slot is required. The length of SGT is calculated as

$$T_{SGT} \geq \frac{D}{v_s} \approx 0.333\ s, \tag{1}$$

where D is the communication distance (500 m), and v_s (1.5 km/s) is the speed of sound wave in the water. Here we found that time duration of 8 symbols (0.4 s) is sufficient enough. By considering the tradeoff between the system overhead and PER, the number of the OFDM symbols in 1 packet is set to be 30. We make 1 packet occupies 1 time slot (1.9 s).

Ⅳ. Evaluation of Link-level Performances

In this section, we discuss link-level performances for the proposed frame structure. Practical channel estimation and one-tap zero-forcing (ZF) equalizer are implemented. The pilot spacing in time domain is calculated as

$$n_t \ll \frac{T_{c,50}}{T_{OFDM}} = \frac{9}{16\pi B_d T_s} \approx 1.12, \tag{2}$$

where $T_{c,50}$ denotes 50% coherence time of the channel, and B_d is the maximum doppler spread with the node speed of 0.15 m/s. For the frequency domain, pilot spacing is calculated as

$$n_f \ll \frac{B_{c,50}}{\Delta f_{OFDM}} = \frac{T_s}{5\tau_{rms}} \approx 1.78, \tag{3}$$

where $B_{c,50}$ presents 50% coherence bandwidth and τ_{rms} is root mean square (RMS) delay spread. Large Doppler effect and long delay spread result in dense pilot patten for channel estimation. The perfect frequency and timing synchroniza- tion is assumed.

Fig. 3 shows PER comparisons of different modulation and coding schemes. BPSK with 1/3 convolutional coding (BPSK r=1/3) has the best PER performance. While BPSK r=1/2 is not preferred due to its lower modulation order but similar PER compared with QPSK r=1/3. Note that, 16QAM r=1/3 can not work due to its high PER.

According to PER, the average system throughput is calculated as

$$C = \frac{(1-PER)\times n_{bit-packet}}{T_{packet}(s)} \times r, \tag{4}$$

where $n_{bit-packet}$ is the number of bits in a packet, T_{packet} is 1 packet duration and r is coding rate. Fig. 4 shows the MCS levels for the UWA system. In order to maximize the system throughput, MCS levels are selected and summarized in Table 2 with the threshold of Eb/N0 value.

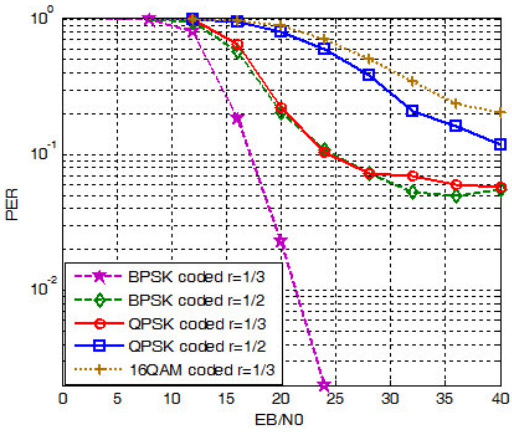

Fig. 3. PER performance for the OFDM based short-range UWA communications system.

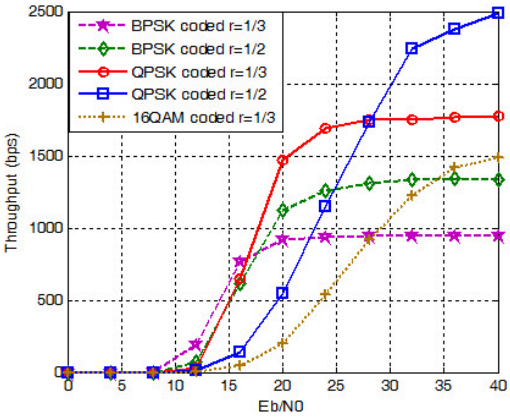

Fig. 4. MCS levels for the OFDM based short-range UWA communications system

Table 2. MCS level selection.

Threshold (dB)	Modulation	Code Rate
< 16	BPSK	1/2
16 - 27	QPSK	1/3
> 27	QPSK	1/2

V. Conclusions

In this paper, we propose the multi-hop frame structure as well as corresponding parameters to achieve high rate services for the OFDM based short-range UWA communications system. Link-level performances are obtained by applying the designed multi-hop frame structure under the measured channel model. Simulation results provide the optimal MCS levels for the short-range UWA network.

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