Method of selecting signals with spatial-temporal diversity for underwater communication using OFDM technique

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ABSTRACT

In this paper, we propose a reliable communication solution using space-time diversity technique but using only one transceiver antenna applied to mobile OFDM system in underwater communication environment. In our solution, instead of using multiple receive antennas, the transmitter transmits an OFDM signal N times consecutively. The moving transmitter during sending OFDM frames will creat both spatial and temporal diversity of the received signal. To decode the signal from N received OFDM signal frames, we propose an optimal frame selection method to increase efficiency as well as save decoding time. The simulation and experimental results show that the system can achieve a better SER error rate than the MRC technique applied to N received data frames and the number of calculations in our algorithm is also less than that of combination maximum cases of N frames.

Keywords: Underwater Acoustic Communications (UAC); OFDM; Doppler frequency compensation.

1. INTRODUCTION

Multi-antenna MIMO transceiver system is widely used in wireless systems to improve bandwidth efficiency or increase transmission rate and signal quality. The use of multiple transceiver antennas is achieved by the spatial and temporal diversity of the radio signal. Spatial diversity technique is understood as the change of position between transceiver antennas thereby changing the channel state. The time diversity technique is based on the time-dependent of the radio channel so that a signal can be transmitted at different times. Combined with the space-time diversity for the signal, many coding techniques have been applied such as STBC (Space Time Block Coding), SFBC (Space Frequency Block Coding), Alamouiti,…[1].

In the underwater communication environment, the signal bandwidth is very limited, only a few tens of KHz. So to increase bandwidth efficiency, people often use OFDM techniques [2- 5]. However, the propagation speed of sound waves is very low compared to the propagation speed of electromagnetic waves, any relative motion between the transmitter and receiver will cause a very large Doppler shift in the receiving signal [6, 8]. Therefore, in underwater communication systems to improve signal quality as well as bandwidth efficiency, it is necessary to use multiple transceiver antennas to take advantage of the advantages of spatial and temporal diversity signal. However, in many cases, a system with too many antennas will become cumbersome, consume a lot of energy and hinder the movement of equipment. In this paper, we apply the space-time diversity technique to the underwater communication system but only use one transceiver antenna. The technique we use is suitable for communication environments where there is relative motion between transmitter and receiver. In the case of motion, there will be a spatial and temporal change in position, thereby creating a space-time diversity of the received signal.

Because underwater channels are often affected by high noise, the quality and bandwidth is much worse than that of conventional radio channels. In this paper, we propose to transmit a hydroacoustic signal from a transceiver antenna, but the transmitted signal will be repeated N times. Number N will be depended on the quality of the transmission channel condiction. The signals are transmitted repeatedly at different times, thus creating time diversity. Due to the relative motion between the transmitter and receiver, the same signal will be transmitted at two different locations, which creates diversity in the signal space.

The transmission of the same signal many times is equivalent to a system of 1 transmit antenna N receive antenna. But in a system of 1 transmit and N receive antennas, we only have spatial diversity of the received signal, but no temporal diversity.

The most common signal decoding for a system of 1 transmitting antenna N receiving antenna is using the MRC technique (Maximum Ratio Combination) [7]. In MRC technique, the same transmit signal received from multiple receiving antennas will be combined to give the best reception result. However, using signals from all antennas for decoding is sometimes not the best, especially in the case of underwater communications where the communication medium is greatly affected by noise and factors such as waves, wind, weather,... Therefore, the signal received in the hydroacoustic environment has a great difference. This will affect the signal decoding results if MRC is used. Therefore, in this paper, we also propose an algorithm to choose the optimal transmission frame to increase decoding efficiency when using MRC technique.

This paper is organized as follows: Section 1 will introduces this paper. Section 2 describes the proposed architechture of an acoustic OFDM system. The proposed transmitting Frames and selection method is presented in section 3 and 4. The experimental results of thesystem using our method is discussed in section 5. Section 6 concludes the paper.

2. SYSTEM DESCRIPTION

Our OFDM modulation and demodulation system is shown in Fig. 1. The details of the operating principle of the system are described in [8]. Fig. 1: The block structure of the implemented OFDM-based UWA system using the proposed algorithm [8].

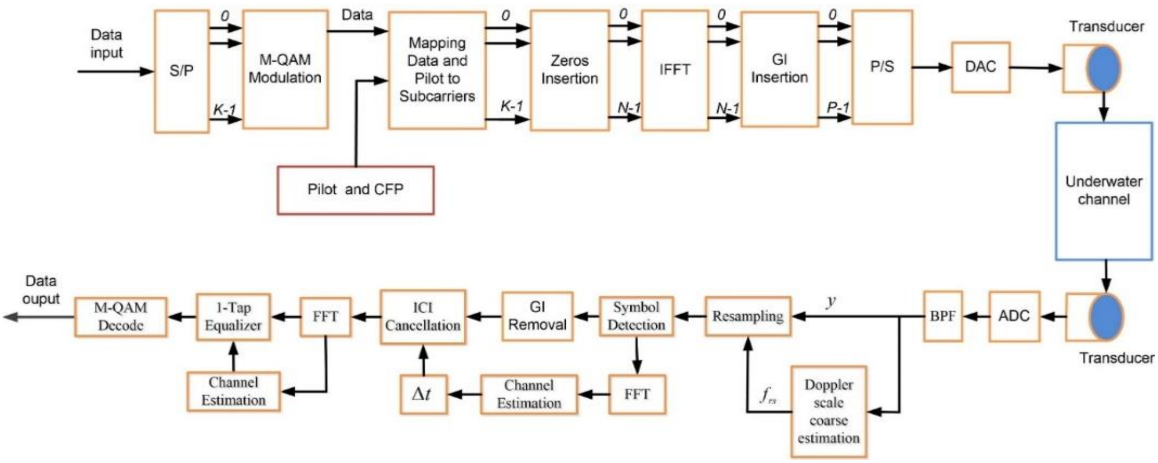

Figure 1. *The block structure of the implemented OFDM-based UWA system using the proposed algorithm [8].*

3. PROPOSED TRANSMITTING SIGNALS

For MIMO transceiver multiple antenna systems, the case of a single transmit antenna with multiple receive antennas is a special case (SIMO).

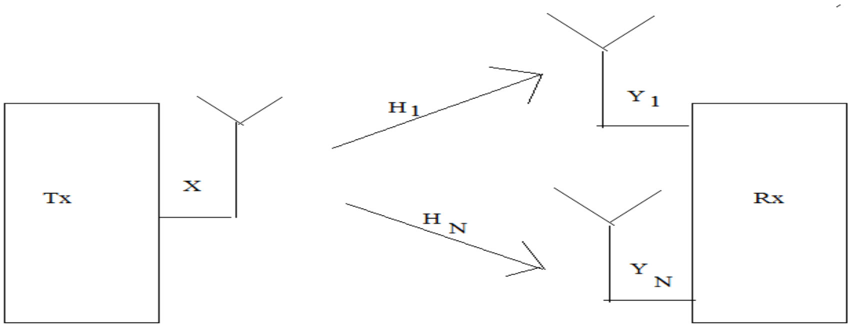

Figure 2. *Single Input Multiple Output system (SIMO).*

A system of 1 transmitting antenna with N receiving antennas is shown in figure 2.

Where X is transmitting signal,

H is channel between transmitting anten and N receiving antennas:

$$H = \begin{bmatrix} H_1 \\ \vdots \\ H_N \end{bmatrix} \quad (1)$$

Y is receiving signals from N antennas.

$$Y = \begin{bmatrix} Y_1 \\ \vdots \\ Y_N \end{bmatrix} \quad (2)$$

The relation between X,H,Y is

$$Y = H.X + N \quad (3)$$

Where N is Gaussion noise.

The signal decoding technique according to MRC method applied to the system of a single transmit and receive multiple antenna is implemented as follows.

$$X_r = \frac{H^H Y}{H^H H} \quad (4)$$

Where H^H is transposition and complex conjugation;

X_r is decoded signal.

For hydroacoustic communication system, instead of using multiple receiving antennas, we suggest using 1 receiving antenna but the transmitter will transmit an outgoing signal N times in succession see Fig. 3.

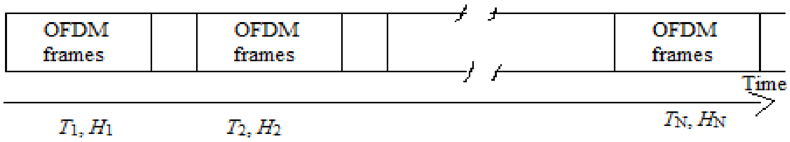

Figure 3. *One OFDM signal frame is transmitted repeatedly N times.*

In this case, T_i is transmitting time *i* and H_i is channel at time *i*. With *N* transmissions we have the transmission channel of the system like equation (1). And receiving signal from *N* transmission times like equation (2). The relation between transmitting signal, channel and receiving signals is equation (3). Thus, our proposal for the case of one transceiver antenna is also equivalent to a system of one transmitting antenna N receiving antennas.

4. PROPOSED FRAME SELECTION METHOD

In SIMO system, the accuracy of the decoding signal increases as the number of receiving antennas increases. However, if increasing number of receiving antennas, the system will become cumbersome and decrease the space diversity capability. In our case, the moving tranceivers is an advantages. This this moving will create space-time diversity for the hydroacoustic signal.

For hydroacoustic signals, the received signal is N frames. But using N frames to decode the signal by MRC conventional method is not an optimal choice because of the fact that very high noise in water will creat the big difference in signal quality between receiving frames. Therefore, applying MRC technique to N frames is not the most optimal solution. Normally, to optimize the decoding signal, we need to combine all possible cases with N frames, there will be all Q possibilities.

$$Q = \sum_{i}^{N} C_N^i \tag{5}$$

For a large value of N, for example, with N=10 there will be 1023 possibilities. This will not be suitable for a real-time communication application or will affect the transmission speed.

To choose the best solution, we propose an optimal decoding algorithm for the N received OFDM signal frames. The decryption algorithm is described as shown below. The algorithm works as follows.

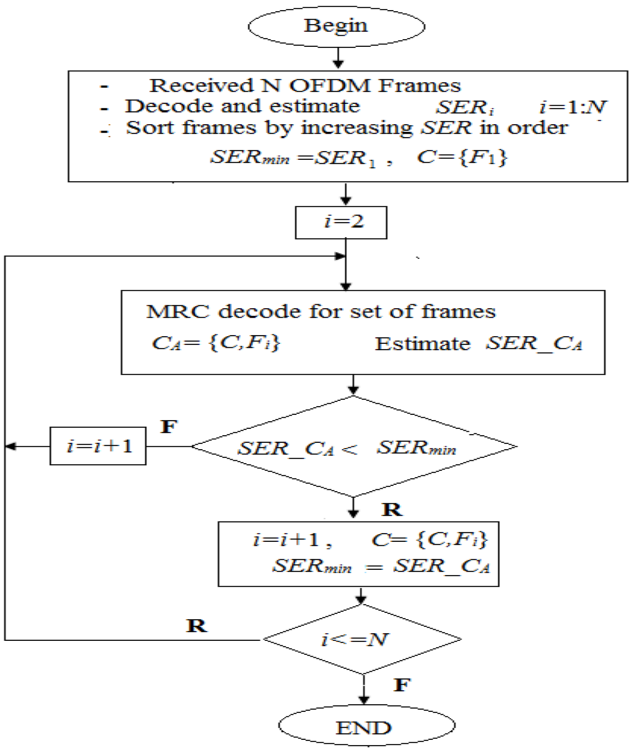

***Figure 4.** Optimal Decoding Algorithm for N receiving frames.*

To apply the algorithm diagram in Fig. 4. We need to estimate the *SER* (Symbol Error Rate) of decoding signal. To estimate the *SER*, We use an algorithm to estimate the size of stars in the signal constellation M-QAM by calculating the size of a circle which has radius r (red inner circle in Fig. 5).

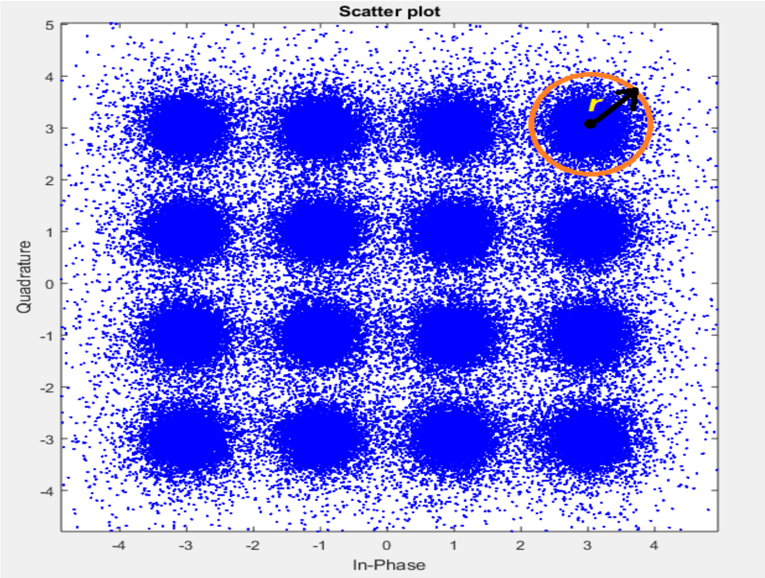

Figure 5. *16-QAM Constellation.*

The algorithm used to calculate the average size of stars in the signal constellation as follow.

X_r obtained from decoding OFDM signal frames in equation (4) will be used to estimate *SER* in below algorithm:

Step 1: $X_d = demod(X_r)$ Demodulation of decoded signal X_r **Step 2**: $\widetilde{X_r} = mod(X_d)$ Redemodulate X_d signal to get $\widetilde{X_r}$ signal **Step 3**: Calculate the distance between two signals X_r and $\widetilde{X_r}$ $r = mean\left\|X_r - \tilde{X}_r\right\|$

Figure 6. *SER Estimation Algorithm.*

The smaller *r* this mean the lower the SER of the decoded signal.

The algorithm diagram Fig. 4 can be divided into two steps.

Step 1: When receiving N data frames, the system will decode and estimate the *SER* of all signal frames based on the *SER* estimation algorithm in Fig. 6. Next will rearrange the order of the frames according to the *SER* values of the frames from smallest to largest. Assign name of frames from F_1 to F_N. Set the SER_{min} value equal to the *SER* of the first frame F_1. We set C is a set of first frame $C=\{F_1\}$.

Step 2 Next step, set value i=2. Call $C_A=\{C,F_i\}$ is a set include all frame in set *C* and frame F_i. Using MRC technique to decode all frames in set C_A and estimate *SER* of set C_A. If $SER\_C_A<SER_{min}$ then continue **R** brand or follow **F** brand in Fig. 4 diagram.

5. EXPERIMENTAL AND RESULTS

We perform all simulations and experiments.

We first perform simulations in the case of 16-QAM modulation, channel is rayleigh. The received signal is 10 frames (N=10). These frames have a decreasing *SNR* value from the first frame's *SNR* signal SNR_{max}=5 (dB) according to the table:

Table 1. *SNR Frames.*

Frame	1	2	3	4	5	6	7	8	9	10
SNR	1	1.4142	2.2361	3.1623	3.8730	4.4721	5	5.4772	5.9161	6.3246

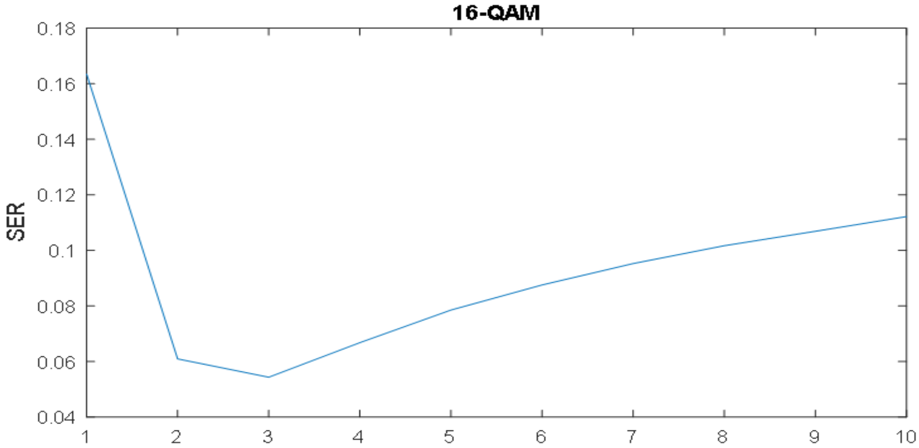

Figure 7*. The relation between SER number of decoding frames.*

From Fig.7 it is observed that using the best 3 frames out of 10 received signal frames is effective. The use of additional frames with poor signal quality does not increase the decoding efficiency of the MRC method. However, this is only a simulation result with the SNR value shown in table 1.

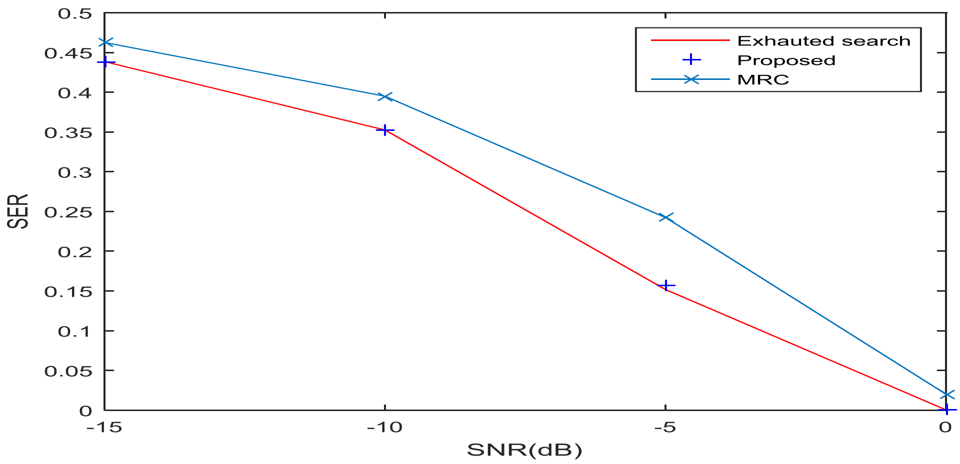

Figure 8. *Comparison proposed, MRC and Exhauted search method*

In Fig. 8 the *SNR* axis is the minimum SNR value of the first frame. The remaining frames have an increasing SNR value in 2 dB increments. Fig. 8 shows that using MRC technique to combine decoding of N signal frames is not effective. The proposed method is approximately the same as the optimal method. However, the optimal method with N frames will have to perform.

In exhauted search method we need Q combination (eq. (5)) (for example, with N=10, there will be 1023 possibilities. According to the proposed method, we use only 2N-1 possibilities need to be done.

We also made experiments test bed. The underwater experiments were carried out at Hotien lake at Hanoi University of Science and Technology (HUST). The experiment setup is illustrated in Fig. 9. In this experiment, the receiver is set at the fixed location beside the lake. The transmitter is on the small boat which is towed by rope from both side in right direction toward the receiver

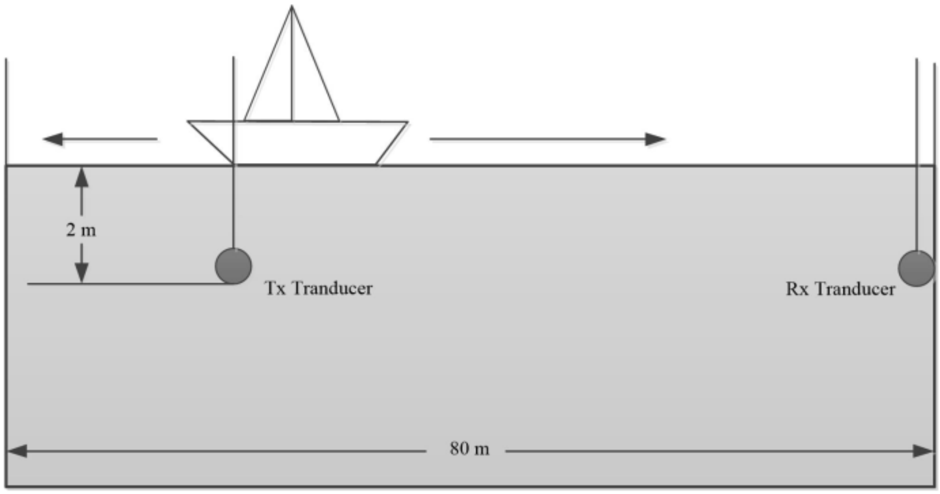

Figure 9. *Illustration of the Experimental setup in Hotien Lake.*

Table 2. *The OFDM system parameters.*

Parameter	**Value**
1 Transmitter – 1 Receiver	SISO
Frequency sampling	96Khz
Bandwidth (Khz)	20-28
FFT length (*N*)	2048
Guard interval length (*GI*)	1024
Multilevel modulation	QPSK
OFDM symbol length (*ms*)	32
The distance between OFDM subcarriers (Hz)	46.865
Number of OFDM symbol/Frame (N_s)	30
Frame length (*ms*)	960
Amplitude of CFP	6
Roll-off factor raised cosin filter (α)	0.2
Time gap between frames T_d (ms)	150
Amplitude of normal Pilot	1.4142
Length of *g(t)* in samples (2*L*+1)	15

Then, the results were processed by the software, which was developed by the Wireless Communication Laboratory of HUST. The OFDM system parameters are shown in table 2. The signals were modulated by QPSK, with N = 2048, the guard interval length is 1024. The system bandwidth is from 20 *kHz* to 28 *kHz*. Signals are transmitted consecutive frames separated by about 0.15 *s*. Each frame consists of OFDM symbols *Ns*. Transmitting parameter of OFDM system is showed in table I.

In experiments, we sent 10 frames in consecutively (N=10).

Figure 10. *10 OFDM received Frames.*

In Fig. 10 is ten OFDM received Frames.

The decoded SER of individual frame results shown in table 3 below.

Table 3. *SER of individual frame.*

Frame	SER
1	0.015909
2	0.040909
3	0.19318
4	0.1053
5	0.13636
6	0.14545
7	0.60985
8	0.21364
9	0.095455
10	0.07803

In table 4 is *SER* obtained when applying our algorithm. The first best result appears when combining frames 1,2,10,9,4. After adding frame 5^{th}, SER get worse then frame 5^{th} is removes. Frame 6^{th} does not decrese effective so it is kept, frames number 3,8,7 do not decrease SER, are removed also.

Table 4. *SER of combination Frames after sorting from smallest to largest.*

Frame	SER from smallest to largest	Frame combinations	*SER*
1	0.015909	1	0.015909
2	0.040909	1,2	0.0022727
10	0.07803	1,2,10	0.0016398
9	0.095455	1,2,10,9	0.0011042
4	0.1053	1,2,10,9,4	0.00075758
5	0.13636	1,2,10,9,4,5	0.00101467
6	0.14545	1,2,10,9,4,6	0.00075758
3	0.19318	1,2,10,9,4,6,3	0.00189931
8	0.21364	1,2,10,9,4,6,8	0.00097566
7	0.60985	1,2,10,9,4,6,7	0.00128191

6. CONCLUSIONS

Underwater communication environment is very complex due to the influence of many physical conditions. The signal received when decoding often has a lot of errors. Therefore, the use of the OFDM repeater transmission technique and the application of appropriate MRC decoding technique will increase the accuracy of information transmission. Employing such technique also allows us to reduce complex and cumbersome hardware devices such as transceivers. Moreover, our proposal for the case of one tranceiver antenna and N receiving antennas (SIMO).

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TÓM TẮT

Phương pháp giải mã phân tập không gian-thời gian cho truyền thông dưới nước sử dụng kỹ thuật OFDM

Trong bài báo này, chúng tôi đề xuất một giải pháp truyền thông tin cậy sử dụng kỹ thuật phân tập không gian thời gian nhưng chỉ sử dụng một anten thu phát áp dụng cho hệ thống OFDM di động trong môi trường truyền thông dưới nước. Giải pháp chúng tôi đề xuất là thay vì sử dụng nhiều anten thu thì bên phát sẽ truyền một tín hiệu OFDM N lần liên tiếp. Việc nhận N tín hiệu liên tục trong môi trường chuyển động của tín hiệu OFDM cũng tương đương với việc tạo ra sự phân tập về cả không gian và thời gian của tín hiệu thu. Để giải mã tín hiệu từ N khung tín hiệu OFDM nhận được chúng tôi đề xuất một phương pháp lựa chọn khung tối ưu nhằm tăng hiệu quả cũng như tiết kiệm thời gian giải mã. Các kết quả mô phỏng và thực nghiệm cho thấy, hệ thống có thể đạt được một tỷ lệ lỗi SER tốt hơn so với kỹ thuật MRC áp dụng cho N khung dữ liệu và số lượng phép tính để tối ưu cũng ít hơn so với phương pháp thử tối đa các trường hợp. Đặc biệt là, chất lượng tín hiệu thu được trong trường hợp có sự di chuyển giữa bên phát và thu tốt hơn là khi không có sự di chuyển.

Từ khoá: Truyền thông sóng âm trong môi trường nước; Điều chế đa sóng mang phân chia theo tần số trực giao; Bù dịch tần Doppler.