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Signal to Noise Ratio and Bit Error Rate for Multiuser using Passive Time Reversal Technique in Underwater Communication

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ABSTRACT

Underwater channel characterized by multipath propagation requires focusing of acoustic signal to overcome delay spread. This is achieved by time reversal. This paper simulates underwater acoustic communication using passive time reversal technique with transmitter and receiver separated in range by 4 Km in 120m deep water. The Passive Time Reversal (PTR) system is simulated for both singleuser and multiuser transmissions. Using Quadrature Phase Shift Keying (QPSK) modulation, input bit sequence is transmitted through the underwater channel. A 32 element Vertical Receiver Array (VRA) focuses the signal enabling to reduce the bit errors. Successful implementation of passive time reversal is carried out and the performance of the system is analyzed. Simulation result show that better Bit Error Rate (BER) can be achieved with respect to number of receiver elements with the time reversal techniques and comparison of the same is carried without passive time reversal. Also BER is found to vary with the distance between the users as also with the number of users.

Keywords : Multipath, Multiuser Communication, Passive Time Reversal, Underwater Acoustic Communication

I. INTRODUCTION

So far terrestrial communication has evolved greatly with techniques for both wired and wireless systems. Most of the wireless communications are implemented using Electromagnetic (EM) waves due to many advantages like high speed, high bandwidth, high data rate, lower cost of equipment and lower power requirement compared to acoustic waves. In contrast to this, the underwater environment has seen only wired communication due to its inherent challenges. In this project, our aim is to simulate wireless transmission in the underwater channel [1-2].

II. TERRESTRIAL Vs UNDERWATER

EM waves, while transmitting in underwater, experience severe attenuation because of their high frequency. Due to this they travel very short distances. Hence for long distance communications in underwater, acoustic waves are used. But reliable, high data rate communication in a time-varying multipath shallow-water environment is a highly challenging problem [3-6]. This is due to the following factors:

1) Delay spread due to multipath propagation.
   Multipath is a phenomenon, which occurs, in wireless transmission where the same signal traverses different paths towards the receiver, and experiences different delay and attenuation in each path. Delay spread results in Inter symbol Interference (ISI) between the transmitted symbols.
2) Doppler spread.
   This occurs due to environmental fluctuations and/or relative motion between transmitter and receiver. It results in shift in the original frequency of the signal
3) Bandwidth limitation of the channel and
4) Very low data rate.

The speed of signal transmission is $3x10^8$ m/s in free space while it is limited to 1.5×10^3 m/s in underwater. Hence maximum achievable data rate is in the range of 5-20 kbps while it is in the range of Gbps in terrestrial systems. Very high SNR of about 100 dB can be achieved on land but maximum achievable SNR in water is around 14 dB. Limitations on distance between transmitters to receiver as well as those on bandwidth severely affect the performance. In shallow water, the problem of multi path occurs due to signal reflection from the surface and bottom of the water body, while in deep water it occurs due to ray bending which is the characteristic of acoustic waves to travel along the axis of lowest sound speed [7-10].

III. EVOLUTION OF UNDERWATER COMMUNICATION

The evolution of underwater communication can be traced back to the days (during 1970s) when analog communication was carried out using loudspeakers. But they had no capability for mitigating the distortion introduced by the highly reverberant underwater channel. The next generation of systems employed frequency-shift-keyed (FSK) modulation of digitally encoded data. As an energy-detection (incoherent) rather than phase-detection (coherent) algorithm, FSK systems were intrinsically robust to the time and frequency spreading of the channel as they used energy-detection algorithm rather than phase detection algorithm.

The use of digital techniques has become important in two respects. First, it allows the use of explicit error-correction techniques to increase reliability of transmissions. Second, it permits some level of compensation for the channel reverberation both in time (multipath) and frequency (Doppler spreading). During 1990's coherent systems such as QPSK were used in conjunction with adaptive channel equalization. Adaptive channel equalization employs weighted linear filters to combat ISI and channel variations. But these techniques suffered from computational complexity, algorithm stability and selection of channel parameters [4, 11-12]. In recent systems advanced techniques such as time reversal are implemented.

Time Reversal is one of the simplest techniques that is used to mitigate ISI by means of its property of temporal focusing. There are two types of Time Reversal techniques, namely active time reversal and passive time reversal. The two approaches essentially are equivalent with the communications link being in the opposite directions.

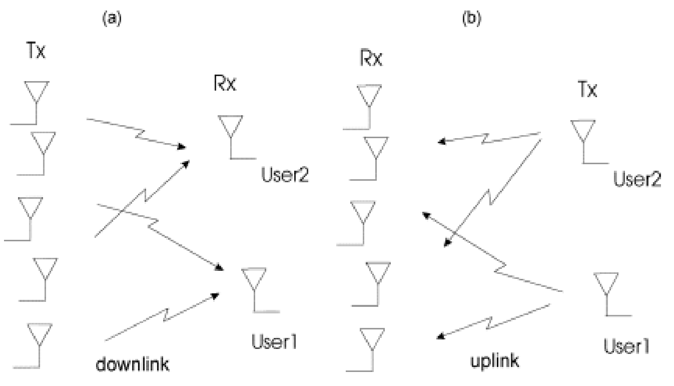

Figure 1 (a) Active Time Reversal Communication (b) Passive Time Reversal Communication

Active time reversal implements downlink communication whereas passive employs uplink transmission as shown in Figure. 1.1. The multiple-element array on the left-hand side of the Figure is called Time Reversal Mirror (TRM) and it corresponds to a base station in a terrestrial cellular system. Active time reversal has been implemented practically for both single user as well as multi user cases. Passive time reversal has been demonstrated for single user case and research is going on in extending it for multi user scenario.

IV. SIMULATION RESULTS

The passive time reversal system for underwater communication was simulated, for both single user and multi user cases, using MATLAB 7.1. The following assumptions were made for simulation:

- The underwater channel is time invariant and hence no equalizer is required.
- The transmitter and receiver array are fixed and hence the channel is devoid of Doppler spread.
- System implementation is carried out in a single water layer with a particular sound speed which does not vary.

SIMULATION PARAMETERS

In order to create an underwater environment, several parameters were given as inputs to the simulation and the performance of the system was analyzed. An acoustic frequency of 1.5 KHz was chosen in order to enable long distance communication. The average values of temperature, salinity and pH values were studied for all the oceans and they came down to 8oC, 35 parts per thousand and 8 respectively. The depth and range of the system were chosen depending on the practical feasibility. From the frequency value, fr, the velocity of sound wave underwater was calculated according to Eqn (1) and it takes the value of 1484.5 m/s. The maximum number of receiver elements of TRM was restricted to 32, due to practical constraints in deployment of the transducers. The symbol rate was chosen as 500 symbols/s to get a data rate of 1 Kbps, which is a result of QPSK modulation in which each symbol corresponds to two bits of the input binary data.
The parameters are listed in Table 1.

TABLE 1 Simulation Parameters

Parameter	Symbol	Value
Acoustic frequency	fr	1500 m/s
Temperature	T	8°C
Salinity of ocean water	S	35 ppt
pH value of ocean water	pH	8
Distance between transmitter and TRM	R	4 Km
Depth of the system	D	120 m
Velocity of sound	c	1484.5 m/s
Number of receiver array elements	M	1-32
Symbol rate	SR	500 symbols/s
Incident grazing angle	Θ_{in}	10°
Scattered grazing angle	Θ_{out}	10°
Scattered bistatic angle	Φ_{out}	180°

SINGLE USER

Initially passive time reversal is simulated for transmission of signal from a single user.

BER PERFORMANCE

To analyze the performance of the same, the number of receiver array elements in TRM is varied from 1 to 32. For a particular size of TRM, the signal transmitted through the underwater channel, that undergoes multipath propagation, is received and the BER is calculated. The same procedure is repeated by increasing the size of receiver array alone, and BER is calculated for each case. By doing so, it is observed that as the number of receiver array elements increases, BER decreases and the system performance is improved. This is evident from the output shown in Figure 2

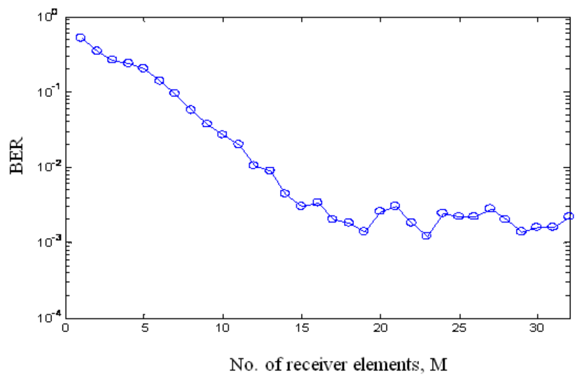

Figure 2. Performance of BER with PTR

To prove that performance is improved on implementation of passive time reversal, the same system is analyzed without matched filter processing. Figure 3 shows that there is a random variation of BER with the number of receiver array elements. This arises due to uncertainty in the phase changes of the various signals arriving at the receiver element. Due to linear summation of these out of phase signals, error increases leading to a higher value of BER. The peak value of BER is around 0.53 while it is just 10^{-3} with passive time reversal.

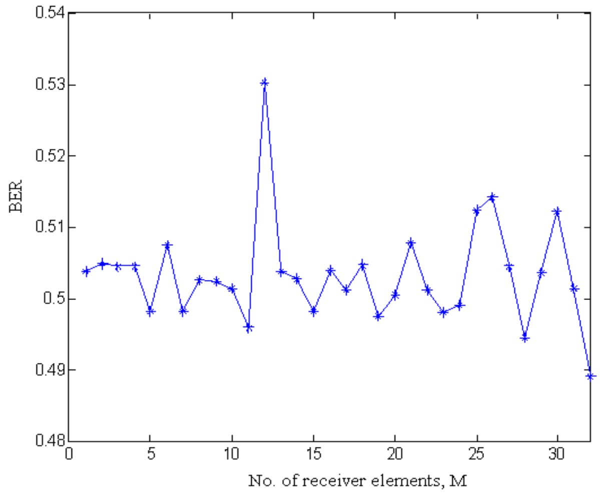

Figure 3. Performance of BER without PTR

SNR PERFORMANCE

Signal to noise ratio is computed as the ratio of the signal power (dB) to the noise power (dB). The signal in consideration is the output of the adder following the matched filters. As the length of the TRM is varied from 1 to 32, SNR is calculated for each case. On plotting, as in Figure 4, it is seen that SNR increases with increase in TRM size. This phenomenon arises because while the noise remains constant there is a consistent increase in signal strength at the receiver.

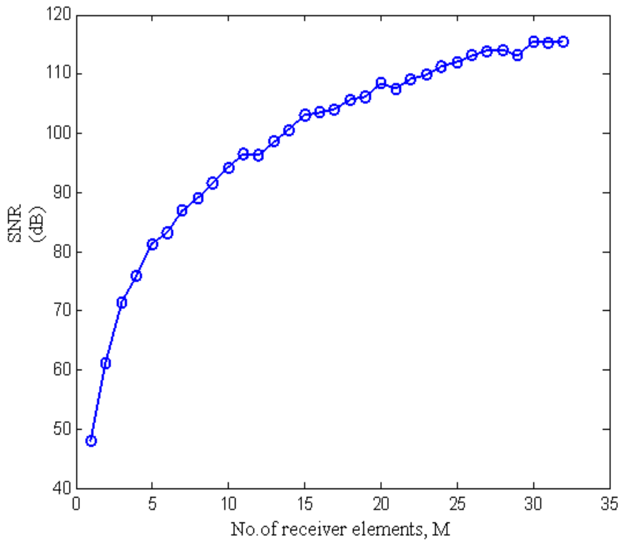

Figure 4. SNR Performance for Single User

MULTI USER

The single user system was translated into multi user with modification in receiver to separate the signals from various sources.

BER PERFORMANCE

In this scenario there is additional deterioration in performance due to presence of cross talk which is essentially the interference of signals from various users. As a result the BER values increase .The peak value of BER is observed to be around 0.2 from Figure 5(a) for two users for a single element TRM. Also as TRM size is varied the precision improves on a relative basis (to single element) but error is high compared to single user case.

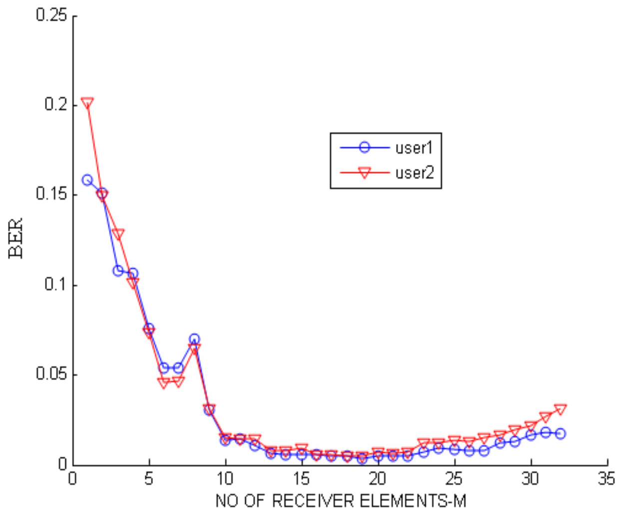

Figure 5 (a). BER Performance for 2 Users

The peak value of BER is observed to be around 0.25 from Figure 5(b) for three users for a single element TRM. Also as TRM size is varied the precision improves on a relative basis (to single element) but error is high compared to two users case due to increased interference.

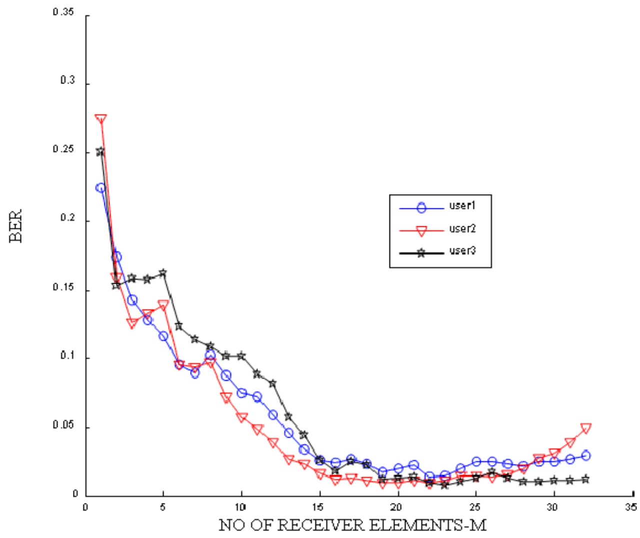

Figure 5 (b). BER Performance for 3 Users

The peak value of BER is observed to be around 0.3 from Figure 5(c) for four users for a single element TRM. Also as TRM size is varied the precision improves on a relative basis (to single element) but error is high compared to three users case due to increased interference.

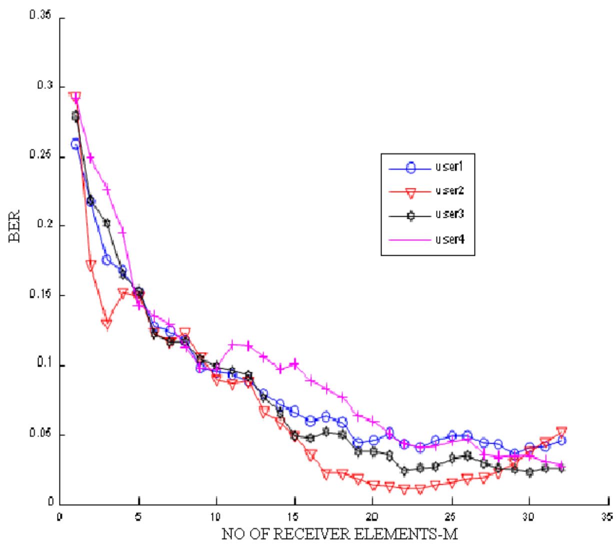

Figure 5 (c). BER Performance for 4 Users

The peak value of BER is observed to be around 0.35 from Figure 5(d) for five users for a single element TRM. Also as TRM size is varied the precision improves on a relative basis (to single element) but error is high compared to four users case due to increased interference

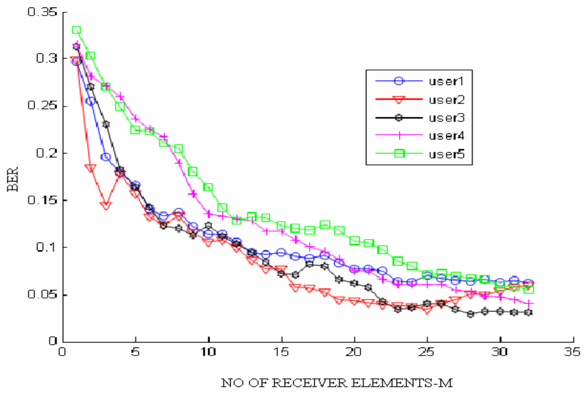

Figure 5 (d). BER Performance for 5 Users

There is a scaling down of performance on shifting from two to three, three to four and four to five users. Thus there is continuous rise in BER with increased number of users. The number of users therefore is determined by the performance required which further depends on the application.

SNR PERFORMANCE

The subsequent Figures depict the variation of SNR with varying number of users. On comparison, from Figure 6, it is evident that SNR is not much affected with increase in users. In the system model all signals pass through the same underwater channel. Hence the signals from all users are affected by the same level of ambient noise. There is not much variation in signal strength for each user across the channel. Due to these subtle alterations in values SNR remains almost constant. The SNR is around 21 for two, three, four as well as five users .

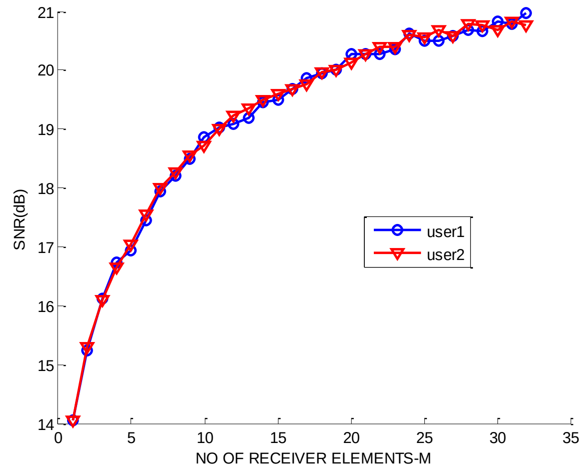

Figure 6 (a). SNR Performance for 2 Users

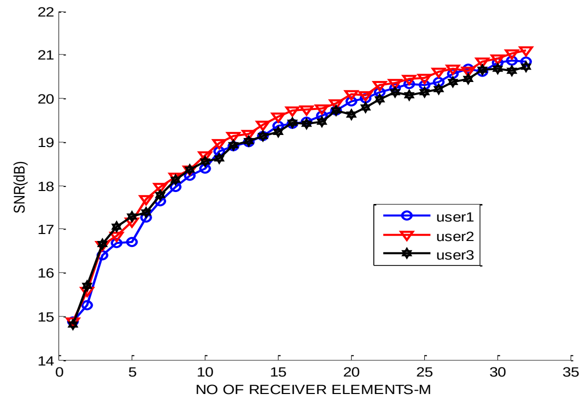

Figure 6 (b). SNR Performance for 3 Users

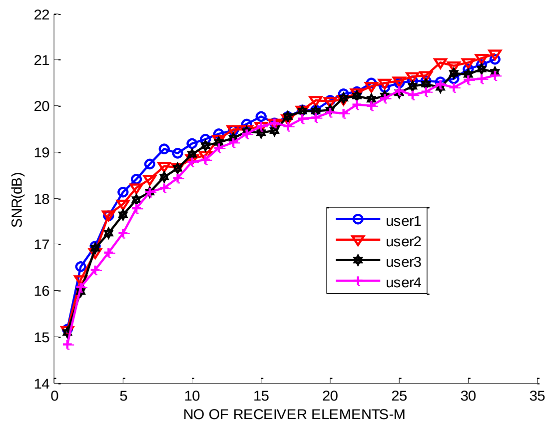

Figure 6 (c). SNR Performance for 4 Users

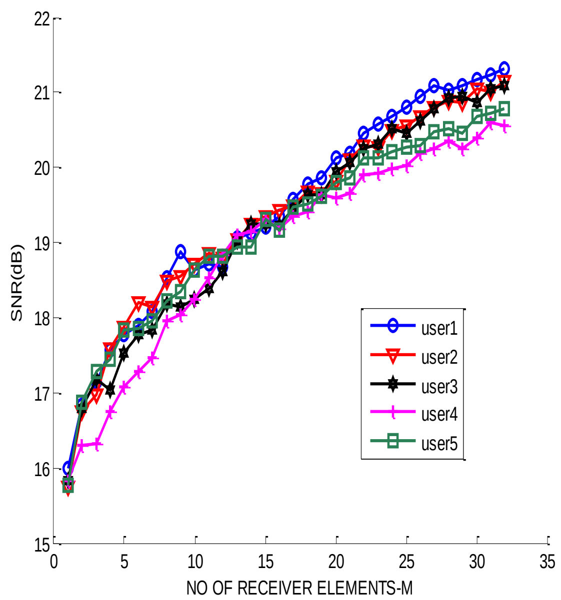

Figure 6 (d). SNR Performance for 5 Users

BER PERFORMANCE WITH VARIATION IN USER DISTANCE

The distances of separation between users determine the amount of overlap in signals. The simulation is carried out for two users which would enable to determine the inter user spacing. It is observed that as the distance increases the performance is better. Reduction in interference is reflected in BER values, which undergoes a decrease. However there are restrictions in amount of separation. Further the separation, the signal strength from the user at the TRM is affected. The separation distance for which performance is optimal is deduced to be around 10m, from the analysis of the Figure. 7. Thus two users separated in depth by 10 m from each other yield sufficient value of BER for good communication.

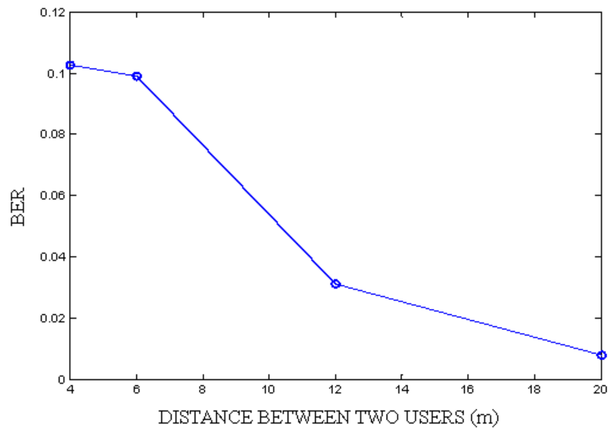

Figure 7. BER Performance with Distance between 2 Users

Telemetry data is collected by submerged acoustic instruments such as hydrophones, seismometers, sonars or various other instruments which collect information about currents, tides, pollution, etc, and it also may include very low rate image data. Data rates on the order of one to tens of kbps are required for these applications. The reliability requirements are not so stringent as for the command signals, and a probability of bit error of 10^{-3} to 10^{-4} is acceptable for many of the applications.

V. DISCUSSION

The various performance plots for single user and multi user are analyzed. The effect of changes in parameters such as distance and number of users is studied. Based on these observations the conclusions regarding TRM size and distance of separation of elements are derived.

VI. CONCLUSION

Single user and multiuser communications using passive time reversal in underwater have been simulated using MATLAB by considering the entire system including the users and the TRM separated in range from 10-m to a maximum of 4-km in 120-m deep water. The water is assumed to have a temperature of 8 °C and salinity of 35 ppt. The 32 element TRM receiver array has 2-m element spacing. In the single user case, the source is located at a distance of 4-Km from the receiver. The performance improves as the array size of the TRM increases. BER is minimized to as low as 10^{-3}. For multiple users, simulation has been carried out for situations where adjacent users are separated by distances of 4-m, 6-m, 12-m and 20-m as well as for different number of users starting from 2 to 5. Experimental results suggest that as many as five users can transmit information simultaneously for BER to remain within acceptable limits. Also the distance between two adjacent users has to be a minimum of 10-m for minimising the interference between the users, and hence the error. Better performance is achieved as the TRM array size increases. If the size is greater than 16 elements the transmission is reliable but the complexity of the system increases manifold with the array size grater than 32. Therefore the optimum range is determined to be from 16 to 32 elements.

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