

# An Underwater Acoustic OFDM Communication System with Shrimp (Impulsive) Noise Cancelling

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**Abstract**— OFDM based acoustic communication system for underwater application is proposed. In order to mitigate a shrimp (impulsive) noise created by ocean living creature, time and frequency domain noise canceller is introduced. 2 dimensional DFT based channel estimation is also adopted to enhance the mobility of the communication system. Ocean measurement was performed in the experiment, and 53.0 m distance communication with Bit Error Rate of 0.01 was successfully confirmed. BER reduction by the proposed time and frequency domain shrimp noise canceller is also realized with 0.3 to 0.6 m/s mobility.

**Keywords**—underwater; acoustic; OFDM; ICI cancellation; impulsive noise; shrimp noise;

## I. INTRODUCTION

The needs of not only wireless communication in the air but also underwater wireless communication is increasing in order to explore marine natural resources using remote robotic control or to enable rapid information exchange between diver and so on. Especially in order to send real-time moving pictures, high bandwidth digital communication is required. Since radio wave degrades rapidly in the water, acoustic communication is one of the most promising method for underwater applications. Orthogonal Frequency Division Multiplexing (OFDM) modulation can achieve high bandwidth under severe multipath condition, then application of OFDM is expanding in radio application such as wireless LAN, WiMAX, terrestrial digital TV broadcasting, and mobile phones.

Figure 1 shows an underwater communication scene in the ocean. Multipath propagation also happens in the ocean as well as wireless radio communication. The wave transmitted from transmitter to receiver is reflected by the bottom of the ocean, the surface and other objects as shown in figure 1. The various studies of underwater acoustic communication have been carried out and performed experiment in ocean so far [1-2], multipath propagation in the shallow ocean is particularly prominent. On the other hand, random impulsive noise, which is generated by marine creature such as shrimps [3], is usually observed as an acoustic interference. Then we have designed an underwater acoustic OFDM communication system with shrimp (impulsive) noise canceler. The proposed system utilizes one TX transducer and one RX transducer with center frequency of 24 KHz ultrasonic sound. Section II describes the detail of

communication system. Experiment results will be disclosed in Section III. Finally, conclusion is given in Section IV.

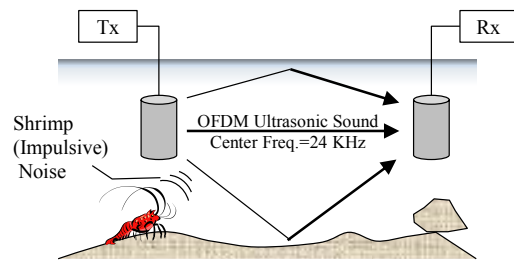


Fig. 1. Underwater Acoustic Communication

## II. OVERVIEW OF THE SYSTEM

Figure 2 shows an underwater acoustic OFDM communication system diagram and the detail features are shown in TABLE I. The system utilizes 20 to 28 KHz (8 KHz bandwidth) ultrasonic sound for OFDM communication for shallow ocean underwater communication. Two operational modes are supported such as MODE2 (1K FFT) and MODE3 (2K FFT) with sampling frequency of 96 KHz. Then OFDM symbol length is 10.667 ms for MODE2 and 21.333 ms for MODE3, respectively. In order to send same data amount for both modes, number of subcarriers are 81 for MODE2 and 161 for MODE3. 25% of subcarriers are used for pilot to estimate channel and remaining 75% of subcarriers are used for data transmission.

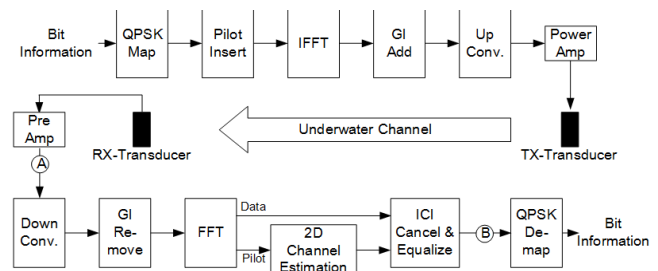
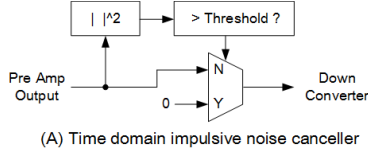


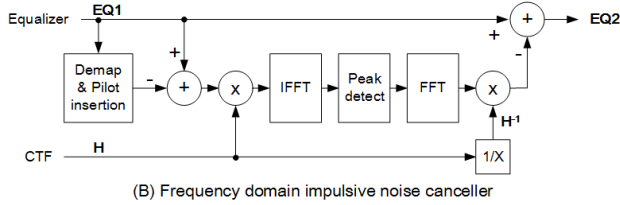
Fig. 2. System Block Diagram

This study has been carried out as the part of the Strategic Information and Communications R&D Promotion Program (SCOPE) Project of the Ministry of Internal Affairs and Communications Japan.

In transmitter (TX) side, data are QPSK-modulated and BPSK modulated pilot are inserted. After the IFFT calculation, Guard Interval (GI) is added. Then the baseband signal is up converted to 24 KHz center frequency. Finally, the output of TX is emitted into underwater channel through TX-transducer.



(A) Time domain impulsive noise canceller



(B) Frequency domain impulsive noise canceller

Fig. 3. (A) Time domain and (B) Frequency domain impulsive noise canceller

In receiver (RX) side, received signal by RX-transducer is amplified by pre-amp and after GI removal, FFT is performed. In order to estimate Channel Transfer Function (CTF), scattered pilots are used and by performing two dimensional (2D) DFT computation [4], Doppler and Delay profile 2D surface can be computed. In order to mitigate a shrimp (impulsive) noise, as shown in figure 3, both time domain (A) and frequency domain (B) impulsive noise canceller [5-7] is utilized at point A and B in figure 2. The time domain method is simply to replace a large signal more than threshold with ZERO, so called as BLANKING. The frequency domain method (B) is to reproduce the added impulsive noise by IFFT and subtract the effect of impulsive noise from 1<sup>st</sup> Equalized output to generated 2<sup>nd</sup> Equalized output.

TABLE I. OFDM SYSTEM FEATURE

Parameters	Mode	
	2	3
TX-RX Elements	1 TX and 1 RX Transducer	
Sampling Frequency	96000 Hz	
TX Center Frequency	24000 Hz	
Band Width	8000 Hz	
FFT Size	1024	2048
OFDM symbol length T	10.667 ms	21.333 ms
GI length	0.5T	0.5T
Sub Carrier Spacing	93.75 Hz	46.875 Hz
Number of Sub Carrier	81	161

### III. EXPERIMENTAL RESULT

#### A. Ocean Experiment Parameters

TABLE II shows ocean experiment parameters. The ocean depth is roughly 3 to 5 m and transducers are set 1 m below the ocean surface as shown in figure 4. As you can see, there are some boat near transducers. Then it is considered that experiment

is performed under sever multipath condition with shallow ocean.

TABLE II. OCEAN EXPERIMENT PARAMETERS

Item	Content
TX-RX Distance	0 to 53 m
Ocean Depth	3 to 5 m
Transducer Depth	1 m
Transducer Velocity	0 (stable), 0.3, 0.6 m/s
Weather	No wind

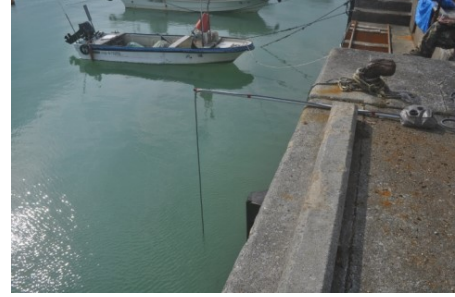


Fig. 4. Setting the Receiving Transducer

#### B. Distance vs Bit Error Rate (BER)

Figure 5 shows Graph on Distance vs BER. Between TX-transducer and RX-transducer, there is a Line-Of-Sight (LOS). However, both transducers are placed from the wharf by 1.5m apart. Then, it is considered that multipath condition is severe.

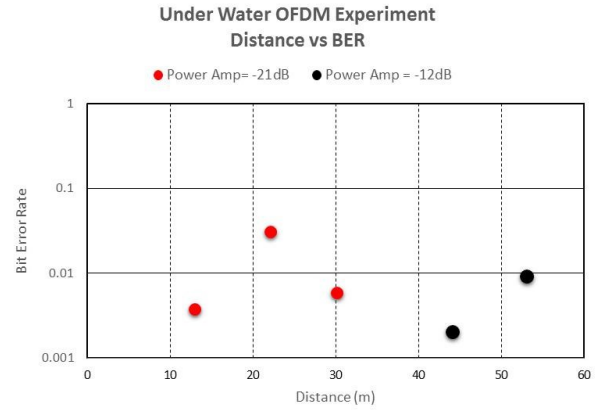


Fig. 5. Distance vs Bit Error Rate (BER)

TX power amplifier gain and RX pre-amplifier gain is also adjusted according to the change of distance. TX power amplifier gain of -21 dB is for 13.0 m, 22.2 m, 30.2 m and -12 dB for 44.1 m, 53.0 m are used. RX pre-amplifier gain of 0 dB for 13.0 m, 22.2 m, 30.2 m, 44.1 m and 20 dB for 53.0 m are used. At 22.2 m, relatively higher Bit Error Rate (BER) is observed. It is observed that the reason of the degradation is much worse frequency selective fading caused by multipath condition. According to the figure 5, proposed underwater OFDM communication system has realized at least 53.0 m distance communication.

C. Received waveform with Shrimp (Impulsive) Noise

In the case of 28m, the received MODE3 signal are shown in figure 6. The received signal is found to contain a randomly generated impulsive noise.

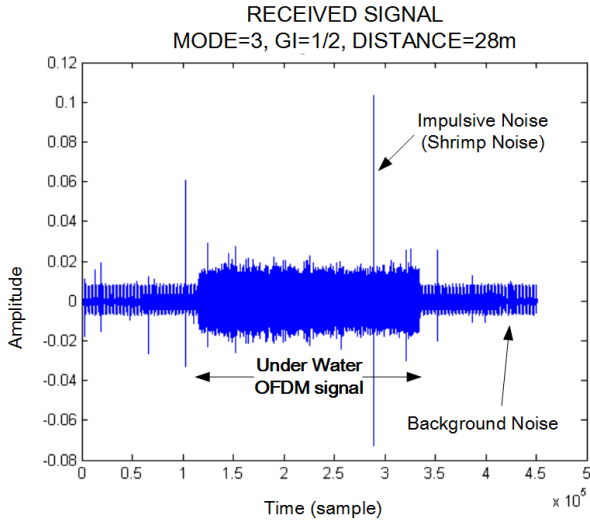


Fig. 6. Received Signal (Mode=3, GI=1/2, Distance=28m)

D. TX Transducer with mobility

The case of moving TX transducer is examined. Figure 7 shows a student is walking with TX transducer. The velocity of 0.3m/s, -0.3m/s, 0.6m/s and -0.6m/s are examined.



Fig. 7. Moving TX Transducer

By performing 2 dimensional (2D) DFT on Scattered pilot, 2D Doppler and Delay profile can be obtained as shown in figure 8. Since 25% of subcarriers are pilot, the 2D profile includes one real profile and three aliases. The peak of real profile corresponds to roughly -4 Hz Doppler shift. By performing inverse 2D DFT on successfully aliases removed profile such as figure 9, transmission channel can be estimated.

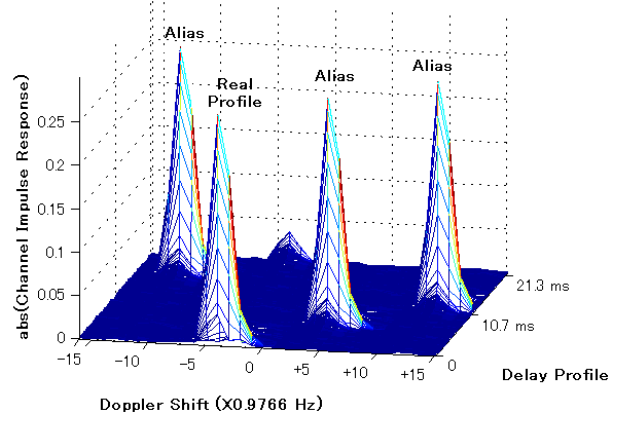


Fig. 8. 2D profile (Doppler / Delay Profile)

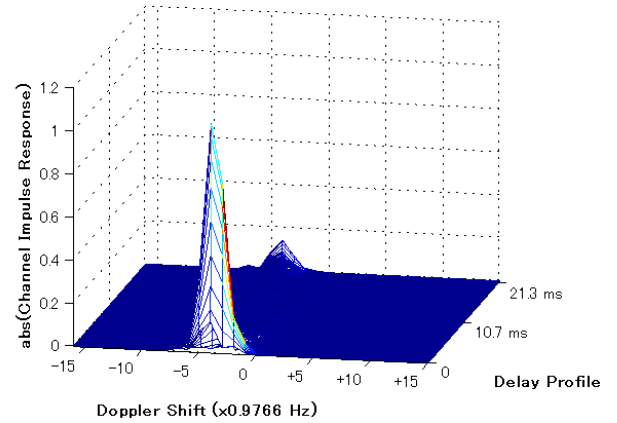


Fig. 9. 2D profile after remove aliases (Mode=3, GI=1/2, Distance=28m)

Figure 10 shows the equalized constellation. The left is Real-Imaginary plane. The Right is subcarrier number vs Real of constellation.

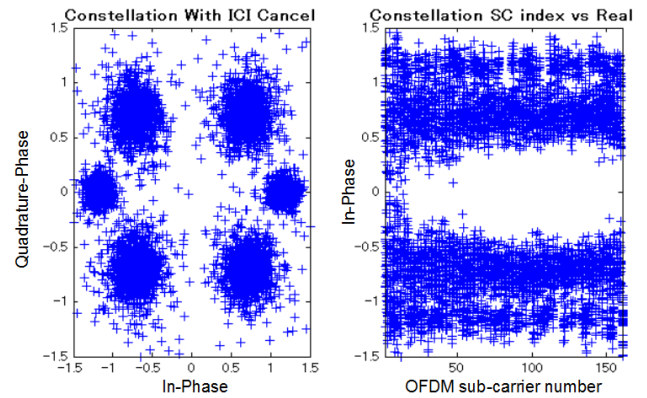


Fig. 10. Constellation with ICI cancel (Mode=3, GI=1/2, Distance=28m)

Moving the transducer causes Doppler shift as indicated in figure 8. Then 2D Doppler and Delay profile is shifted by Doppler. By utilizing the 2D channel estimator, reception performance enhancement is possible with successfully removing the aliases.

Figure 11 shows the comparison of successful or not-successful alias reductions for both MODE2 and MODE3. Dashed lines are corresponds to the successful case and solid line to non-successful case. According to the figure 11, it is obvious that 2D channel estimation with successful alias removing improves BER.

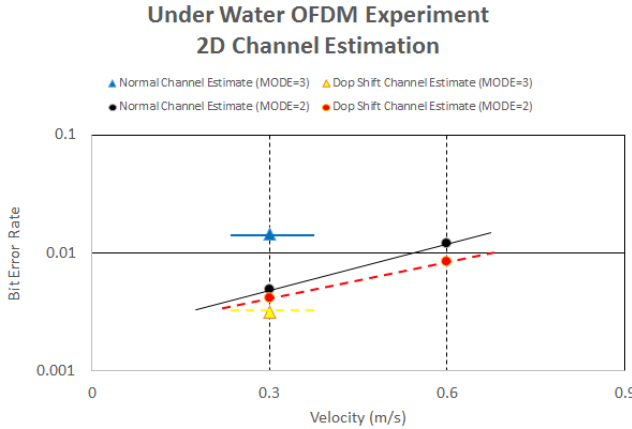


Fig. 11. The BER performances for moving the TX transducer with using the 2D channel estimation

### E. Shrimp (Impulsive) Noise Reduction

Figure 12 shows the comparison with or without impulsive noise canceller for MODE2 and MODE3 with changing the TX-transduce velocity. Positive velocity corresponds to TX approaching to RX and negative velocity corresponds to TX moving apart from RX.

By applying both time domain and frequency domain shrimp (impulsive) noise canceller, roughly BER of 0.005 improvement is observed. This looks like small improvements. However, shrimp (impulsive) noise causes pin-point large interference (burst error).

Figure 13 shows received signal amplitude (upper) and BER of each OFDM symbol (blue = canceller off, red = on) of each OFDM symbol for MODE3, velocity=0.3m/s case (lower). According the figure 13, the BER improvements at the burst error position is significant. In addition, some cases in figure 12 shows small improvements. However, those are just lucky case without significant shrimp (impulsive) noise happened.

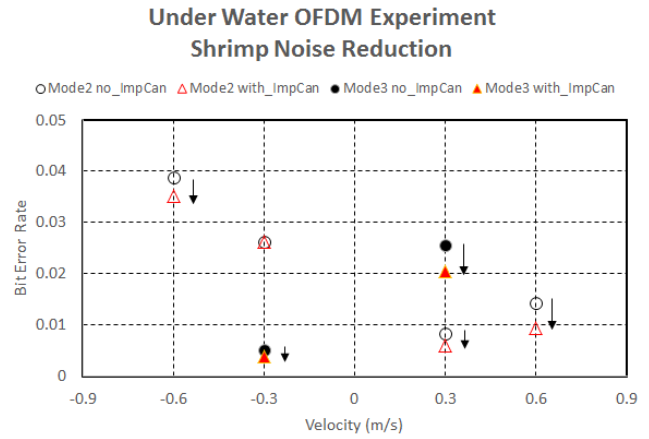


Fig. 12. BER value for shrimp noise reduction

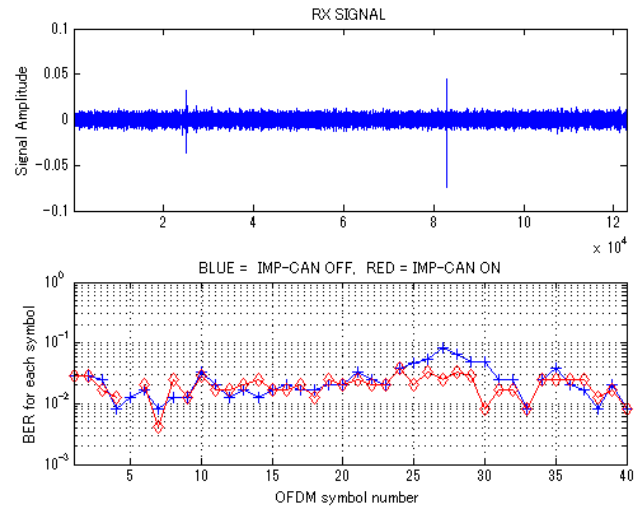


Fig. 13. Received signal and BER of each symbol ( Impulsive Noise Reduction OFF and ON) at MODE3, 0.3m/s

## IV. CONCLUSIONS

In this paper, we present an underwater acoustic OFDM communication system which designed to mitigate a shrimp (impulsive) noise.

By performing experiment in the ocean, proposed underwater OFDM communication system has realized at least 53.0 m distance communication. In the experiment, Doppler shift caused by moving TX transducer is confirmed in the 2D profile, and BER improvement is observed by utilizing the 2D channel estimator.

In addition, as a result of analyzing the received OFDM signal, randomly generated impulsive noise is found in the received signal. And BER reduction is confirmed by applying

proposed time and frequency domain shrimp (impulsive) noise canceller.

It is considered that BER performances will be improved to applying the scheme of diversity [8], so we will implement the method of space diversity to the underwater acoustic OFDM communication system, and verify the effectiveness of the method by performing experiment in future research.

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