ULTRASONIC DIVERSITY OFDM TRANSCEIVER ARCHITECTURE WITH IMPULSIVE NOISE CANCELLING FOR SHALLOW SEA COMMUNICATION

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Abstract: *In order to support shallow sea under water communication to explore marine natural resources using remote robotic control or to enable rapid information exchange between divers and so on, a robust Digital Communication method under the multiple delayed refraction wave circumstance is necessary. We propose OFDM Ultrasonic communication system with Diversity receiver. It utilizes 20-28 (KHz) ultrasonic channel and Subcarrier Spacing of 46.875 (Hz), 161-subcarriers OFDM modulation. Living creatures in shallow sea generate Impulsive Noise so called Shrimp Noise. Then Our OFDM diversity receiver has Time and Frequency Domain Impulsive noise Canceller with Maximum ration combiner. The paper shows the proposed Diversity OFDM Transceivers architecture and Experimental results taken at a fishing port in Okinawa Japan, which has shown QPSK communication more than 50m distance shallow sea. In addition, an Inter-Carrier Interference Canceller is incorporated, and experiments with moving receivers at 0.6 (m/s) and 0.9 (m/s) are conducted as well.*

Keywords: *OFDM, Impulsive Noise, Inter-Carrier Interference, Maximum Ratio Combiner*

1. INTRODUCTION

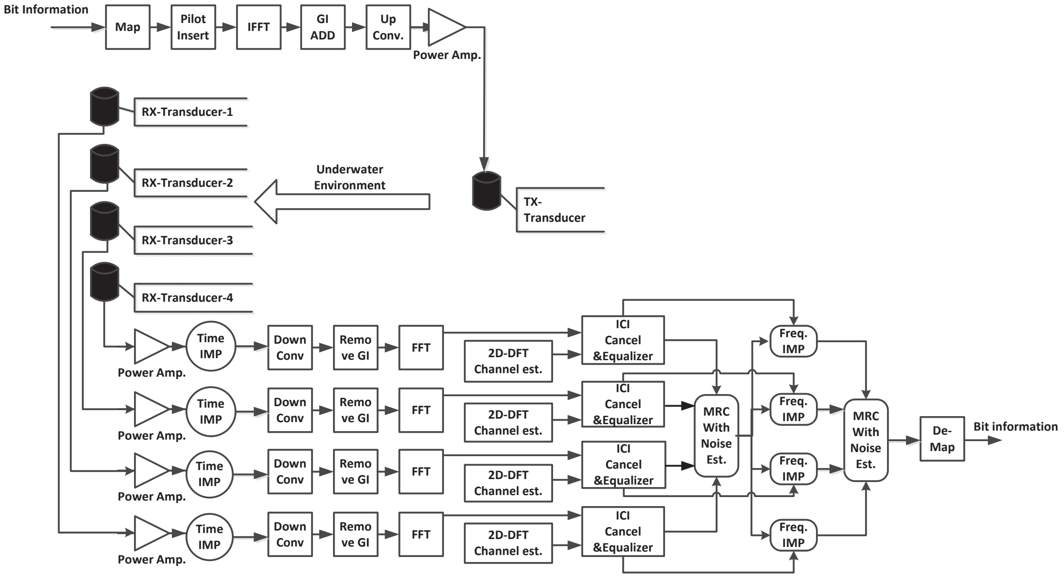

Fig. 1: Proposal Transceiver Architecture

While underwater communication brings great benefits, the underwater transmission poses many challenges, especially for a high speed communication system. First, though acoustic signal rather than high frequency radio signal is used for underwater communication, the signal strength still degrades quickly. Second, the speed of acoustic signal in water environment is about 1500 m/s, so the signal will suffer very a long delay and high Doppler spread that causes ICI. Finally, the presence of impulsive noise also degrades reception signal.

To solve those four challenges, we propose an ultrasonic OFDM system consists of four diverse receivers [1], 2D-DFT channel estimation, ICI cancelling [2-4], and combining time and frequency impulsive cancelling [5-6]. Fig. 1 shows the whole proposal system.

The rest of this paper is organized as follow. Section 1 describes the proposal system architecture. Experimental results are shown in Section 2. Finally, conclusion is presented in Section 3.

Parameters	**Mode**	
	2	***3***
TX-RX Elements	1 TX and 4 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

Table 1: System Parameters

2. THE PROPOSAL SYSTEM DESCRIPTION

2.1. Pilot Structure and 2D-DFT Channel Estimation

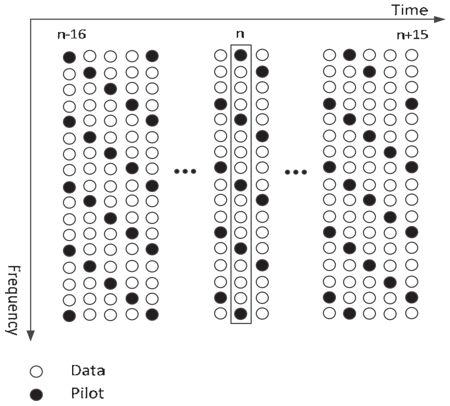

Fig. 2: Pilot Structure

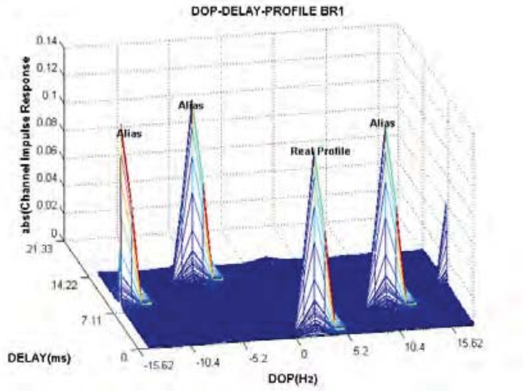

Fig. 3: 2D Doppler-Delay Profile

Fig. 2 shows the pilot structure. Channel is measured by scattered pilots in both time and frequency domain. As shown in Fig. 2, with any given sub-carrier, channel is measured by pilots spacing 3 OFDM symbol in time domain. Since channel transfer function (H) at pilot positions is measured, a 2D-DFT interpolation is employed to interpolate the whole channel transfer function at all positions. After the 2D-DFT process, a 2D Doppler-Delay profile as Fig 3 including a real Doppler-Profile and three aliases. Those aliases have to be removed before converting back the Doppler-Profile to channel transfer function.

2.2. Inter-Carrier Interference Cancellation

According to [1-3], the ICI equation can be written as follow

$$Y(k) = X(k) \cdot H_{k,k} + \sum_{l=0, l \neq k}^{N-1} X(l) \cdot H_{k,l} + W(k) \tag{1}$$

X(k) and Y(k) denotes transmitted and received signal, respectively and l, k are sub-carrier indexes. N is number of sub-carriers and W(k) is random noise. $H(k,l)$ denotes the channel transfer function from l^{th} to k^{th} sub-carrier, and is calculated as (2).

$$H_{k,l} = \frac{1}{N} \sum_{n=0}^{N-1} \sum_{m=0}^{N-1} h(m,n) \cdot e^{-j\frac{2\pi lm}{N}} \cdot e^{-j\frac{2\pi}{N}n(k-l)} \tag{2}$$

Here, $h(m,n)$ is channel impulse response, with m and n are delay path and time index, respectively. The main idea in [1-3] is to linearly approximate the time varying channel h$h(m,n)$ within one OFDM symbol, then $H(k,l)$ can be determined. Then, ICI can be removed from received subcarrier. In more detail, please refer to [2-4].

2.3. Frequency Diversity MRC

Due to multipath effect, signal of a given sub-carrier can be constructed or destructed at different places. So, a four diverse receivers system based on MRC [1] is proposed to combine signal from four branches after equalization. Following [1], to compute combing coefficient, noise is taken into account as follow

$$\mathrm{MRC(k)} = \frac{EQ(k)_1 \cdot \frac{|H_{kk1}|^2}{\sigma_{n1}^2} + EQ(k)_2 \cdot \frac{|H_{kk2}|^2}{\sigma_{n2}^2} + EQ(k)_3 \cdot \frac{|H_{kk3}|^2}{\sigma_{n3}^2} + EQ(k)_2 \cdot \frac{|H_{kk4}|^2}{\sigma_{n4}^2}}{\frac{|H_{kk1}|^2}{\sigma_{n1}^2} + \frac{|H_{kk2}|^2}{\sigma_{n2}^2} + \frac{|H_{kk3}|^2}{\sigma_{n3}^2} + \frac{|H_{kk4}|^2}{\sigma_{n4}^2}} \tag{3}$$

Here σ_{n1}^2, σ_{n2}^2, σ_{n3}^2, and σ_{n4}^2 are estimated average noise power at branch1, branch 2, branch 3, and branch 4, respectively.

2.4. Time and Frequency Impulsive Noise Cancelling

Because the presence of impulsive noise so-called shrimp noise, time and frequency noise cancelling (time-IMP, freq.-IMP) methods [5-6] are employed in the proposal system. Time-IMP detects impulsive noise samples in time domain, then clips the impulsive noise samples as follow

$$y(n) = \begin{cases} r(n) \quad if\ |r(n)|^2 \leq 5.P_{avg} \\ r(n) = 0\ if\ |r(n)| > 5.P_{avg} \end{cases} \tag{4}$$

Here $r(n)$ is n^{th} time sample of received signal after pre-amplifier, P_{avg} is the average power of an OFDM symbol. In addition, a frequency impulsive noise cancellation [6] is applied. For more detail about the freq.-IMP, please refer to [6].

3. EXPERIMENTAL RESULTS

The experimental parameters are shown in Table 2 and Fig. 4. Fig. 5-8 compares bit error rate among 1 single receiver (1BR), 2 diverse receivers (2BR) and four diverse receivers (4BR). The black square marked line means T-IMP and Freq-IMP are OFF, and no ICI cancelling. The blue triangle marked line means T-IMP and Freq-IMP are OFF, and ICI cancelling is applied. Finally, the red line is T-IMP and Freq-IMP are ON, and ICI cancelling is applied. In addition, Fig. 5 and 6 show Mode 3 when receivers are no moving and moving at 0.6 (m/s), respectively. Similarly, Fig. 7 and 8 shows Mode 2 when receivers are no moving and moving at 0.9 (m/s), respectively.

First, obviously, the four diversity improved bit error rate significantly for both no moving and no moving cases.

Next, considering moving cases, as shown in Fig. 6 and 8, the blue triangle marked line BER is better than the black square marked line BER. This proved that ICI cancelling improved performance. In Fig. 8, blue triangle marked line is just slightly better than black square marked line because OFDM symbol length of Mode 2 is shorter than Mode3, so Mode2 is more resistant to time varying channel.

Finally, the red line demonstrates that when freq.-IMP is applied, it also helps improve bit error rate. Fig. 9 will show more clearly improvement BER by applying freq.-IMP.

Item	Content
TX-RX Distance	51 m
4RX Interval	0.3 m
Ocean Depth	3 to 5 m
Transducer Depth	1 m
RX Transducer Velocity	0 (stable), 0.6, 0.9 m/s
Weather	No wind

Table 2: Experiment Parameters

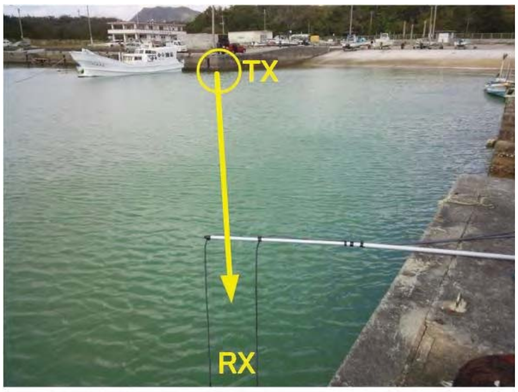

Fig. 4: Experiment Site

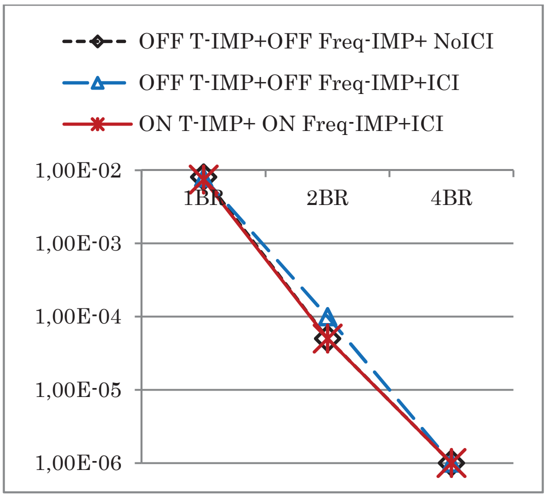

Fig.5: Mode3, QPSK, No Moving,

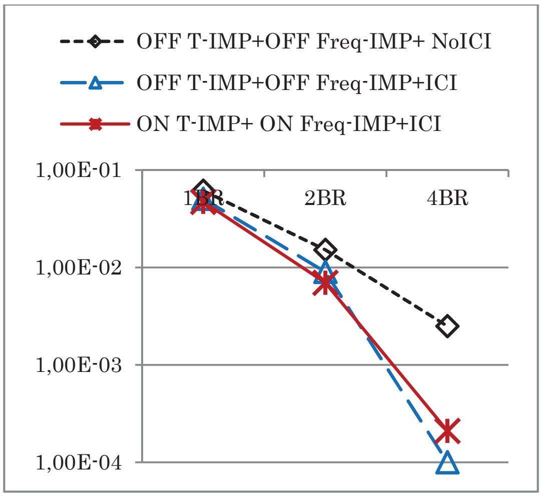

Fig.6: Mode3, QPSK, Moving 0.6m/s

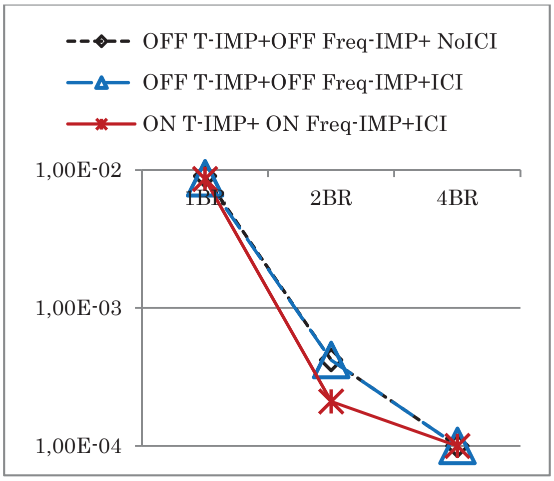

Fig.7: Mode 2, QPSK, No Moving

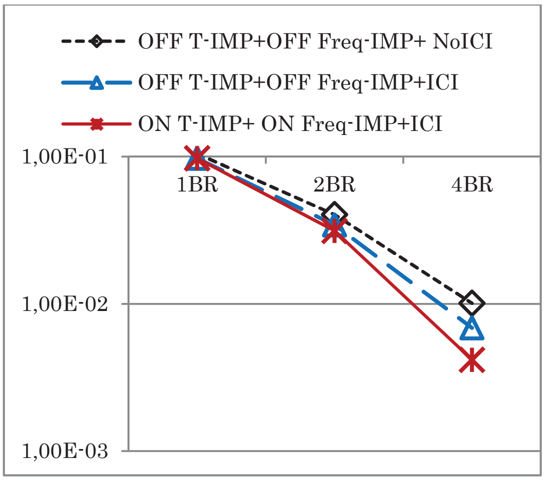

Fig.8: Mode2, QPSK, Moving 0.9m/s

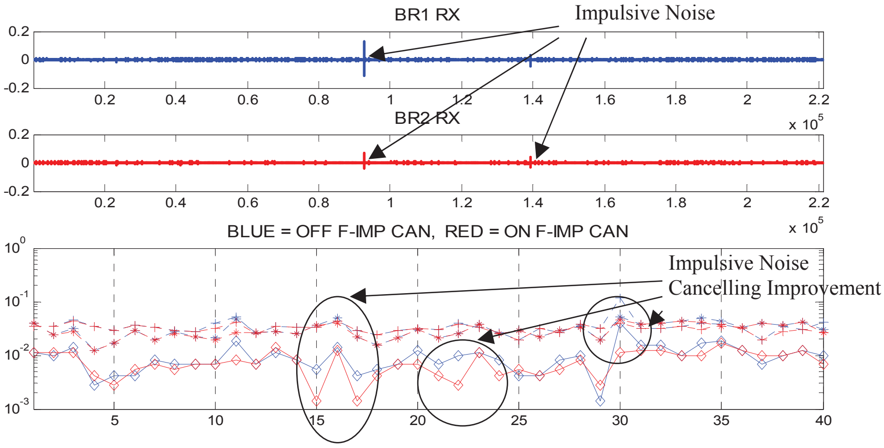

Fig.9: Time and Freq.-IMP Performance, Mode3, 64 QAM, 113m reception

In Fig. 9, received signal suffers impulsive noise, the red line means freq.-IMP is ON, and the blue line means freq.-IMP is OFF. At 13, 15, 17, 30 OFDM symbol point, impulsive noise is compensated successfully.

4. CONCLUSION

In this paper, an ultrasonic OFDM transceiver architecture with four diverse receivers, supporting Mode2 and Mode3, is proposed. Experiments were conducted to evaluate performance. To deal with challenges posed by the shallow sea transmission channel, we employed four techniques including diversity receiver, 2D-DFT channel estimation, ICI cancelling, time-IMP and freq.-IMP. As experimental result showed, those techniques have improved performance.

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