Channel Transfer Function Estimation based on Delay and Doppler Profile for Underwater Acoustic OFDM Communication System

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Summary
In this paper, we proposed Channel Transfer Function estimation based on Delay and Doppler Profile for underwater acoustic OFDM communication system. It improved the estimation accuracy of the channel transfer function by linear time interpolation the change of Scattered Pilot (SP) insertion frequency in the time direction and the time by Delay and Doppler profile that analyzes the multipath situation of the channel investigated the performance of interpolation by simulation and report it. Previous works is inserted SP every 4 OFDM. It was effective under the environment without multipath, but it has observed that the effect of CTF compensation has been lowered in multipath channel condition. In addition to be better when inserted SP every 2 OFDM. But the amount of sending data will be decrease. Therefore, we conducted research to improve 4 OFDM with new interpolator. A computer simulation was performed as a comparison of SP inserted every 4 OFDM, SP inserted every 2 OFDM, and 4 OFDM with new interpolator. the performance of the proposed system is overwhelmingly improved, and the performance is slightly improved even 64 QAM.
Keywords:
CTF, AUV, underwater acoustic communication, OFDM, Delay and Doppler estimation

I. Introduction

In recent years, deep sea exploration has become indispensable due to the development of offshore natural resources such as hydrothermal deposits. To accelerate the creation of seafloor fine topographic maps, deep sea area such as more than 3000 meter must be scanned by Autonomous Underwater Vehicles (AUVs). Exploration will be more convenient if high-speed AUVs and motherships can transmit data via underwater acoustic wireless communication. In mobile multipath communication without delayed waves, received wave compensation by resampling (31), compensation by two samples (36), and CTF compensation (63) have been used to improve reception performance for direct waves. Multipath occurs due to reflection from the sea surface in horizontal communication between the mothership and AUV. In a multipath situation, the main wave can be compensated by the above resampling, but the delay waves arriving from different angles and different moving speeds, so the above resampling cannot completely cope with them. It shows in Fig.1. Also, in order to improve reception performance, it is necessary to accurately estimate changes in the time direction of the channel transfer function due to delayed waves.

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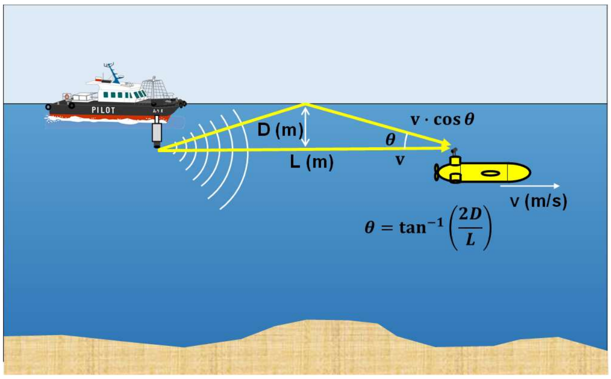


Fig.1: An image of the two-pass Doppler effect occurring

In this paper, in order to improve the estimation accuracy of the channel transfer function by linear time interpolation that has been improved, the change of SP (Scattered Pilot) insertion frequency in the time direction and the time by Delay and Doppler profile that analyzes the multipath situation of the channel. We investigated the performance of interpolation by computer simulation and report it.

II. Architecture

This section is explained about previous works and proposed system. In this section, our previous work and new proposal are explained.

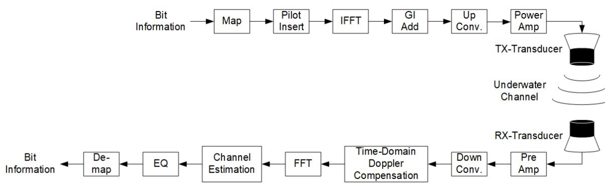
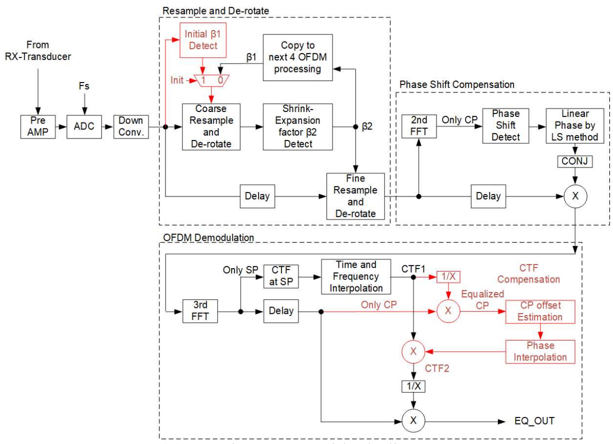


Fig. 2: OFDM block diagram

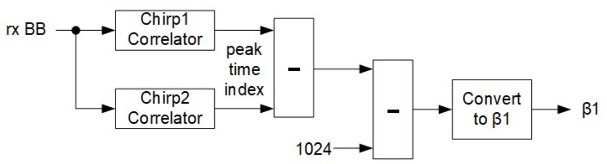
A) *Previous Work*

Previous work is proposed Improved Doppler compensation and Initial Synchronization[1]. In the previous work, the methos of both Improved Doppler compensation and Initial Synchronization are proposed. It is based on [5] and [6]. Fig.2 is OFDM block diagram. It added Time-Domain Doppler Compensation before FFT. Fig.3 is proposed receiver system block diagram with (1) receiver system block diagram and (2) block diagram of initial $\beta 1$ detector.

The upper side red part is system detects the initial phase shift β1 using a chirp signal in (1) of Fig.3. Lower side is CTF-corrected SP signal and 13 phase-corrected CP signals Corrected and added and improved the equalizer as a result, it be able to confirm that the BER value was reduced, and the performance was improved even when moving at high acceleration. (2) of Fig.3 is block diagram of initial $\beta 1$ detector. It shows OFDM Signaling Packets with two Chirp preamble for Initial $\beta 1$ detection [6].



(1) Receiver system block diagram



(2) Block diagram of initial $\beta 1$ detector

Fig. 3: Proposed receiver system block diagram with (1) receiver system

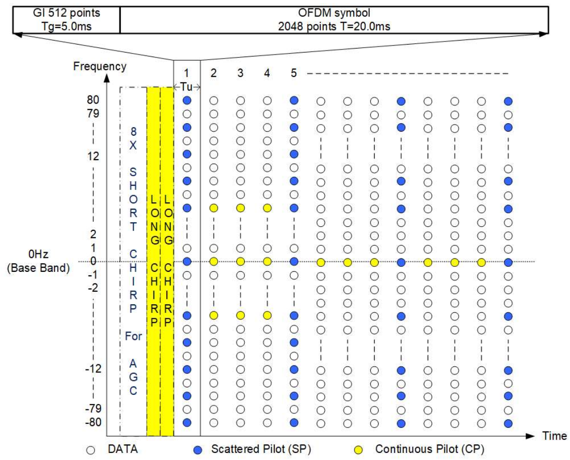


Fig. 4: Time-Frequency structure of OFDM that is inserted SP

By Inserting up-chirp and down-chirp signal, correlation positions move different direction for each chirp signals. Then Initial velocity can be estimated. This is a method of correcting the Doppler effect by inserting two long chirp signals at the beginning of an OFDM signal, detecting the difference in frequency between the two signals, and applying that value to the initial value of β1. The detail of β1 is shown in (2) of Fig. 3. Each chirp signal has a sampling frequency of 102.4ksps. Chirp 1 is -4kHz ~ +4kHz and chirp 2 is +4kHz ~ -4kHz. Fig.6 shows Time-Frequency structure of OFDM. SP is inserted every 4 OFDM. Time-Frequency structure of OFDM in Fig.4. The blue color is SP that is inserted every 4 OFDM. Table.1 is the OFDM system parameter. OFDM symbol length is 2048, Guard Interval length is

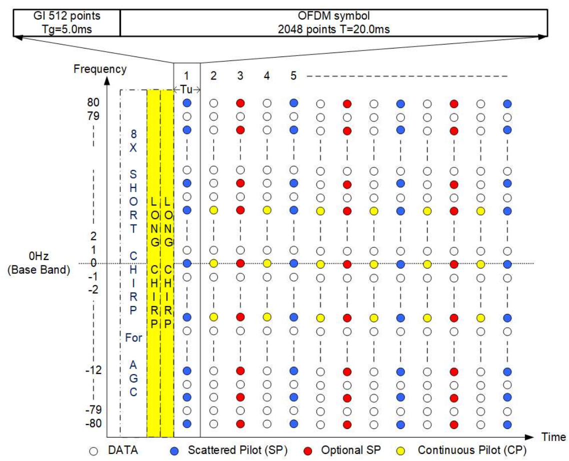


Fig. 5: Time-Frequency structure of OFDM that is inserted SP

Table 1: OFDM system parameter

Parameters	Value
Sampling Frequency Fs	102.4kHz
Band Width	8 kHz
FFT size	2048
OFDM symbol length T	20.0 ms (2048 point)
Guard Interval length Tg	5.0 ms (512 point)
Sub-carrier spacing	50 Hz
Number of sub-carrier	161
Scattered pilot	81 every 4/2 OFDM symbol
Continuous pilot	13
Carrier Modulation	QPSK/16QAM/64QAM

512, and Carrier Modulation is QPSK, 16QAM and 64 QAM.

As a result of the computer simulation, the Doppler compensation is effective. The newly added initial β1 detector was effective and could be detected cleanly even at 64 QAM at the computer simulation stage. Experiments in a non-reflection pool show that 16QAM can be detected clear, and even 64QAM with CTF compensation can be detected cleanly, proving that the new system can improve the Doppler effect.

Although the proposed CTF compensation has drastically decreased the number of BER at high transducer acceleration in the pool experiment, it has observed that the effect of CTF compensation has been lowered in multipath channel condition[1].

Fig.5 is time-frequency structure of OFDM that is inserted SP every 2 OFDM. It will better than inserted SP every 4 OFDM, but the amount of sending data will be decrease. Therefore, we proposed 4 OFDM with new interpolator.

B) *Improved Channel Transfer Function estimation based on Delay and Doppler Profile*

References [2-4] describe methods for detecting delay profiles and Doppler profiles of transmission channels using pilot signals embedded in OFDM subcarriers. Fig.6 is block diagram of improved system. Red part is changed. Fig.7 is Delayed path with Doppler Shift. Fig.7 shows 5 OFDM symbols with one delayed

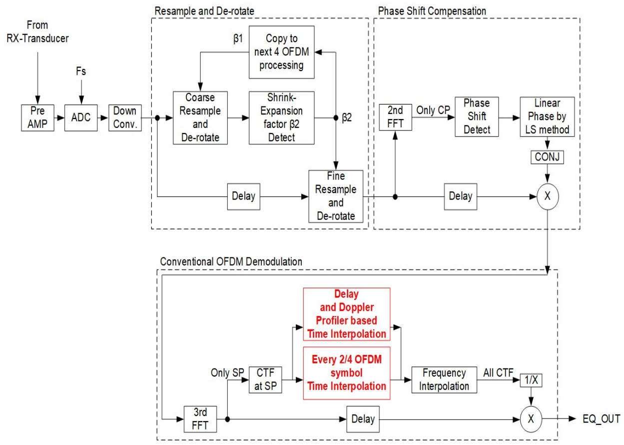


Fig. 6: Detail of receiver block diagram

path for no moving and moving cases. By using the method of previous work, the resampled signals are shown in the bottom of the figure. Since the delayed path signal has affected by different Doppler velocity as $v * cos\theta$, resampled delayed signal virtually affected by Doppler shift of $v(1 - cos\theta)$. As shown in Fig. 8, a SP inserted every 4 OFDM symbols was used in an underwater OFDM communication system, and complex pilot signals were used for each i-th path signal that constitutes a multipath with a delay and Doppler profile. By finding the attenuation factor r_i, the relative delay time τ_i and the Doppler frequency α_i normalized by the subcarrier spacing frequency f_0, the Channel Transfer Function of each delay path can be calculated as follows. N is the FFT size, N_p is the total number of delay paths, T_s is the sum of OFDM symbol length and guard interval length, and $h(k, l)$ is the channel transfer function with symbol number k and sub-carry index l.

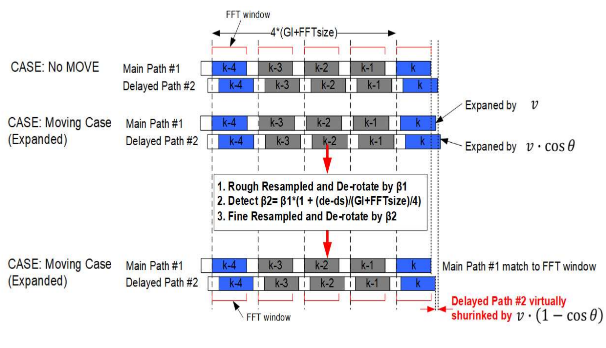


Fig. 7: Delayed Path with Doppler Shift

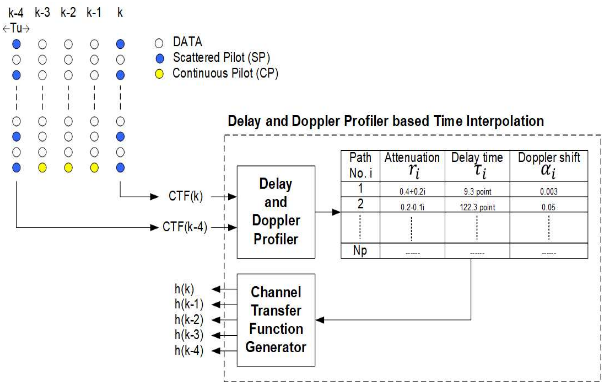


Fig. 8: Detail of Delay and Doppler interpolator

$$h(k,l) = \sum_{i=1}^{N_P} \frac{1}{N} \frac{\sin\{\pi(\alpha_i)\}}{\sin \frac{\pi(\alpha_i)}{N}} \times e^{j\frac{\pi(N-1)\alpha_i}{N}} \times e^{j2\pi\alpha_i f_0 T_s k} \times r_i e^{-j2\pi f_0 (l+\alpha_i)\tau_i} \quad \cdots (1)$$

That is, if the delay and Doppler profile are known, changing the symbol number k can obtain CTF at different times.

The method of obtaining the parameters in each delay path of the delay and Doppler profile is also detailed in references [2-4], but now scattered pilots are inserted at symbol numbers k and $k-4$, Estimation is performed using the channel transfer function of that part. Consider the following estimated evaluation function $E(k)$. CTF is the CTF value measured by the scattered pilots, h is the channel transfer function to estimate, and h is estimated by minimizing $E(k)$.

$$E(k) = \sum_P |CTF(k,l) - h(k,l)|^2 + \sum_P |CTF(k-4,l) - h(k-4,l)|^2 \cdots (2)$$

First, the maximum power delayed wave in each delay path is detected by minimizing the following equation.

$$E_1(k) = \sum_P \left|CTF(k,l) - f(\alpha_1) r_1 e^{-j2\pi f_0 (l+\alpha_1)\tau_1}\right|^2 + \sum_P \left|CTF(k-4,l) - f(\alpha_1) e^{j2\pi\alpha_1 f_0 T_s(-4)} r_1 e^{-j2\pi f_0 (l+\alpha_1)\tau_1}\right|^2 \ldots (3)$$

where $f(\alpha_1)$ is given by

$$f(\alpha_i) = \frac{1}{N} \frac{\sin\{\pi(\alpha_i)\}}{\sin\frac{\pi(\alpha_i)}{N}} \times e^{j\frac{\pi(N-1)\alpha_i}{N}} \times e^{j2\pi\alpha_i f_0 T_s k} \quad \ldots (4)$$

Details are given in reference [2-4], but r_1, τ_1, and α_1 can be obtained by minimizing $E_1(k)$.
This yields the channel transfer function of the first pass according to equation (1). By subtracting the obtained channel transfer function of the first pass from the CTF value measured by the SP value, a new CTF value is obtained, and the same calculation is performed to obtain the parameters of the second pass. can. By repeating the above calculations as many times as necessary, the parameters for each pass are obtained. Once the parameters of all N_p paths are known, we can synthesize the channel transfer functions according to equation (1), and by varying the symbol number k, we can obtain the channel transfer functions corresponding to k from $k-4$. can.

III. Computer Simulations

The simulation mainly compares BER and SNR (dB), BER and DUR (dB), and BER and Depth. Table.2 shows the simulation conditions. Number of Symbol is 21, Acceleration is 0 m/s. Velocity is 3 m/s, Initial velocity is 5m. Depth is 1 to 5.8, DUR(dB) is 2 to 16, and SNR(dB) is 2 to 30. It compared inserted SP every 4 OFDM, inserted SP every 2 OFDM and 4 OFDM with Interpolate. Blue line with circle is inserted SP every 4 OFDM version, red line with triangle is inserted SP every 2 OFDM version, green line with square is 4 OFDM with new Interpolator.

Table 2: Simulation Conditions

Parameters	Value
Number of Symbol	21
Acceleration	0 m/s
Velocity	3 m/s
Initial velocity	5 m
Depth	1, 2, 3, 4, 5, 5.8
DUR(dB)	2, 4, 6, 8, 10, 12, 14, 16
SNR(dB)	2, 5, 7, 10, 15, 20 ,25, 30

A) BER vs SNR (dB)

BER and SNR were simulated. DUR is fixed 6 dB, SNR is 2 to 30. Fig.9 to FIig.11 are shown simulation result. Blue line is SP inserted every 4 OFDM. It is kept worse. Red line is SP inserted every 2 OFDM. The BER is getting better from SNR 10 dB. Green line is 4 OFDM with new interpolator that is proposed. The red line and green line are getting better from SNR 10 dB. The red color is the best improved BER, but the green color is better than other line from 5 dB. Fig.10 is 16 QAM. The BER is getting worse but green line that is proposed was lower than green line and red line. Fig.11 is 64 QAM. Overall results are worse and not converged. But green color that is 4 OFDM with new interpolator is lower than other lines.

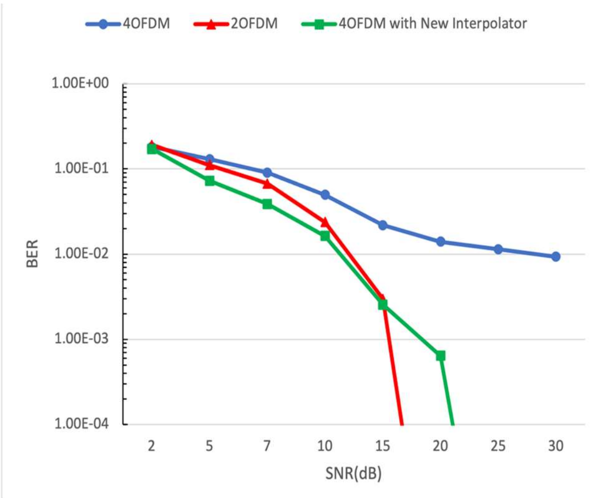


Fig. 9 : BER vs SNR (dB), QPSK

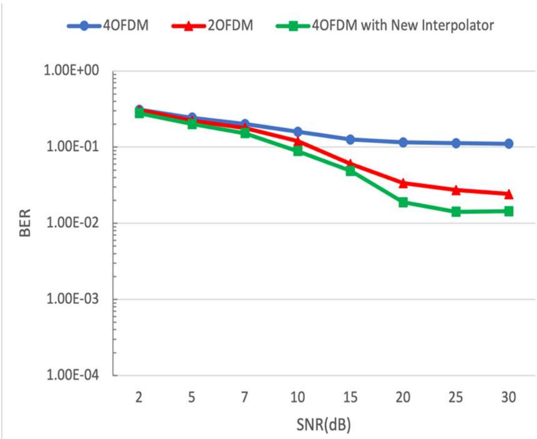


Fig. 10 : BER vs SNR (dB), 16QAM

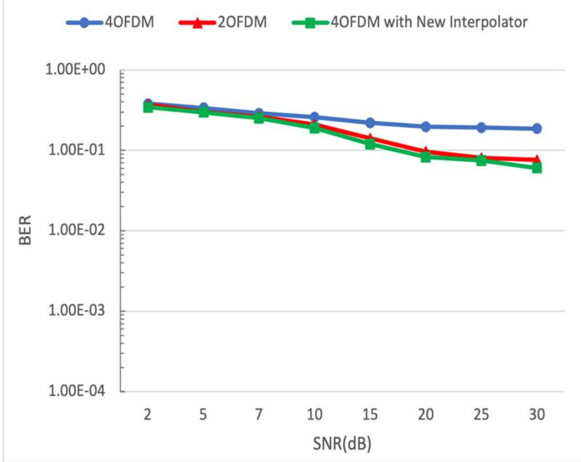


Fig. 11 : BER vs SNR (dB), 64QAM

B) BER vs DUR (dB)

BER and DUR were simulated. SNR is fixed 30 dB, DUR is 2 to 16. Fig.12 to Fig.14 is shown simulation result. DUR means second wave. Blue line is worse more than red line and green line. Fig.13 is 16 QAM. 4 OFDM is kept worse. The red line shows gradual BER improvement from DUR 12 dB. The green line is getting better DUR 9 dB. Fig.14 is 64 QAM. The green line that is proposed is better than other lines. It is getting better from DUR 14 dB.

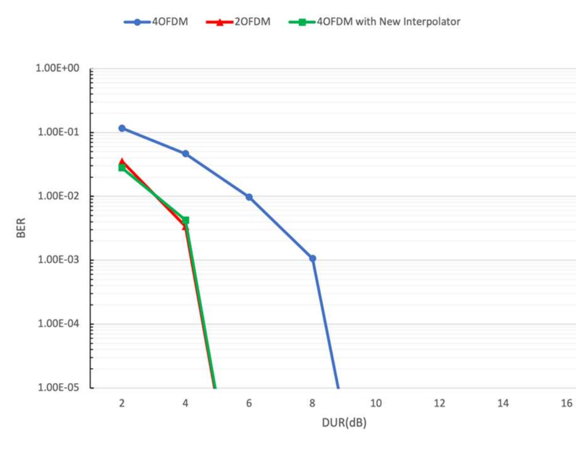


Fig. 12 : BER vs DUR (dB), QPSK

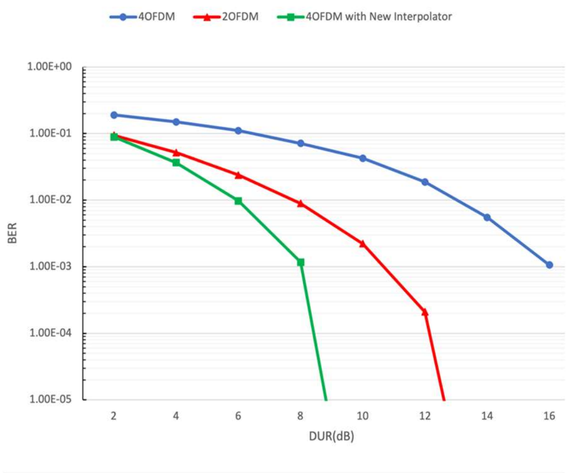


Fig. 13 : BER vs DUR (dB), 16QAM

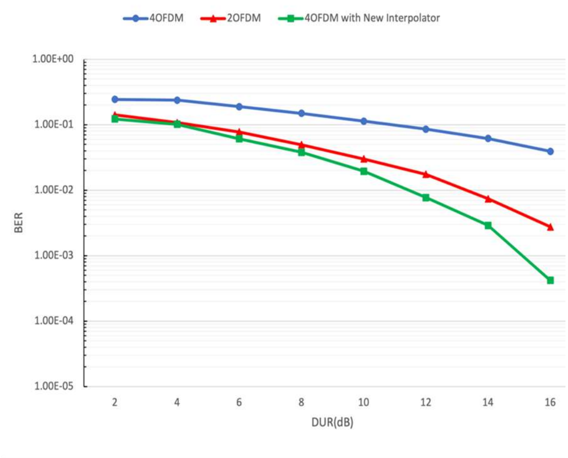


Fig. 14 : BER vs DUR (dB), 64QAM

C) *BER vs Depth (m)*

BER and Depth were simulated. DUR is fixed 6 dB, SNR is fixed 30 dB, Depth is 1 to 5.8. Fig.15 to Fig.17 is shown simulation result. Fig.15 QPSK, blue line is getting worse from 1.8m. Red line and green line is better than blue line. Fig. 16 is 16 QAM. All line were getting worse from 2 m but BER of green line that is proposed were lower than other 2 lines. Fig. 17 is 64QAM. BER of all line were worse. These are considered that there is a lot of interference with other signals and convergence does not occur.

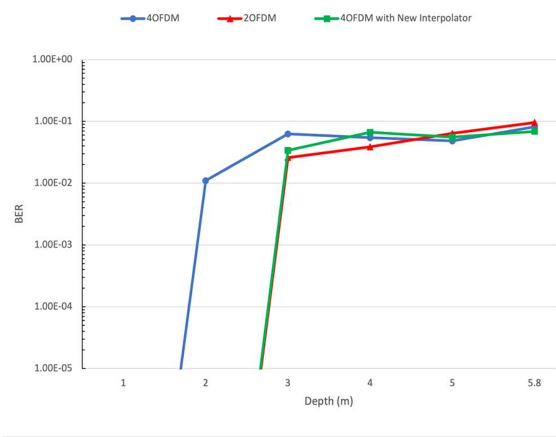


Fig. 15 : BER vs Depth (m), QPSK

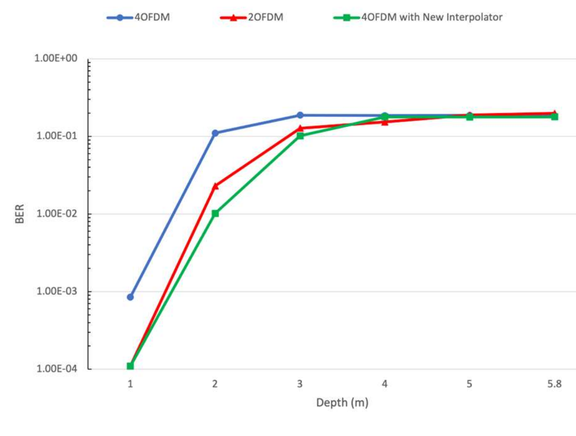


Fig. 16 : BER vs Depth (m), 16QAM

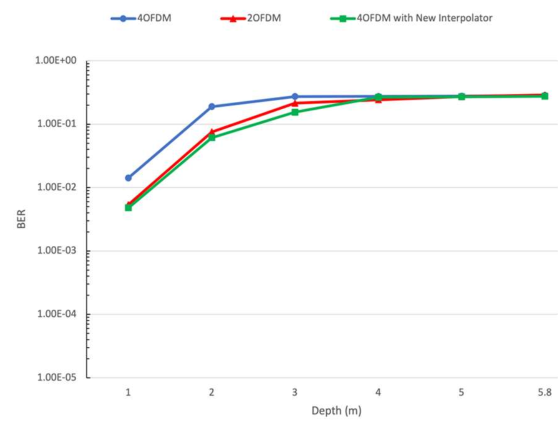


Fig. 17 : BER vs Depth (m), 64QAM

IV. Conclusion

In this paper, in order to improve the estimation accuracy of the channel transfer function by linear time interpolation, the change of SP insertion frequency in the time direction and the time by Delay and Doppler profile that analyzes the multipath situation of the channel I investigated the performance of interpolation by simulation and report it.

Computer simulation is compared BER and SNR (dB) , BER and DUR (dB), and BER and Depth (m). The result of BER and SNR (dB), proposed system is getting better from 21 dB on QPSK. BER and DUR(dB) also getting better from 5 dB on QPSK, and from 9 dB on 16 QAM. BER and Depth (m) is getting worse from 2.8 m on QPSK, and from 2 m on 16 QAM. Overall results, 4 OFDM with new interpolator is getting better than 4 OFDM and 2 OFDM. We performed computer simulation this time. Our future task is more improve the system and do oceans experiment next year.

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