

# A 32 kHz Bandwidth, Robust TDD Synchronization, Underwater Small Area Acoustic Network (USAAN) System

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**Abstract**— Underwater acoustic wireless communication is one of the important foundation key technology to develop the ocean with using equipment such as AUV (Autonomous Underwater Vehicle), ROV (Remotely Operated Vehicle). This paper proposes Underwater Small Area Acoustic Network (USAAN) System with a 32 kHz bandwidth OFDM signals and robust TDD synchronization. We have developed the small hardware system, and ocean experiment has been performed at the barge in Uchiura bay, Shizuoka prefecture Japan. The base station (BS) side transducers are moved vertically with a motor drive for maximum 1.1 m/sec speed. Although the BS-TX is moving, stable DL to UL signal delay time is measured and fine synchronization performance is confirmed, and the demodulated 16QAM constellation is successfully confirmed at the user equipment (UE) side.

**Keywords**—Underwater, Acoustic Communication, Networking, MAC, TDD

## I. INTRODUCTION

Underwater wireless network is being demanded for underwater engineering and researches, to reduce a cable cost and a time to deploy. The typical applications of underwater wireless network include surveillance of areas as harbors, or monitoring of fishes and excavation sites and so on [1]. The design of protocol stack of underwater wireless network with taking into underwater channel and strict requirement is necessary for using technologies in effective application [2]. Because of long propagation delays in underwater acoustic channel, Media Access Control (MAC) design is challenging. Although many radio access MAC protocols are based on handshake type between a sender and a receiver, it is not efficient in underwater. In this paper [3], described about investigation of the performance of handshake-free MAC protocols for underwater communications.

In this paper, we propose an Time Division Duplex (TDD), non-handshake protocol, Underwater Small Area Acoustic Network (USAAN) system with Orthogonal Frequency Division Multiplexing (OFDM) modulation, to transmit control data, higher definition image or movie data packet inside 100 m diameter small underwater area. The system realizes four times bandwidth of 32 kHz to 8 kHz our previous prototype design [4].

Fig. 1 shows the target applications of TDD-USAAN system, such as the machine control and monitoring in civil engineering or marine aquaculture, and human to human communication in marine leisures.

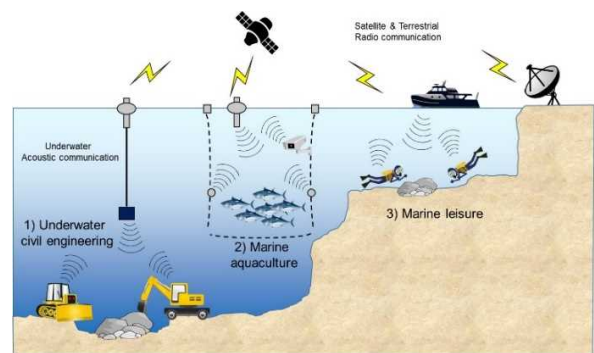


Fig. 1 Target applications of TDD-USAAN system.

## II. PROPOSED SYSTEM

### A. Overview of The System

Fig. 2 shows the overview of our TDD-USAAN system. It makes the wireless service area with one base station and plural of user equipment (UE). The base station transmit a Down Link (DL) signal in every frame of 1.0 sec. During the pre-determined empty slot, one of the UE can send a Up Link (UL) signal with synchronizing to DL signal. The figure shows the two UE case. Between all DL/UL signals, guard time is allocated to prevent interferences.

### B. System Block Diagram

The TABLE I shows the detail system features. This system has 1 TX transducer and 1 RX transducer. The size of FFT is 2048 points. The OFDM symbol length is 20.0 ms and number of subcarriers are 641. Then bandwidth of the signal is 32 kHz, and the range of transmit frequency is 16kHz – 48kHz. Guard Interval (GI) length is 5.0 ms with assuming major multi-path delay of less than 7.5 meter. The DL/UL total actual data transfer rate is 62.4 kbps in the case of using 16QAM modulation.

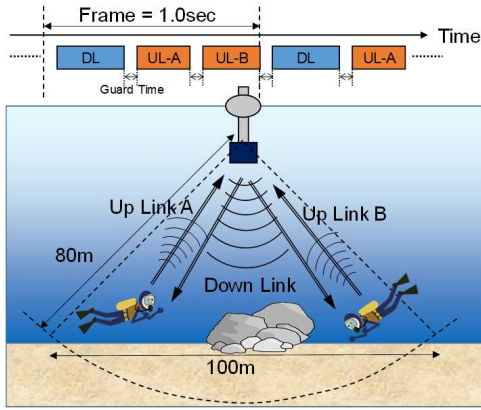


Fig. 2 Overview of TDD-USAAN system. The diameter of supported wireless service area is 100 m. The system support one BS and plural of UE terminal.

Table 1: System Parameters

Parameters	Value
TX-RX Elements	1 TX and 1 RX Transducer
Sampling Frequency	102400 Hz
TX Frequency	16k – 48k Hz
Band Width	32k Hz
FFT Size	2048
OFDM symbol length T	20.0 ms (2048 points)
GI length T <sub>g</sub>	5.0ms (512 points)
Effective Symbol length T <sub>u</sub> =T+T <sub>g</sub>	25.0ms
Chirp Signal Length for Frame Sync	20.0ms
Guard Time between DL/UL packet	55.0ms
Sub Carrier Spacing	50.0 Hz
Number of Sub Carrier	641
Number of Pilot in OFDM symbol	Zadoff–Chu, N <sub>ZC</sub> = 352 and 41
DL+UL Data Rate	62.4kbps (16QAM)

Fig. 3 shows the block diagram of system. The upper side is a transmitter while lower side is a receiver. In the TX side, bits information are modulated by using QPSK/16QAM/64QAM digital modulations, and BPSK modulated pilot symbols are inserted to measure time-varying channel condition. Guard interval (GI) is attached to the head of each OFDM symbol. To realize robust and fine time synchronization, a Chirp signal is prepended to all DL/UL signals. The baseband signal is up-converted to center frequency of 32 kHz. Finally, the OFDM passband signal amplified with the power amplifier is emitted from TX transducer into underwater acoustic channel. In the RX side, the signal amplified by pre-amplifier is down-converted to baseband signal. Time synchronization performed and time-

domain Doppler compensation [5], which consists of Resample, De-rotation, Phase compensation, is performed.

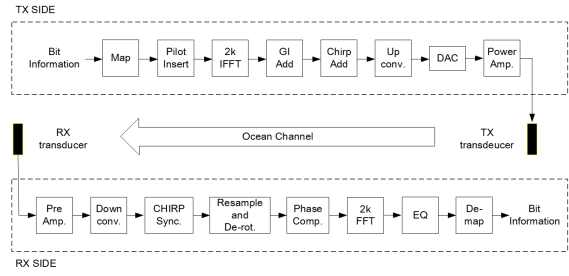


Fig. 3 Block diagram of USAAN system. Upper side is a transmitter while lower side is a receiver. Chirp signal is used for robust time domain synchronization.

Fig. 4 shows the frame design of USAAN system. This system has designed assuming two UE, so the TDD frame is composed of one DL signal and two UL signals (UL1 and UL2). UL1 signal used for UE1 and UL2 signal used for UE2. DL signal composed of a Sync Sub Frame and three Data Sub Frames, and UL1 and UL2 respectively composed of a Sync Sub Frame and two Data Sub Frames. The Sync Sub Frame is composed of three parts as Guard Time, Chirp signal and one OFDM symbol, and timing between the base station terminals is synchronized by a Chirp signal. Each Data Sub Frames respectively composed of four OFDM symbols, so there are 13 OFDM symbols in DL signal and 9 OFDM symbols in UL1/UL2 signal respectively.

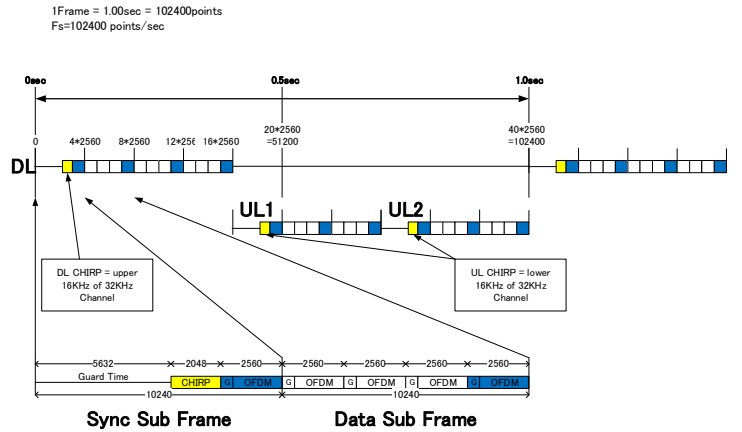


Fig. 4 Frame Design of USAAN system.

Fig. 5 shows the Time-Frequency Diagram of USAAN system. In this figure, the blue coloured symbols corresponds to Scattered Pilots (SP) symbol, and yellow symbols corresponds to Continuous Pilots (CP). The SP placed every even number sub-carriers are used to measure Channel Transfer Function (CTF). The CTF value on the blue sub-carriers are two dimensionally interpolated to get whole CTF values in Time-Frequency Diagram. The 13 CP placed on only even number of sub-carriers of both edges.

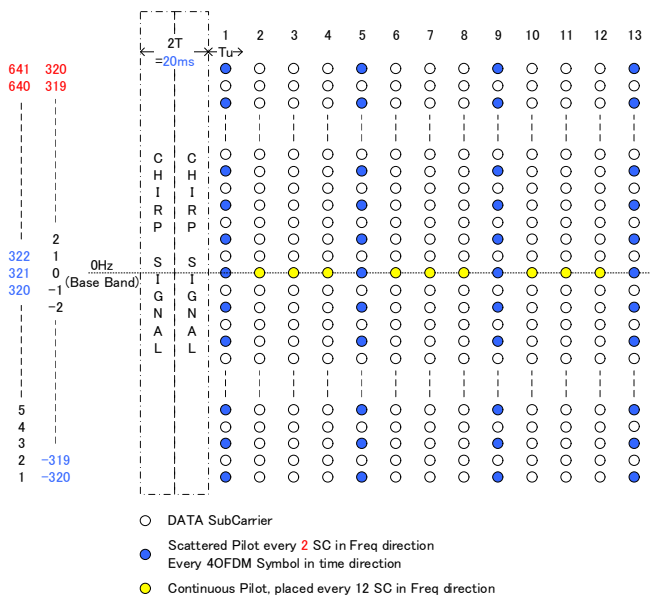


Fig. 5 Time-Frequency Diagram of USAAN system. There are two Chirp Signals before OFDM Signals.

Fig. 6 shows the baseband DL chirp signal. The chirp signal is linearly frequency sweeping signal. The sweeping range of DL chirp signal is 0 Hz to 16 kHz using upper 16 kHz of 32 kHz channel, and as well as this, the range of UL chirp signal is 16 kHz to 0 Hz using lower 16kHz. To realize easy synchronization, there are twice 2048 points sweeps. At the RX side, the DL signal starting point can be detected by chirp signal.

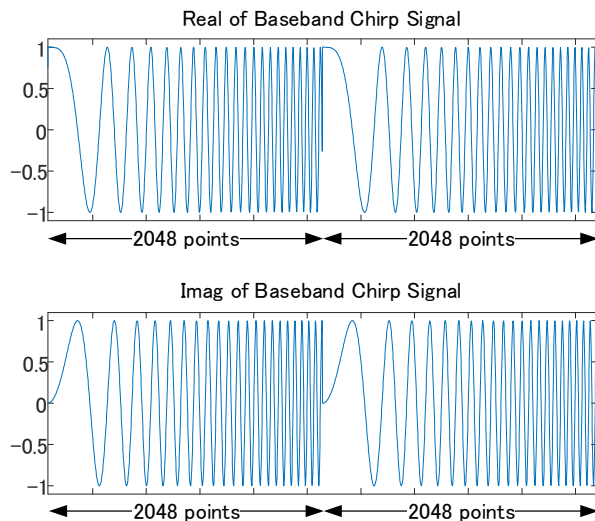


Fig. 6 Baseband DL Chirp Signal.

### C. System Implementation

Fig. 7 shows the block diagram of implemented target system. The target system composed of BS and UE. BS composed same of components of UE. The signal processing board with Xilinx Zynq-7000 (ARM core + FPGA) is used for digital signal processing, and OST 7010 power amplifier drives TX transducer through transmit transformer.

#### USAAN system block diagram

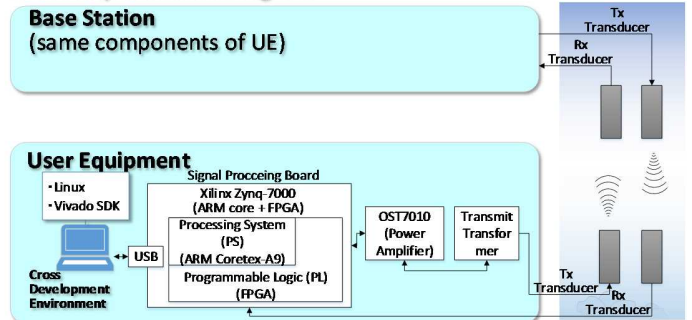


Fig. 7 USAAN implemented target system block diagram. The UE is composed of Signal Processing Board, OST7010 (Power Amplifier), and Transmit Transformer.

Fig. 8 shows the developed small hardware system of BS and UE. The DL/UL total data bandwidth is 62.4 kbps in the case of using 16QAM modulation. This system has the capability to enable communication at a distance of about 1000 m or more in the vertical direction from bottom to surface of sea.



Fig. 8 Developed small hardware system. Zynq7000 ARM-embedded FPGA is used for digital signal processing and OST7010 Power Amplifier drives TX transducer through transformer.

### III. OCEAN EXPERIMENT RESULTS

To verify a robustness of the Chirp synchronization of the system, ocean experiment is performed at the barge in Uchiura bay, Shizuoka prefecture, Japan with the configuration shown in Fig. 8.

BS side transducers are moved up and down vertically with a motor drive in depth of 2m – 6m from surface of sea. The maximum moving speed is 1.1 m/sec. UE side transducers are fixed in 20 m depth from surface of sea. BS side has two transducers, one is a DL-TX and the other is UP-RX transducer

as shown in Fig. 9. The interval of transducers is 30 cm. Fig. 10 shows the scene of ocean experiment at the barge.

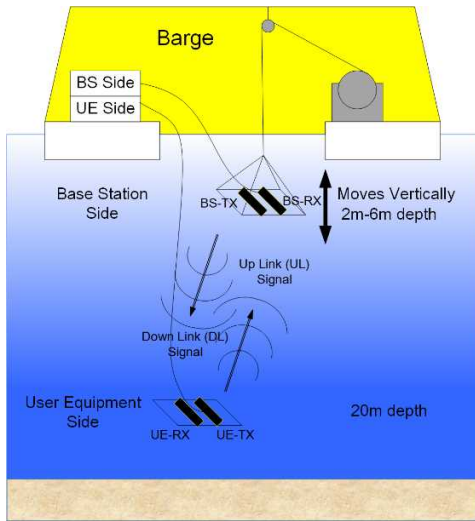


Fig. 8 Ocean Experiment to check Robust TDD synchronization. BS-TX transducer moves vertically while US-RX received signal is used for TDD synchronized.

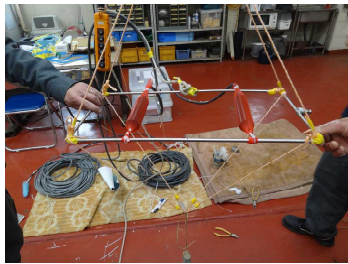


Fig. 9 BS transducers. It is composed of DL-TX and UP-RX transducer. The interval of transducers is 30 cm. UE side is same as above.



Fig. 10 Ocean Experiment scene at the barge. BS side transducers are submerged in water, and moved up and down vertically with a motor drive. UE side transducers are fixed at bottom of sea.

Fig. 11 shows measured time domain DL and UL signal with triggering to the DL signal. Although the BS-TX is moving, stable DL to UL signal delay time is measured and fine synchronization performance is confirmed. Demodulated 16QAM constellation at UE-RX side is successfully confirmed as shown in Fig. 12.

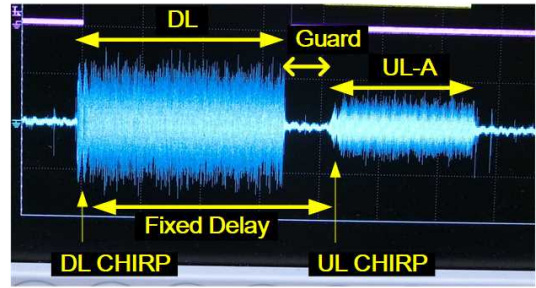


Fig. 11 Measured TDD waveform. Although DL start timing fluctuates according to BS-TX movement, DL to UL-A delay is kept fixed to keep Guard period.

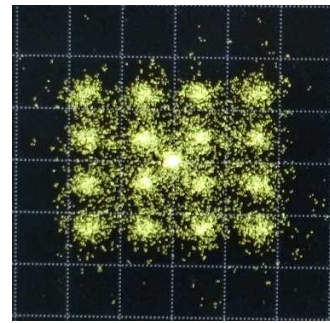


Fig. 12 Demodulated 16QAM constellation at UE-RX side

Fig. 13 shows every frame's UL starting point shift from the previous frame. Frame period is 1.0 sec and in every frame UL signal starting point is determined by the received DL Chirp synchronization. According to the figure, minimum -68 points shift corresponds to 1.00 m/sec BS-TX approach to UE-RX (moving down), and maximum +73 points shift corresponds to 1.07 m/sec BS-TX leave from UE-RX (moving up).

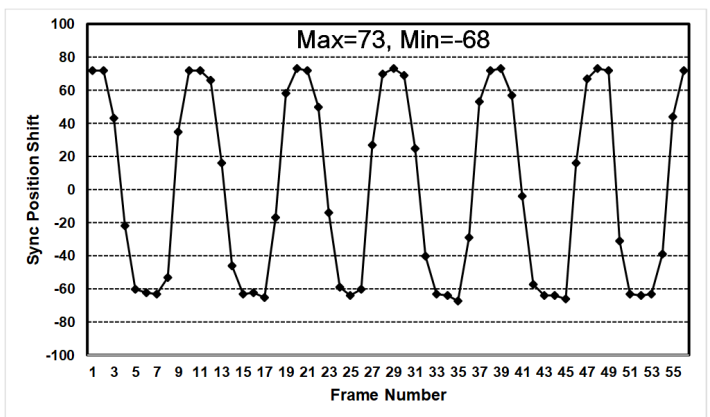


Fig. 13 UL-A starting point shift from previous frame. -68 points shift corresponds to 1.00 m/sec BS-TX approach to UE-RX (moving down), and +73 points shift corresponds to 1.07 m/sec BS-TX leave from UE-RX (moving up).

#### IV. CONCLUSION

Underwater Small Area Acoustic Network (USAAN) System with a 32 kHz bandwidth OFDM signals and robust TDD synchronization is proposed. We have developed the small hardware system using Zynq7000 ARM-embedded FPGA for digital signal processing. To verify a robustness of the Chirp synchronization of the system, ocean experiment has been performed at the barge in Uchiura bay, Shizuoka prefecture, Japan. The BS side transducers are moved up and down vertically with a motor drive for maximum 1.1 m/sec speed. Although the BS-TX is moving, stable DL to UL signal delay time is measured and fine synchronization performance is confirmed, and the demodulated 16QAM constellation is successfully confirmed at the UE side.

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