ISSN (Print) : 0974-6846
Indian Journal of Science and Technology, Vol 9(40), DOI: 10.17485/ijst/2016/v9i40/101535, October 2016 ISSN (Online) : 0974-5645

An Approach to Mitigate Fading Issues for Underwater Communication using MIMO-OFDM-IDMA Scheme

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Abstract

Objectives: We propose an efficient, scalable, adaptive MIMO-OFDM Technique with IDMA scheme to mitigate the fading issues in underwater wireless communications. **Method/Statistical Analysis:** MIMO is the technique to transfer the data independently from more than one antenna simultaneously, and at receiver side data is received by one or more than one antenna. This technique increased the data rate while OFDM saves the bandwidth and combat from the fading. IDMA scheme is better than any other available multiple access schemes which show the best performance result in underwater wireless communication. **Findings:** We test the BER performance of MIMO-OFDM and MIMO-IDMA technique with a different number of users and we found that both techniques show limited performance result. We test the hybrid approach by simulating the MIMO-OFDM with one multiple access scheme i.e., IDMA scheme to reduce the underwater channel noise such as burst error or fading. This technique has the potential to serve as a primer for mitigating the fading issues in future underwater wireless communication. **Application/Improvements:** MIMO-OFDM with IDMA Scheme is employed to improve the below water communication with the help of the most common device known as hydrophones. Since underwater communication uses acoustic waves instead of electromagnetic waves, therefore, there are low data rates compared to another communication medium. This research is being helpful to reduce the fading issues due to low data rate. In this research, we used the random based interleaver in IDMA scheme. For future improvements, we can use new tree based interleaver in IDMA Scheme. The tree based interleaver is used for generating patterns and user separation.

Keywords: Fading Issue for Underwater Communication, IDMA (Interleaver Division Multiple Access) Scheme, MIMO (Multiple Input Multiple Output), OFDM (Orthogonal Frequency-Division Multiplexing), Underwater Communication

1. Introduction

This development of MIMO-OFDM technique with IDMA scheme for underwater wireless communication is challenging due to less speed of acoustic waves, extreme fading issues, extended multiple paths, bandwidth limitations and refractive properties of the sound channels. Our aim of this paper is to develop a technique that operates under large propagation delays in underwater ecological sensing and communication. We concentrate on mitigating the fading issues as well as save the bandwidth too. OFDM technique has the ability to reduce the bandwidth and mitigate the multipath interference in comparison to FDM technique[1]. We compare the BER performance of OFDM to FDM technique for underwater communication. MIMO system transmits the data with more than one antenna and receives the same data with multiple receivers[2]. Underwater wireless communication has very low data rate due to multiple bandwidths, so MIMO controls all the communication bandwidth and increases the data rate. Multiple access schemes are used for the underwater communication so that a large number

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of communication users can share the allocated spectrum or bandwidth in the efficient manner. We perform the result for various multiple access schemes and found that IDMA scheme is showing the better result than other schemes. IDMA scheme is based on an interleaving technique which distributes the data to users' efficiently[3].

The recent technique on underwater wireless communication concentrated on only IDMA scheme or MIMO-OFDM[4] technique and these techniques are not suitable for reducing the challenges of underwater wireless communication medium. Previously FDMD was used in underwater communication but was found to be restrictive and inefficient in terms of bandwidth utilization.

The previous underwater wireless communication technique able to mitigate the fading issues up to some extent but not able to save the bandwidth and increase the data rate. The MIMO-OFDM with IDMA scheme shows the better result than previous technique. OFDM is very popular modulation technique in the current generation of underwater communication. The OFDM technique divides a high bit data stream into a number of lower bit rate streams which are transmitted over a different number of narrow sub-channels[5]. The use of MIMO technology is to drastically improve the spectrum bandwidth and communication channel reliability in underwater wireless communication systems. In the recent research on OFDM-MIMO technology for the mobile network is to reduce the fading caused by a destructive addition of components with multiple paths and interference from another user on the same bandwidth[6]. Several diversity techniques are used to create the replicas of the ideally independent transmitted signal and receive at the receiver.

In the recent literature for IDMA scheme in underwater wireless communication, IDMA shows the better result than any other available multiple access schemes. In IDMA scheme we check the performance of the different type of algorithm, i.e., random interleaver algorithm and tree based interleaver algorithm. Random interleaver algorithm shows the better BER performance in the underwater communication channel.

2. Materials and Methods

2.1 OFDM Technique

Now these days OFDM becomes the most popular technique for transmission of signals over wireless channels. The concept of Orthogonal Frequency Division Multiplex (OFDM) firstly published on basis of principle for transmitting messages simultaneously without suing inter symbol interference. This principal was modified and concluded that designing an efficient parallel system it is necessary to concentrate on crosstalk between the adjacent channels than the individual channel[7]. For a long time, its application is limited due to the high implementation complexity. OFDM converts frequency-selective fading channels to the collection of parallel fading sub channels to simplify the structure of the receiver. OFDM system can provide composite data rate with long symbol duration. This help in illuminating the inter-symbol interference in short symbol duration in a multipath channel. OFDM is widely used in an underwater wireless communication channel. Underwater is high dispersive channel and spectrum is very scattered so maintain the orthogonality between channels we use the OFDM techniques. OFDM divides the available wireless spectrum into multiple sub channels (subcarriers). OFDM pulses usually are used in rectangular shapes and popular in European digital audio broadcasting.

2.2 OFDM Modulation Algorithm

The OFDM modulation block diagram is shown in Figure 1. The message signal Ci[k] is first converted from serial to parallel bit after that IFFT of parallel stream data is taken that guarantee the orthogonality between all parallel bit streams. Basically, the FFT multiplied the different parallel stream with a sinusoidal carrier signal of the different frequency and If m and n are an integer then sin(mt) and sin(nt) will be orthogonal to each other[8]. The signal that is transmitted to channel can be write in mathematical form as shown in Equation (1).

$$c(t) = \sum_{n=1}^{N} m_n(t) \sin(2\pi n t) \qquad (1)$$

The above Equation is equivalent to FFT where m(t) is the message signal and n is any integer. At the receiver side, the serial data is again converted into a parallel stream and applied to FFT block. At last, the data is again back converted into the serial stream and after decoding, the actual message signal get. FFT and IFFT are invertible to each other so interchangeably can be used either at transmitter or receiver side. The use of FFT (Fast Fourier Transform) to perform baseband modulation and demodulation was the first milestone. But FFT reduces the number of air thematic operation from N2 to NlogN (N is FFT Size). Now high-speed FFT chips available which have been developed on VLSI technology. The limitation for applying only OFDM technique to underwater channels is the Doppler distortion. It generates non-uniformity frequency bandwidth in the acoustic signal[9].

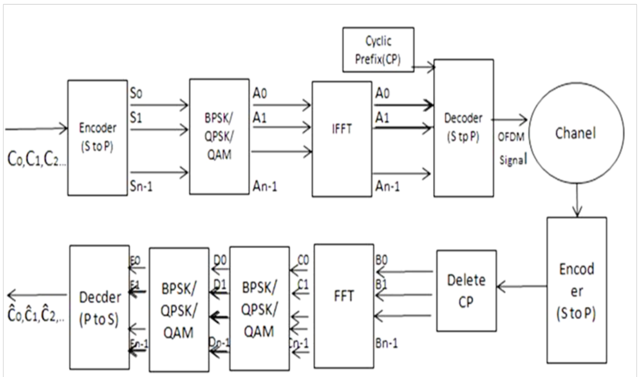

Figure 1. Block diagram of OFDM.

2.3 MIMO-OFDM Technique

Single-Input-Multiple-Output (SIMO) technique gives the stronger signal through diversity but not able to increase the channel capacity. In MIMO-OFDM technology, Multiple-input-multiple-output wireless technology simulated with orthogonal frequency division multiplexing technology[10]. It has been most prominent technology in terms of performance of different channel conditions and low data rate. Multiple-Input-Single-Output (MISO) transmits two signals on single time which is also really unable to increase the channel capacity[11]. Multiple-Input-Multiple-Output antenna configuration provides higher capacity, spectral efficiency and high data rate on single time. OFDM technique transmitted high data rate into low rate parallel sub-streams. Block Diagram of MIMO shown in Figure 2.

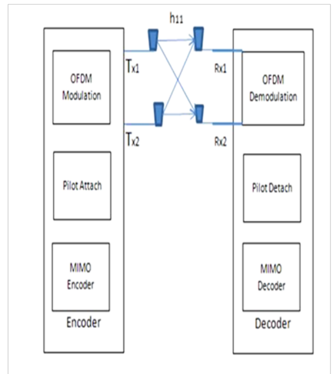

Figure 2. Block diagram of MIMO.

2.4 IDMA Scheme

In wireless communication, access method allows several transmitters and receivers to connect to the same multiple point transmission media to send the signal over it and to share its capacity. The channel access scheme is also based on multiple access protocol and control concept which is also known as multiple access control. This protocol mitigates the issues like as link reply, address the point, assigning multiples channels and avoiding collisions[12]. There are several multiple access schemes as FDMA (Frequency Division Multiple Access), TDMA (Time Division Multiple Access), CDMA (Code Division Multiple Access), SDMA (Space Division Multiple Access) and IDMA (Interleaver Division Multiple Access). Underwater wireless communication channels are having very less data rate and too much noise issues. In this situation to use the channels for multiple users is very difficult and the data rate is also very weak. We consider the IDMA scheme for multiple accesses of channels with high data rate and less fading issues. IDMA scheme is an interleaving technique[13]. In the interleaving mechanism, the input data stream rearranges itself in

Table 1. Comparison between various interleavers

Parameters	RI	MRI	TBI	PI
Memory requirement	High	Low	Low	Lowest
Bandwidth requirement of Interleaver (30 users)	$1.5x10^{6}$	$0.01x10^{6}$	$0.02x10^{6}$	$0.0001x10^{6}$
Complexity	High	Very high	Low	Little high than TBI
Bite error rate for Eb/NO = 10 (24 users)	$0.4x\ 10^{-4}$	$0.4x\ 10^{-4}$	$0.4x\ 10^{-4}$	$0.5x\ 10^{-4}$
BER in coded environment for Eb/NO = 10 (24 users)	$0.6x10^{-5}$	$0.6x10^{-5}$	$0.4x\ 10^{-6}$	$0.4x\ 10^{-6}$
BER in uncoded environment for Eb/NO = 10 (24 users)	$0.6x10^{-4}$	$0.2x\ 10^{-4}$	$0.2x\ 10^{-5}$	$0.2x\ 10^{-5}$
Specific user cross correlation	Low	Low	High	High

such a way so that consecutive data stream bits are split among different blocks and transferred to in a known pattern among it. At the receiver end, it rearranged the interleaved data stream into its original sequence with the help of a deinterleaver. As a result of interleaving, correlated noise in the channel is non-dynamically independent at the receiver and provides highest error correction result. The are several implemented interleaver schemes over underwater wireless communication such as Random Interleavers, Master Random interleavers, Tree based interleavers, Prime interleavers. Table 1 shows the comparison of different interleavers for underwater wireless communication on the basis of their performance result.

The interleaver rearranges the ordering of data bits by using deterministic bijective mapping. Let A = [a0 ,a1,a2,a3,....................aN-1] is sequence of length N. An interleaver maps A onto a sequence such that P is permutation of the elements of C. Considering C and P as a pair of N-dimensional vectors; there is one-to-one correspondence between each element of "a" and each element of "P", as in Figure 3.

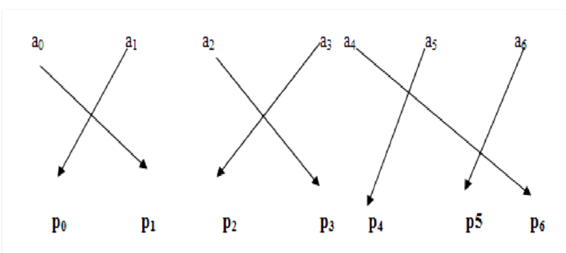

Figure 3. Mechanism of data interleaving.

An interleaver is represented by the one-to-one index mapping function as shown in below Equation (2)

$$\Pi \text{ (B B): } j = \Pi \text{ [i]} \tag{2}$$

where B = {0,1…N-1} for i, j ∊ B

Where term i' and j" are indices respective of an element of the original sequence a" and an interleaved sequence "P". The mapping function called interleaving vector 'Π' is an order set as Equation (3)

$$\Pi = [\Pi\ [0], \Pi\ [1] \ldots \Pi\ [N\text{-}1] \tag{3}$$

The kth element of the permuted sequence P is as shown in Equation (4)

$$Pk = C\ \Pi\ [k] \tag{4}$$

The inverse interleaver stored the permuted sequence to its original order repeatedly. The terms "π" is denoting interleaving vectors and "π−1" deinterleaving vectors.

$$\pi\text{-}1\ [\pi[k]] = \pi[\pi\text{-}1[k]] = k \tag{5}$$

Replacing k by π-1 [n] in Equation (4), then from Equation (5), Equation (6) can be written as-

$$P\ \pi\text{-}1[n] = A\ \pi[\pi\text{-}1[n]] = An \tag{6}$$

An interleaver design condition is that every two interleavers from a set of interleavers "collide" up to least extent. With increment in cross-correlation among the interleavers, the number of collisions also increases, resulting in the increment in Bit Error Rate (BER) of the system. The least collision among specific interleavers depends on its orthogonality. It is an important factor. If the orthogonality is not maintained among the user-specific interleavers, the correlation between the users increases proportionally, with increment in user count resulting in lower BER performance. Therefore, interleavers generated according to the orthogonality criteria having a less number of collisions as part of IDMA systems. Two interleavers Π and Π j (where Πi≠Πj) are said to be orthogonal, if for any two words, c and d, the correlation A(.) is shown in Equation (7)

$$A\ Pi\ c\ \Pi\ j\ b = Pi\ f\ (a))\Pi\ j\ (\ f\ (b))) = 0 \tag{7}$$

Above condition is for the orthogonality check of the user-specific interleaver, adopting an iterative sub-optimal receiver structure, as demonstrated in Figure 4, consisting of the Primary Signal Estimator (PSE) and K single user. For single path propagation, there is only one path for the data transmission. The multiple access schemes and coding parameters are considered individually different for the PSE and DECs that's why the output of these parameters are Log-Likelihood Ratios (LLRs) which is defined below in Equation (8)

$$(X_k(j)) = \log\ (p(y|xk(j) = +1)/(p(y|xk(j) = -1)\ ,\ \forall\ \kappa, j \tag{8}$$

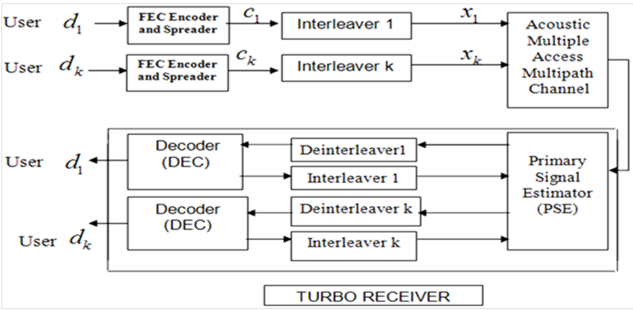

Figure 4. IDMA transmitter and receiver.

Those LLRs are further distinguished by subscripts, i.e., and depending on whether they are generated by the PSE or DECs. For the PSE section, Equation (8) denotes the received channel output DESs formed by the deinterleaved version of the outputs PSE blocks[14,15].

3. Results and Discussion

Performance results of the MIMO-IDMA are simulated in Figure 5. The BER is in the range of .1 to .01 for the user 8 and 16. But when OFDM with MIMO-IDMA has been used there is significant improvement in the performance. This improvement comes due to use of OFDM scheme. OFDM scheme is very effective in fading like underwater channel. There are two transmitter and two receiver used.

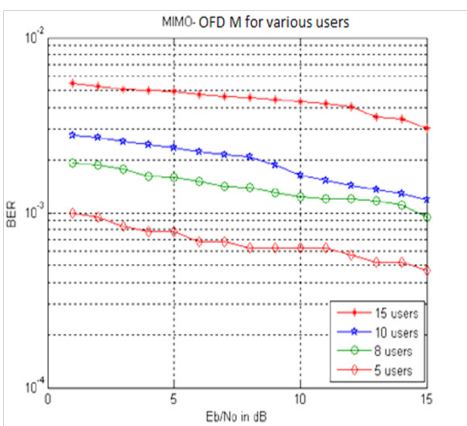

Figure 5. BER performance of the MIMO-IDMA with different users.

OFDM scheme increases the PAPR so LDPC coding is used to mitigate this effect and FFT method is used to generate the orthogonal signals. Random interleaver has been used due to its easy implementation. BPSK modulation has been used in this scheme. The depth of transmitter and receiver is assumed to be 40 meter and temperature of water is 14 degree Celsius. The PH value of water has been taken 6 and the speed of wind is assumed 10 m/s. Salinity of water is taken 3%. In MIMO scheme the MMSE, detection method has been used. The program is simulated for two transmitter-two receiver and three transmitter three receiver respectively.

The MIMO-OFDM scheme with IDMA is simulated for varying different parameter and an optimized result is obtained. The scheme is firstly simulated for varying iteration number. Block length is kept 200, data length 512 and spreading length 16. The number of users has been taken 16 and the no transmitter and receiver antenna taken two respectively. Use either SI (MKS) or CGS as primary units. (SI units are strongly encouraged.) English units may be used as secondary units (in parentheses). This applies to papers in data storage.

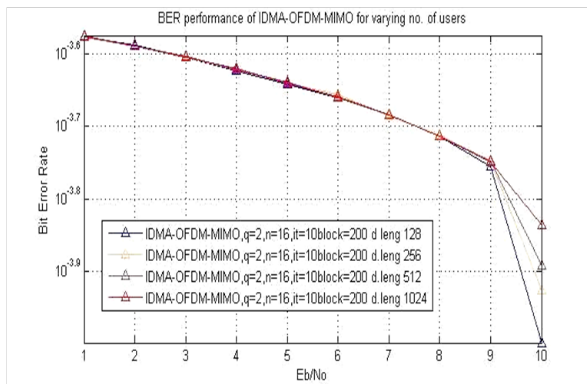

Figure 6. BER performance on varying block length.

The simulated Figure 6 show that this scheme gives the best result as iteration no goes high but at higher number iteration it takes more time to execute so we choose a optimum value 10 whose BER performance is nearly equal to that of 15. Next this scheme is simulated for the varying no of data length 128, 256,512 and 1024 respectively as shown in Figure 6. The iteration no is kept 10 from previous simulated result of varying iteration. Block length, spreading length and no of user has been taken 200, 16 and 16 respectively. The no of transmitter and receiver is same as in previous case. For lower value of data length the BER comes good. So for further simulation data length is chosen 128. Next block length parameter has been varied keeping number of iteration spreading length, data length and no of user constant respectively 10, 24, 128 and 16. There is lower

BER performance for lower block length. On the basis of the above simulated result an optimized value has been chosen. The different parameter has been taken as iteration number 10, data length 512, spreading length 24 and block length 200, no of transmitter antenna = 2, no of receiver antenna = 2 and the number of users has been taken 16,32 and 64 respectively. From Figure 7 it can be seen that the maximum bit error rate is 10^{-4} while in the case of MIMO-IDMA the maximum value is 10^{-2}, so from result it can be concluded that MIMO-OFDM and IDMA scheme gives better performance than MIMO-IDMA. The MIMO-OFDM-IDMA scheme is again simulated for the three transmitters and three receivers and keeping all the parameter same as in previous optimized value case and it is seen that the bit error rate increases on increasing the no of transmitter and receiver as shown in Figure 7. It is due to more interference from others antenna.

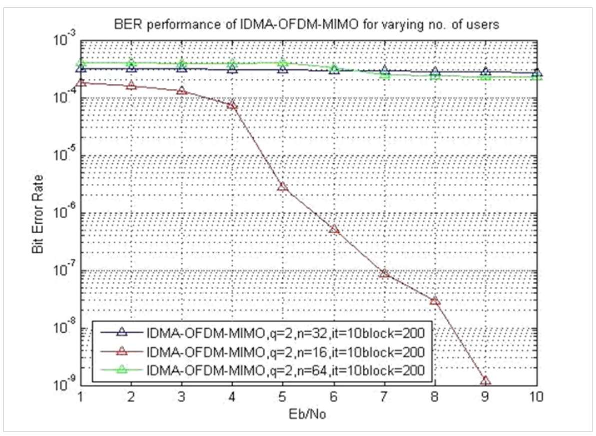

Figure 7. Optimized result.

4. Conclusion

Considering optimum value of different parameters like iteration number, data length, block length and spreading length, the simulated result on OFDM-MIMO with IDMA scheme shows the better performance on underwater wireless communication channel. This simulation is better than only using OFDM-MIMO technique.

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