Survey and Study on High Rate Mimo Ofdm for Underwater Acoustics Communication

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Abstract- This paper presents the comprehensive survey of SISO, SIMO, MISO, MIMO, MIMO-OFDM and MIMO-OFDM based Underwater acoustic communication for high data rate. MIMO-OFDM has proved to be a prominent answer for underwater acoustics communication. MIMO-OFDM combines MIMO and OFDM. The capacity of different signals over multiple antennas is multiplied using MIMO also the radio channel is split into various closely spaced sub channels. This paper presents a study of the latest works in this field. The previous works are reviewed, summarized, and compared accordingly and the problems faced by underwater acoustics communication are also listed. The results for MIMO OFDM for underwater acoustics communication are also listed.

IndexTerms- SISO, SIMO, MISO, MIMO, Underwater acoustic communication.

I. INTRODUCTION

A technique of sending and receiving messages below water is known asunderwater acoustic communication. There are different factors responsible for making underwater acoustic communication difficult and they are multipath propagation, time variations of the channel, small available bandwidth and strong signal attenuation. Underwater communication has low data rates as compared to the terrestrial communication. This is because acoustics waves are used in underwater communication instead of electromagnetic waves. In underwater environment there is attenuation and absorption of electromagnetic waves and hence they can travel only short distances in underwater. Absorption of Electromagnetic energy in sea water is observed to be 45 x f dB per km, where, f is the frequency in hertz. Similar to acoustic communication optical signal is also one of the tools that can be used in underwater communication. But it is observed that optical signal can only pass through limited range in very clean water environment.

Optical signal is also one of the tools that can be used in underwater communication. But it is found that optical signal can only pass through limited range in very clean water environment (e.g. Deep water) thus it is not a proper tool for long distance transmission in underwater. The extremely slow speed of propagation of sound in water is a crucial element that discriminates it from electromagnetic propagation. Underwater the velocity of sound is dependent on various elements like temperature, salinity and pressure. Along the surface of velocity of water is around 1520m/s in water i.e. 4 times the velocity of sound in air. Under water velocity of sound depends on different factors and it increases with increase in water temperature, salinity, and depth. Due to changes in temperature there are changes in sound speed. Salinity changes in the open ocean are small due to which the effect of salinity on sound speed is small. Salinity varies greatly near shore and in estuaries, and can affect the velocity of sound in water. The speed of sound in water depends on water pressure and increases with increase in the depth. Sound will travel slower in colder water and faster in warmer water. The speed of sound increases 4m/s approximately for water temperature. As the depth of the water increases 1km, the sound speed increases roughly 17m/s.

Wave energy gets transformed to another form and gets captivated by the medium during the propagation. For acoustic waves, the inelasticity which converts the wave energy into heat is material imperfection. Multipath is referred to as the signal propagating from the transmitter to the receiver along number of different paths in wireless environment.There are different diversity techniques that compensate fading of the signal.The signal is transmitted through numerous independent fading paths, to obtain diversity at the receiver. Wireless communication is growing at an exponential pace and will continue to grow at same pace in the future. This has led to an increasing demand for high data rate for effective communication. As it depends mainly on the types of antennas used, we will now study each of them in detail. We have four types of antennas configurations available viz. SISO, SIMO, MISO and MIMO.

II. ANTENNA CONFIGURATIONS

A.SISO:

SISO is the simplest antenna technology. There is no diversity and no additional processing required. Let 'x' be the data stream, h1 the channel and 'y' the output data stream. antenna structure and the relation between excitation and response of SISO configuration is as given in fig.1

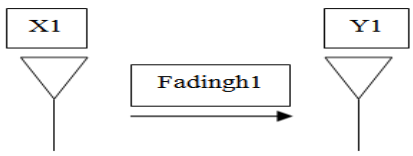

Fig.1: SISO Model

SISO does not require processing in terms of diversity schemes [22]. The SISO channel capacity is given by,

$$C_{SISO}=B\log_2(1+S/N) \quad (1)$$

where C_{SISO} = capacity of channel, B = bandwidth of the signal, S/N= signal to noise ratio.

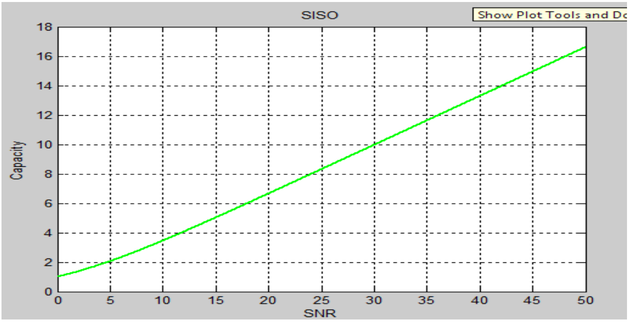

Fig.2: Capacity vs SNR of SISO

B.SIMO:

The antenna structure with one transmitting antenna & numerous receiving antennas is known as the SIMO. To overcome effects of ionosphere fading and for short waves listening and receiving stations SIMO configuration is used. Suppose we have two antennas for receiving. Thechannel capacity has not increased. We can obtain a healthy signal at the receiver side using numerous receive antennas.

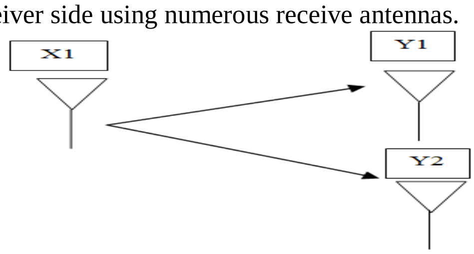

Fig. 3: SIMO Model

The relation between excitation and response and the structure of antenna of a Single input Multiple output is given by

$$C_{SIMO}=M_r B log_2(1+S/N) \quad (2)$$

where, C_{SIMO} = capacity, B = bandwidth, S/N= signal to noise ratio. Mr = no. of antennas at the receiver side.

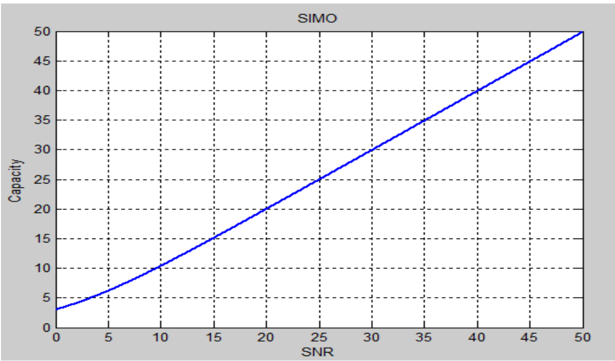

Fig.4: Capacity vs SNR of SIMO

C. MISO:

The antenna structure with numerous transmitting antennas and one individual receive antenna is known as the MISO system. One of the advantage of the MISO system is that the redundancy and coding has been shifted from receiving end towards the transmitting end. Suppose we have 2 antennas at the transmitter side and 1 antenna at the receiver side. The received signal is denoted by y_1 (sum of x_1h_1 and x_2h_2). We transmit the inputs at different time, $-x_1^*$ and x_2^* so as to isolate x_1 and x_2.As we still have to pass on $-x_1^*$ and x_2^* at time 2,the channel capacity has not increased effectively

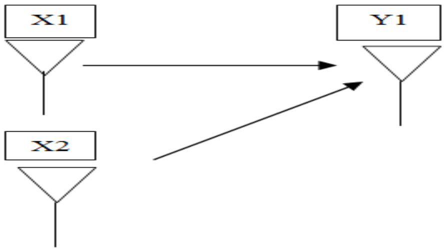

Fig.5: MISO

The MISO capacity is given by,

$$C_{MISO}=M_t B log_2(1+S/N) \quad (3)$$

where C_{MISO} = capacity, B = bandwidth, S/N = signal to noise ratio. M_t= No. of transmitting antennas.

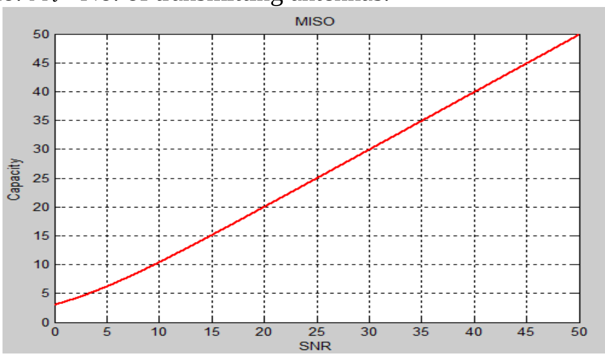

Fig.6: Capacity vs SNR of MISO

D.MIMO:

MIMO is a method in which more than one data signal is transmitted and received over the same radio channel. Multiple Input Multiple Output has several transmitting and receiving antennas and thusexploits spatial diversity. If the data rate is to be enhanced for single user MIMO and if the separate streams are given to different users this is known as multi-user MIMO (MU-MIMO).Since MIMO has multiple antennas at the input, the signals can be transmitted by any of the antenna and signals from different paths take different paths to reach the receiving end i.e. even if we move the antenna by small position the path gets change.

Suppose we have 2 transmit and 2 receive antennas.It's quite simple and intuitive. However, for this model, we assume that the h coefficients of fading are absolute. We will have a obnoxious time searching for a resemblance for inverse of H if they are correlated. In practical terms, this means that we cannot recover x_1 and x_2.

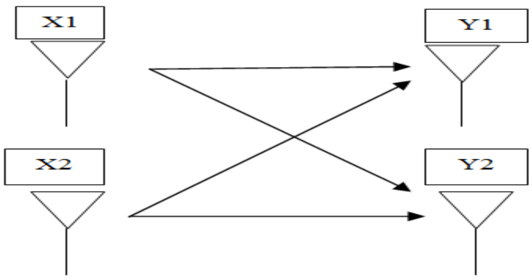

Fig.7: MIMO Model

$y_1 = h_1x_1 + h_2x_2$(4)
$y_2 = h_3x_1 + h_4x_2$(5)

$$\begin{vmatrix} y_1 \\ y_2 \end{vmatrix} = \begin{vmatrix} h_1 & h_2 \\ h_3 & h_4 \end{vmatrix} \begin{vmatrix} x_1 \\ x_2 \end{vmatrix} + \begin{vmatrix} w_1 \\ w_2 \end{vmatrix}$$

Finally Assume there is some white Gaussian Noise, and we have a set of linear equations

$$y = Hx + w \quad (6)$$

All 2 degrees of freedom are being utilized in the MIMO case, giving us Spatial Multiplexing. The response of MIMO channel in matrix is given as :

$$H(\tau, t) = \begin{bmatrix} h1,1(\tau,t) & \cdots & h1,N(\tau,t) \\ \vdots & \ddots & \vdots \\ hM,1(\tau,t) & \cdots & hM,N(\tau,t) \end{bmatrix}$$

The signal received at the i[th] receive antenna is givenby

$$y_i y_i(t) = \sum_{j=1}^{N} h_{i,j} h_{i,j}(\tau,t) * s_j s_j(t) + n_i(t),\ i = 1,2\ldots,M \quad (7)$$

where * is the convolution and $n_i(t)$ = noise added in the receiver.

$\bar{h}h(\tau,t)=[h_1(\tau,t)\ \ h_2(\tau,t)\ \ \ldots\ \ h_N(\tau,t)]$

The received signal can be represented as

$$y(t) = \sum_{j=1}^{N} h_{i,j} h_{i,j}(\tau,t) * s_j(t) + n(t) \quad (8)$$

And in the vector form it is given as

$$y(t)= h(\tau,t)* s(t)+n(t)$$

$$\bar{s}(t)=[s_1(t)\ s_2(t)\ \ldots\ s_N(t)\ ]^T (9)$$

Compared to other systems MIMO has higher capacity. The MIMO capacity is given by,

$$C_{MIMO}=M_tM_rB\log_2(1+S/N) \quad (10)$$

where, C_{MIMO}= capacity, B= bandwidth, S/N = signal to noise ratio. M_t= No. of transmitting antennas &M_r = No. of receiving antennas.

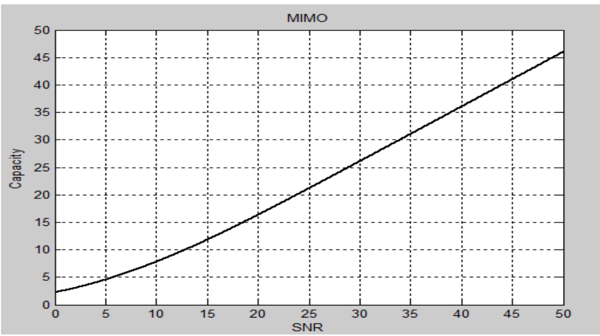

Fig.8: Capacity vs SNR of MIMO

The graph in fig.9 compares the capacity of SIMO system and MIMO systems.

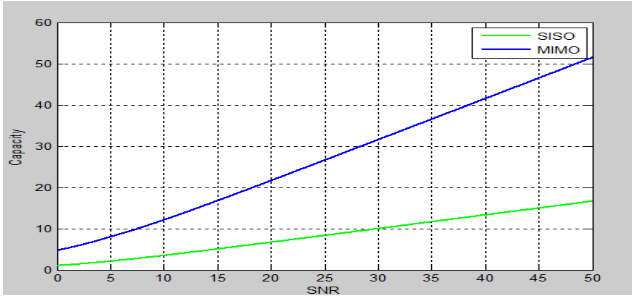

Fig 9: Capacity vs SNR of SISO and MIMO

The graph in fig.10 is a capacity vs SNR graph of SISO, MISO, MIMO. From the graph below it s observed that the capacity increases as we increase the no. of receive and transmit antennas.

In the graph in fig 10 the SISO, MISO and MIMO antenna configurations are compared using different schemes. The black line shows the capacity of a SISO system. Blue and Pink lines indicate the MISO configurations with 2 and 3 antennas at the input respectively. Similarly, Brown and Green lines indicates the capacity of MIMO antenna configuration with 2, 3 antennas at the transmitter and receiver respectively.

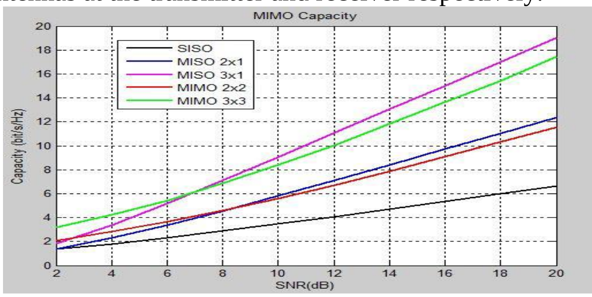

Fig.10: Capacity vs SNR of SISO, MISO, MIMO

Table 1 Comparison of SISO,SIMO,MIMO,MIMO-OFDM

Sr.. No.	Parameters	SISO	SIMO	MISO	MIMO	MIMO - OFDM
1	BER	Lowest	Better than SISO	Better than SIMO	Optimized BER	Optimized BER
2	Throughput	Less	Less	Slightly better than SIMO	Best	Best
3	Input	Single	Single	Multiple	Multiple	Multiple
4	Output	Single	Multiple	single	Multiple	Multiple
5	Data rate	Less	Less	Better than SIMO	Better than MISO	Best
6	Applications	Wi-fi, TV, Radio broadcasting	Listening and receiving short waves	Wire-less LAN, Digital TV	All advanced wireless communication	Underwater communications

Thus, from table 1 above we can see that MIMO antenna configuration is most suitable configuration for meeting the expectations of today's world wireless communication.

E.OFDM:

Inter-symbol interference is often caused while transmitting data at high data rates and ISI which gives rise to distortion in transmitted signals. A simple solution to this problem is Orthogonal frequency division multiplexing (OFDM). In OFDM data is simultaneously transmitted after converting a high data stream into a number of small data streams.

Various advantages of OFDM systems are:

- It is Simple to implement using IFFT/FFT.
- It has a receiver with less complexity.
- Due to orthogonal subcarriers it has high spectral efficiency
- It has Robust performance.

OFDM is preferred over FDM because FDM signals need guard band between them to protect leakage interference. While OFDM signals are orthogonal hence there is no need of guard bands.

F. MIMO-OFDM:

The future wireless communication systems face the major challenge of providing high rate data access.It is a fact that spectrum is a limited resource and fading and interference from other users led to unfavorable propagation conditions.To improve link reliability this conditions calls for means to radically increase spectral efficiency. Multiple antennas and delay spread in broadband MIMO channels endeavor spatial diversity and frequency diversity.The receiver complexity in wireless broadband systems is reduced by OFDM.The key for future broadband wireless systems is the use of MIMO along with OFDM.MIMO-OFDM merges OFDM with MIMO. MIMO transmit different signals over multiple antennas thereby multiplying the capacity. It contributes to high capacity and data throughput. MIMO-OFDM is the basic for most progressive wireless communication and mobile broadband network standards. It is the future of 4G and 5G broadband communications. In MIMO-OFDM, CP andIFFT/FFT operations are being performed at each receiveand transmit antennas.

Depending on the way in which MIMO coding is applied, the MIMO-OFDM systems are classified into three types.

- Space Time Block Coded(STBC) MIMO OFDM system.
- Space Frequency Block Coded (SFBC) MIMO-OFDM system.
- No coding is used in Spatial Multiplexing (SM) MIMO-OFDM system.

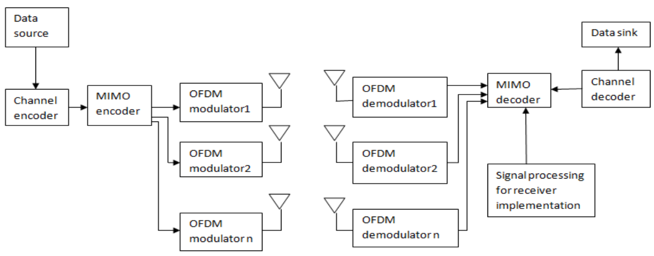

Fig.11: Block diagram of MIMO-OFDM system.

G. System model for MIMO-OFDM:

Consider a MIMO-OFDM system with N_t transmitting antennas and N_r receiving antennas. Each OFDM symbol will have K subcarriers. M-PSK or M-QAM modulator is used formodulation of the data to be transmitted. K symbols each to be transmitted on different antennas are then grouped into $N_t$groups. According to the type of MIMO-OFDM system, the grouped symbols are coded and superimposed on K subcarriers. CP is added to each group,after applying IFFT. The channel length L is larger than length of CP. Each antenna transmits OFDM symbols. Signals from all the transmitting antennas will be received at the receiver with noise and noise is expected to be AWGN. At receiver FFT is applied after removing CP from the signals. A decoder is used to decode the symbols fooled by the demodulator to obtain back the transferred binary data. Binary data are classified depending on the modulation scheme whether it is M-QAM or M-PSKat a transmission time *n*, anddepending on the coding to be used mapped onto different subcarriers.

$$y(n)=\sum_{i=1}^{N_T} H_{ij}[n,k]X_i[n,k] + W_j[n,k] \quad (11)$$

$$Y_j[n,k]= \sum_{i=1}^{N_T} H_{ij}[n,k]X_i[n,k] + W_j[n,k] \quad (12)$$

The ergodic capacity of the MIMO-OFDM system is obtained as:

$$C=\frac{1}{N}\sum_{k=0}^{Nc-1} E\{\log[\det(I_{Nr} + \frac{\rho}{Nt}H(e^{j2\pi k/Nc})H^H(e^{j2\pi k/Nc}))]\} \quad (13)$$

where, N_C = No. of subcarriers, ρ = average Signal-to-Noise Ratio (SNR) at each respect to $H(e^{j2\pi k/Nc})$ which symbolize the equation of the channel matrix in frequency.

III. MIMO-OFDM FOR UWA

After FFT demodulationthe received signal is modeled as [19]

$$y_k^r(n) = \sum_{t=1}^{M_T} H_k^{tr}(n)\, d_k^t(n)\, e^{j\theta_k^t(n)} + z_k^r(n) \quad (14)$$

The phase shift is given as[19]

$$\theta_k^t(n) = \theta_k^t(n\text{-}1) + a^t(n) \,.\, 2\pi f_k T' \quad (15)$$

where, $f_k=f_0$ +k$\Delta f$is the kth carrier frequency,

$$T'= T+Tg \quad (16)$$

is the time for one block of OFDM.

The received signal in matrix form, is given as [19]

$$y_k y_k(n) = d_k d_k(n)\Theta_k(n)H_k(n) + z_k(n) \quad (17)$$

where,

$$y_k(n) = [\, y_k^1(n) \quad \dots \quad y_k^{M_R}(n)]$$

$$d_k(n) = [\, d_k^1(n) \quad \dots \quad d_k^{M_T}(n)]$$

$$z_k(n) = [\, z_k^1(n) \quad \dots \quad z_k^{M_R}(n)]$$

and

$$H_k(n) = [H_k^{tr}(n)]_{t=1,\dots M_T\ ,r=1,\dots\ M_R}$$

$$\Theta_k(n) = \mathrm{diag}[e^{j\theta_k^t(n)}\ ]_{t=1,\dots M_T}$$

Bandwidth, BER, Channel estimation etc are the different factors that are needed to be considered so as to increase the data rate or in other words for high data rate. Let us see how these factors can be improved by using various techniques.

a. Bandwidth:

The method proposed in [5]employed a bandwidth-efficient SC-FDE with a decision directed channel evaluation method to improve the capability of channel tracking and maintain high bandwidth efficiency. To regain the excitation data for the FDE, one bigdata block is divided into small sub-blocks, and employed a data window consisting of the present sub-block and parts of earlier and successive sub-blocks. To eliminate post cursor and precursor interference symbols of preceding and following sub-blocks were used.A group-wise phase correction method corrected the phase rotation of equalized symbols. A decision-directed method estimated the pilot symbols and re-estimated the identified sub-block symbols in the UWA MIMO channels. In the proposed FDE scheme, the channel impulse responses were predicted, followed by the detected symbols. Therefore, the recommended method considerably improved the bandwidth capacityat the expense of raised complications. The system execution improved and efficiency of data transmission was

also considerably increased by the proposed algorithm. It was experimentally proved that the time-varying UWA channels were effectively tracked by the proposed scheme.

b. Channel estimation:

In [6] a new technique for enhanced data ratewas proposed. During detection separate operations were performed such as interference cancellation and phase compensation and to achieve enhanced performance, MIMO linear equalization was operated. The proposed scheme was experimentally tested and results showed the robustness of the scheme.

In 2007 B.Li.et.el designed and experimentally tested a OFDM-MIMO scheme where two transmitters simultaneously transmitted two independent data streams. At the transmitting side null sub carriers were added in order to simplify the compensation and estimation of Doppler shifts at the receiving end. ZF Detector was found to perform better compared to the MAP Detector [1].

c. Spectral efficiency:

The Doppler effect was compensated by the detector designed in [3]. In carrier offset frequency evaluation method the search for best CFO estimate is done using the energy of the null subcarriers. A speed of 125.7 kb/swas achieved and tested from three different experiments.

Further experiments using higher order modulation schemes and more than two transmitters showed that higher order modulation elevated the spectral efficiency appreciably[2].

Channel estimation is an important aspect in Underwater communication. LS does not need channel statistics and is a technique with low complexity and reasonable performance. MMSE is a technique with good performance and more complexity. In MMSE the reversal of a matrix is necessary as the autocorrelation matrix used all the channel evaluation methods and thus complexity of the system is increased. In [12] a low complexity adaptive channel estimation technique was proposed. The proposed algorithm used symbol decision and did not require the inactive carrier which resulted in less no. of pilots.

Doppler spreadsand compensation accuracy are the two factors that greatly affect the realization of channel estimation. Blind (semiblind)channel estimation and pilot assisted channel estimation are included in the typical channel evaluation method. Blind channel evaluation is a reliable technique for underwater acoustic communications. Underwater acoustic communication channel is naturally sparse. Due to this sparsity subspace algorithm method is more efficient compared to the traditional LS method.

According to the recent studies in information theory significant gains can be obtained by using MIMO. At the receiver, STTC's, LSTC's are used for high data rate communications[17]. Several modifications are made to the canonical decision feedback equalizer in the proposed equalizer to use them in UWA channel. To compensate inter-symbol interference, co-channel, a powerful technique used is iterative equalizer. The equalizers proposed in [17] are repetitive in nature allowing them to interchange data with the channel decoder in a closed loop, decreasing the error rates. The results were collected by processing real at sea data assembled in a very activating UWA channel in the Pacific Ocean. It was observed the transmission rates in UWA channel can further be increased by adaptive modulation and coding added to MIMO signaling. Very high data rates are obtained by using MIMO and STC.

d. Doppler compensation:

Doppler shift is one of the problems of underwater channel. To ease Doppler compensation, null subcarriers were used.

In Distinct climaticconditions various acute values for Delay spreads and doppler were calculated, with distinct number of pilot symbols and subcarriers, beyond which the data couldn't be predicted and deciphered accurately [4, 33].

In [9] a two step method is proposed to compensate for Doppler effect. A low-complexity blind method to eliminate amplitude/phase uncertainty thatarises in the subspace is proposed [9]. In this method the phase data was obtained by applying interleaved symbol mapping schemes to attain no rotational symmetry. Simulation results revealed that the recommended technique efficiently eliminated the uncertainty in magnitude and enhanced the spectrum efficiency of underwater acoustic communication.

For compensating the ICI over fluctuating UWAC, J. Han et al. in 2016 introduced and implemented a newly arriving partial FFT technique [18].He proposed a flexible algorithm with zero a-priory channel data presumption. This adaptive algorithm implemented weight updating, data detection and channel estimation by sliding window.

e. Transmission scheme:

In 2008 Y. Emre developed a transmission scheme,in which a turbo-coded, OFDM-MIMO model modulated byPSK, for UWAC was projected. Two transmission schemes were used and they are coherent and differential transmission schemes. Knowing that adjoining frequencies experience nearly equal distortion differential scheme dispose of the need of channel estimation.
In [8] SC-FDMA transceiver technique is recommended for MIMO underwater acoustic communications. It has a lower PAPR than an Orthogonal Frequency Division Multiplexing scheme. Similar to the CFO and channel approximation at the receiving end there is signaling of pilot symbols on transmitter side in an OFDM system. At the expense of raised complexity in channel evaluation, identical pilot subcarrier was engaged for all transmitters to achieve high spectral efficiency. Moreover, CFO as estimated using the pilot symbols. The effective frequency-domain turbo equalization method was selected to identify the data symbols. The performance gain of turbo equalization and the feasibility of the recommended transceiver scheme was demonstrated experimentally.Compressed sensing is a topic of interest in high speed underwater communication. According to the simulation execution CS-MP has a better performance compared to the LS and OMP algorithms. CS-MD technique improves the frequency spectrum efficiency and leads to exact channel state information with fewer pilots.
Based on adaptive channel estimation, the coherent detection is preferred over differential coherent detection. Since the adaptive channel evaluation became more difficult across longer blocks it resulted in failure of coherent detection [14]. STBC's are well-known because of their ingenuousness. In order to achieve reliability in underwater acoustic communication channels STBC codes are used. A BEM-based differential OSTBC coding method is developed in [15] for MIMO UWA communications. Compared to control group the scheme proposed in [15] had a better performance. The suggested method reliability is examined with the natural components. BEM-DOSTBC depends on the DFT for combating channel frequency diversity. The proposedScheme is tested at the Rescheduled Acoustic Communication Experiment. The multipath diversity benefit was inspected with Signal to Noise Ratio greater than 10dB using LCF coding. Butwhen SNR was less than 20 dB the coding gain was slightly compromised. The data rate for the recommended BEM–DOSTBC method was determined as:

$$d_{rate} = 1/T_s *M/(M+CP)/ (Q+1)*m \qquad (21)$$

where, T_s =duration of symbol duration, M = length of the block, CP= length of CP, and m=2 for QPSK, or m=3 for 8 PSK. The data rate for the projected BEM-DOSTBC method was found to be 2.66kb/s for QPSK and 3.99kb/s for 8PSK. The recommended BEM-DOSTBC method is reliable. The equivalent values between the Bit error rates and the experimental data was verified and it was confirmed that the method suggested is sturdy contrary to the fluctuating circumstances in sea [15].
Severe multipath, time fluctuating property and restricted bandwidth of the channel makes high rate underwater communication very challenging. The problems introduced by fast fluctuating channels can be mitigated by performing Doppler tracing and frequent channel estimation. The suggested receiver has low complexity.
Receiver performance is also enhanced by using SIC into the receiver structure. SNR of output is improved upto 3dB by using SIC. It was found that attainable data rates can be raised up to four times by utilizing the identical bandwidth as the individual source structure.

f. Spatial modulation:

The spatial dispersion of signal is controlled byspatial modulation. To create autonomous communication channels spatial modulation uses numerous, resolvable propagation courses bounded by 2 arrays.
From the two experiments conducted in [20] it can be concluded that by using spatial modulation higher data rates and power throughputs can be obtained and nearly 50% greater capacity can be obtained [20].
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IV. CONCLUSION

In [3] three experiments AUV07, RACE08, & VHF08 were carried out for enhancing the data rate of UWAC. According to the AUV07 BER results, 64 blocks for stream1 and stream2 were tested and only 2 out of sixty four blocks had problem in deciphering data stream2 for 500m case while for the 1500m case there were no errors.

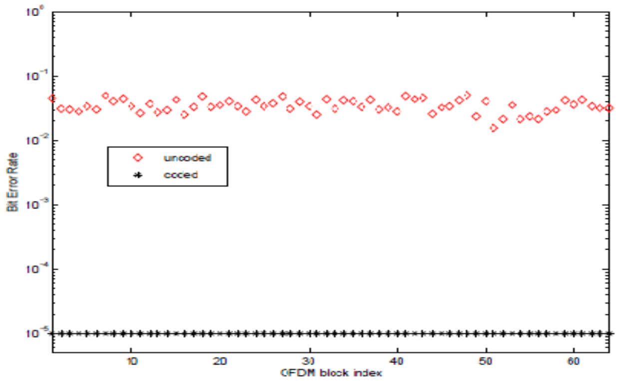

Fig.12: Result of 500m case in AUV07 Experiment.

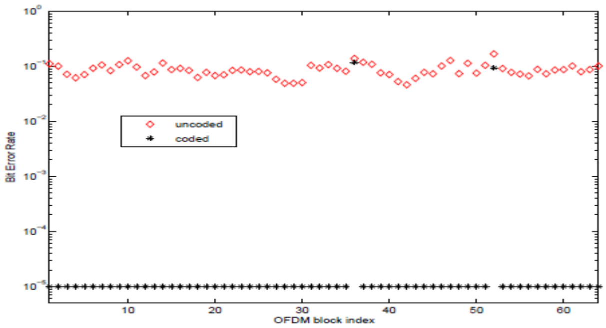

Fig.13: Result of 1500m case in AUV07 Experiment.

Table 2 Performance Result with 2 transmitters and 12 receivers, RACE 08.

	Spectral efficiency bits/s/Hz	Data streams	Average BER	Average BER
2IMO,QPSK	1.17	Stream 1 Stream 2	4 . 10^{-4} 0	2 . 10^{-3} 0
2IMO,8QAM	1.76	Stream 1 Stream 2	0 0	0 0
2IMO,16QAM	2.35	Stream 1 Stream 2	6 . 10^{-3} 3 . 10^{-3}	3 . 10^{-2} 1 . 10^{-2}
2IMO,64QAM	3.52	Stream 1 Stream 2	7 . 10^{-2} 1 . 10^{-2}	4 . 10^{-1} 5 . 10^{-2}

Table 3 Performance Result with 3 transmitters and 12 receivers,RACE08

	Spectral efficiency bits/s/Hz	Data streams	Average BER	Average BER
3IMO, QPSK	1.76	Stream 1 Stream 2 Stream 3	2 . 10^{-2} 0 5 . 10^{-4}	1 . 10^{-1} 0 2 . 10^{-3}
3IMO,8QAM	2.64	Stream 1 Stream 2 Stream 3	1 . 10^{-2} 1 . 10^{-3} 8 . 10^{-4}	5 . 10^{-2} 6 . 10^{-3} 3 . 10^{-3}
3IMO,16QAM	3.52	Stream 1 Stream 2 Stream 3	4 . 10^{-2} 1 . 10^{-2} 2 . 10^{-2}	1.6 . 10^{-1} 4 . 10^{-2} 8 . 10^{-2}

Table 4 Performance Results with 4 transmitters and 12 receivers, RACE08.

	Spectral efficiency bits/s/Hz	Data streams	Average BER	Average BER
4IMO, QPSK	2.35	Stream 1 Stream 2 Stream 3 Stream 4	8 . 10^{-2} 2 . 10^{-2} 3 . 10^{-3} 3 . 10^{-3}	7 . 10^{-2} 4 . 10^{-2} 3 . 10^{-2} 3 . 10^{-2}
4IMO,8QAM	3.52	Stream 1 Stream 2 Stream 3 Stream 4	4 . 10^{-1} 7 . 10^{-3} 1 . 10^{-2} 8 . 10^{-3}	2 . 10^{-1} 1 . 10^{-1} 8 . 10^{-2} 8 . 10^{-2}

Table 5 Performance results for the VHF08 Experiment, 2 transmitters, rate ½ coding.

	Spectral efficiency bits/s/Hz	Data rate kb/s	Data streams	Uncoded BER	Coded BER
B = 31.25kHz, QPSK	1.0055	31.4214	Stream 1 Stream 2	0.0025 0	0 0
B = 31.25kHz, 8-QAM	1.5082	47.1320	Stream 1 Stream 2	0.0378 0.0049	0 0
B = 31.25kHz, 16-QAM	2.0010	62.8438	Stream 1 Stream 2	0.0868 0.0319	0 0
B = 31.25kHz, QPSK	1.0055	62.8427	Stream 1 Stream 2	0.0512 0.0193	0 0
B = 31.25kHz, 8-QAM	1.5082	94.2640	Stream 1 Stream 2	0.1102 0.0488	0 0
B = 31.25kHz, 16-QAM	2.0010	125.6875	Stream 1 Stream 2	0.1938 0.1290	0 0

From the tables 5 it is observed that error free data set was achieved with more than 2 rounds of repetitive demodulation and decoding.

V. CONCLUSION

This paper compares different antenna configurations such as SISO, SIMO, MISO, MIMO and founds MIMO to be more effective than other three. Further problems of underwater communication and various techniques for underwater communication are also described. It is found that MIMO-OFDM instead of MIMO is more effective for underwater communications. MIMO configuration exploits diversity and OFDM takes care of the ISI and ICI. Various researchers have concentrated on diverse problems and no one particular technique is found to be perfect that can be used in all conditions in underwater communication. Underwater MIMO-

OFDM is a comparatively novel field and there is a substantial scope for further researches. Results of three different experiments are also shown which shows that MIMO along with OFDM is a favorable answer for high data rate MIMO OFDM.

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