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MIMO-OFDM and IDMA scheme in underwater communication

Ajay Patel[1], Ruchi Gupta[2], Sanjeev Kumar Mishra[3]
[1,3] *Department of Electronics Engineering*
[2] *Department of Electronics and Communication Engineering*
[1,3] *Harcourt Butler Technological Institute, Kanpur, India*
[2]*Amity University Uttar Pradesh, Lucknow, India*

Abstract— The past three decades have seen a growing interest in UWA communications because of its applications in marine research, marine commercial operations, the offshore oil industry, oceanography and defense. However the ability to communicate effectively in underwater still remains challenging due to the unique channel characteristics such as fadings, extended multi-paths, bandwidth limitations or refractive properties of sound channel.[1][2] There is highly need of underwater communication technique to explore the ocean but here the condition is not as simple as in air. Coaxial wire or optical fiber or electromagnetic waves can't be used due its limitation in underwater. Therefore there is only one option to use acoustics waves but the bandwidth of acoustic signal is very less. Due to less speed of acoustic waves there is also very much fading. For efficient communication there is requirement of high spectral efficiency i.e. high data rate and low fading. Thus to mitigate this problem MIMO-OFDM scheme with IDMA has been used. 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. Thus this technique increased the data rate where as OFDM save the bandwidth and combat from the fading.
Keywords—MIMO, IDMA, ISI, CDMA, FDMA, TDMA

I. INTRODUCTION

In recent years OFDM becomes a very popular multi-carrier modulation technique [3] for sending signal over wireless channel. The main reason of popularity of OFDM technique is due to its ability to reduce the bandwidth and mitigate the multipath interference. Firstly, OFDM scheme has been used in implementing digital audio broadcasting (DAB) [6] system and digital video broadcasting (DVB) [7] system. Secondly, it has been selected as the basis for the air interface for the new broadband wireless access (Wi-Max) standard IEEE 802.16 [8]. With OFDM systems getting more popular applications, the requirements for a better performance is becoming higher. OFDM technology is used in two types of environment when it is used for wired communication, it is called digital multi toned (DMT). DMT is the main technology used for all the XDSL (digital subscriber lines) systems that provide high-speed data service via existing telephone networks. However in wireless communication, it is referred to as OFDM. In conventional FDM (Frequency Division Multiplexing), a guard band is introduced to avoid interference but this is inefficient use of bandwidth while in OFDM all the carriers overlapped. OFDM is widely adapted because of a number of its advantages, orthogonality of subcarrier signal allows easy generation of transmit signal through an inverse fast Fourier transform, easy separation of the transmitted data symbol at the receiver through a fast block, easy equalization through a scalar gain per subcarrier, easy adoption of multiple input multiple output (MIMO). Closely spaced orthogonal subcarriers partition the available bandwidth into a maximum collection of narrow sub bands. Adaptive modulation schemes can be applied to subcarrier bands to maximize the bandwidth efficiency and transmission rate a special structures of OFDM symbol simplifies the task of carrier and symbol synchronization.

In this paper, OFDM scheme is presented and its long path development from evolution (in 1950) to till data is described. Further the working principle and its advantage and shortcoming has been discussed. DCT is another technique to get orthogonal signal and it also save the bandwidth and reduced PAPR. Comparisons between conventional FDM scheme and OFDM scheme have been also done that shows the OFDM scheme is bandwidth efficient.

II. OFDM SCHEME

A. Introduction of OFDM Scheme

The basic idea of OFDM is to spread a wide-band high-data-speed stream over a large number of narrow-band low-data-speed sub channels. In conventional frequency division multiplex (FDM) systems, sub channels are separated in the frequency domain by guard band, therefore they do not interfere with each other but it is inefficient use of frequency, While in OFDM systems, all

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sub channels are overlap with each other. Due to overlapping, bandwidth is utilized very efficiently in OFDM without causing the inter-carrier interference and the subcarriers are orthogonal in time domain that make the easy separation of signal at the receiver side.

OFDM technology is used in two types of environment when it is used for wired communication, it is called digital multi toned (DMT). DMT is the main technology used for all the XDSL(digital subscriber lines) systems that provide high-speed data service via existing telephone networks. However in wireless communication it is referred to as OFDM. In conventional FDM (Frequency Division Multiplexing), a guard band is introduced to avoid interference but this is inefficient use of bandwidth while in OFDM all the carriers overlapped.

The difference between OFDM and FDM is shown below.

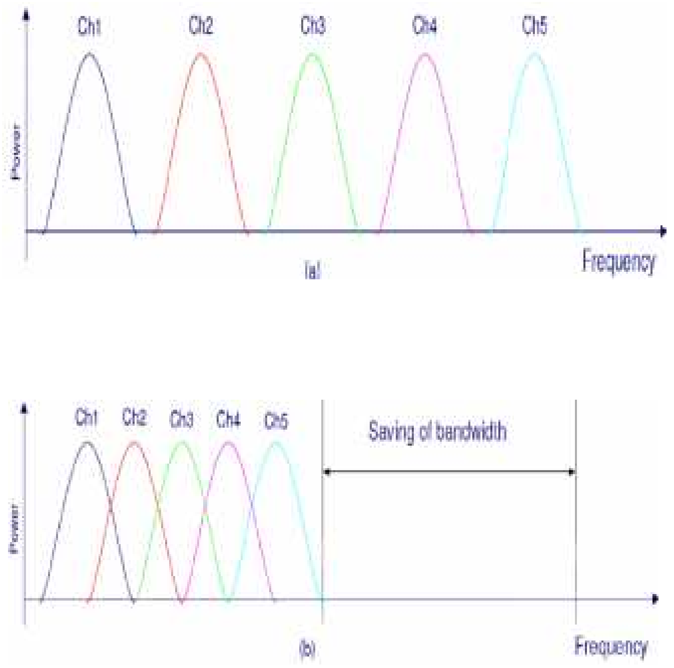

Fig.1: Difference between FDM and OFDM scheme

Thus OFDM technique saves the bandwidth that can be seen from above fig1.

The block diagram of OFDM is shown in fig 2. The message signal $X_i[k]$ is first converted serial to parallel bit after that IDFT of parallel stream data is taken that guarantee the orthogonality between all parallel bit stream. Basically the FFT multiplied the different parallel stream with sinusoidal carrier signal of different frequency and if m and n are integer then sin(mt) and sin(nt) will be orthogonal to each other

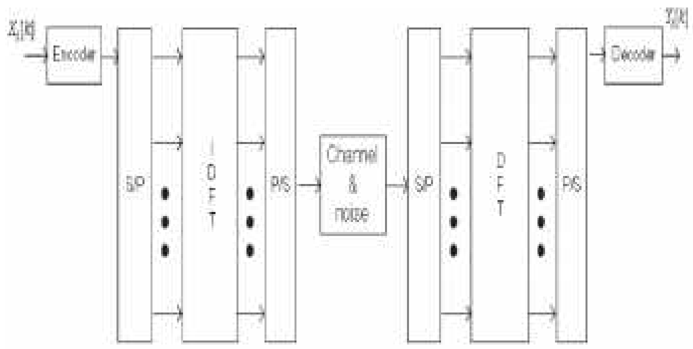

Fig.2: Block diagram of OFDM

After taking FFT, the signal is again converted into serial data and transmitted from the channel, .the signal that is transmitted to channel can be written in mathematical form as follows:

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

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 parallel stream and applied to IDFT block. At last the data is again converted into serial stream and after decoding, the actual message signal get. DFT and IDFT are invertible to each other so interchangeably can be used either at transmitter or receiver side.

In the place of FFT (Fast Fourier transform), DCT (Discrete Cosine Transform) can be used to generate the orthogonal signals because it reduces the computational speed (as only real calculation is required) and implementation area. DCT based OFDM system is a better technology for underwater acoustic communication, because the bandwidth required for DCT is half of that required for DFT when both system have same number of subcarriers. DCT basis have excellent spectral compaction and energy concentration properties which lead to improved performance with suitable channel estimation. This OFDM system also provides higher peak-to-average ratio (PAPR) reduction and achieves better noise immunity and hence a better bit error rate performance than standard OFDM.

B. Advantages of OFDM Scheme

OFDM is widely adapted because of a number of its advantages.[1] Orthogonality of subcarrier signal allows easy generation of transmit signal through an inverse fast Fourier transform, easy separation of the transmitted data symbol at the receiver through a fast block, easy equalization through a scalar gain per subcarrier, easy adoption of multiple input multiple output (MIMO). Closely spaced orthogonal subcarriers partition the available bandwidth into a maximum collection of narrow sub-bands.[3] Adaptive modulation schemes can be applied to subcarrier bands to maximize the bandwidth efficiency and transmission rate. A special structure of OFDM symbol simplifies the task of carrier and symbol synchronization.

III. MIMO (MULTIPLE INPUT MULTIPLE OUTPUT) SYSTEM

The use of multiple elements at the transmitter and the receiver in a wireless system, known as multi-input multi-output (MIMO) wireless communications, an emerging technology that promises significant improvements in capacity, spectral efficiency and link reliability. The use of MIMO is especially convenient in underwater communications, because the mentioned gains are achieved simply by adding multiple receivers transmitters and non-complex processing stages. Additionally, neither the bandwidth nor the transmission powers need to be increased.

***A.** MIMO transmitter architecture*

In VBLAST encoder the message bits first decompose into N_t parallel sub stream then each sub stream is modulated using a 2^b-ary constellation interleaved and then assigned to a transmit antenna. The spatial rate of this scheme is bN_t. When channel coding is used with interleaving in VBLAST, the VBLAST becomes HBLAST.

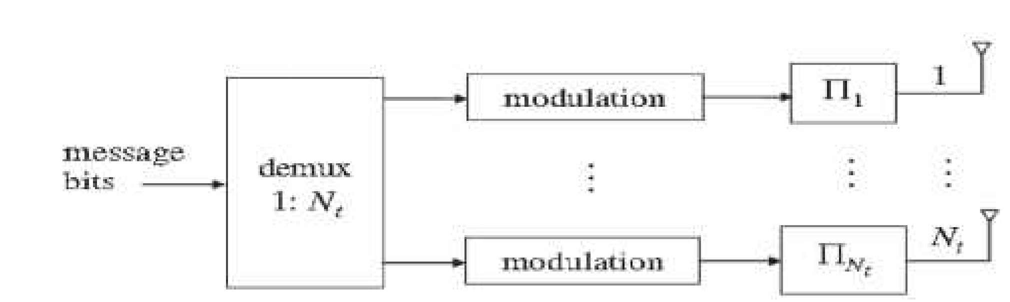

Fig.3: HBLAST

The differences between VBLAST and HBLAST are shown in the fig (3) & (4).

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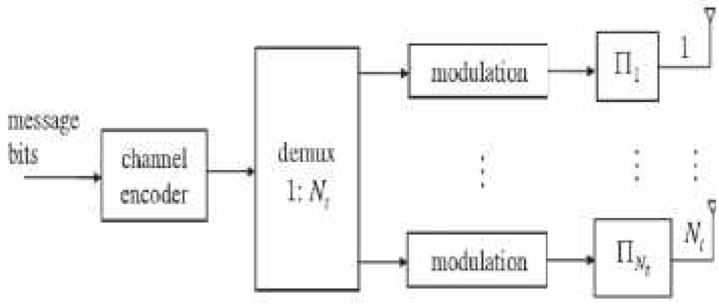

Fig.4: VBLAST

In VBLAST scheme each layer is encoded by a separate channel code, yielding flexibility in accommodating different users and/or different data rates.
In SCBLAST architecture a single channel coding scheme is used for all the layers. The SCBLAST architecture is shown in fig (5).

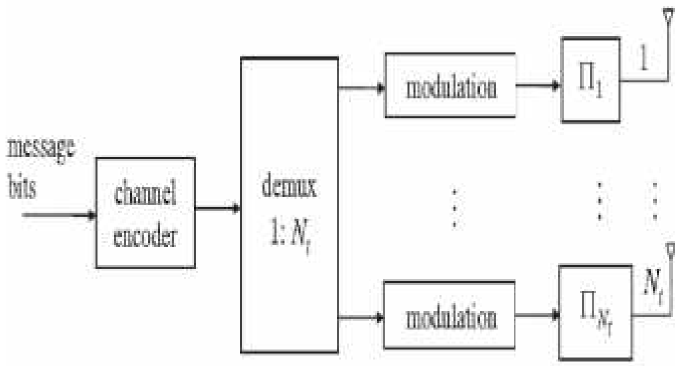

Fig.5: SCBLAST

B. Detection Algorithm

The optimal technique to detect blast signal is maximum likelihood detector but there is a disadvantages of it that the complexity of system grows exponentially as the number of transmit antenna and the number of the states of the channel code increases. That's why this technique is not used practically.
There is other two techniques Minimum mean squared error (MMSE) and zero force (ZF) technique that is less complex. In the ZF technique, when layer is detected, interference coming from undetected layers is suppressed, whereas in the MMSE technique, compromise between interference suppression and noise reduction is achieved. Both techniques are nearly same but ZF is less practical than MMSE because the complete interference suppression achieved by ZF comes at the expense of enhancing the noise power which leads to power degradation and one more difference is that number of receiver should be equal or greater than number of transmit antenna in the case of ZF while there is no such condition in case of MMSE.

IV. UNDERWATER CHANNEL

The underwater acoustic (UAV) channel is quite different from the terrestrial radio channel in many aspects and has more challenges. The UWA channel is affected by noise, multipath, transmission loss, Doppler spreading and variable delay. This makes underwater acoustic communication challenging. There are three types of carrier wave for underwater environment that are most commonly used in wireless communication. Using electromagnetic wave, the communication can be established at higher frequency and bandwidth.[1] The limitation is due to high absorption/attenuation that has significant effect on the transmitted signal. Radio Frequency wave travels long distance over conductive salty water but at very low frequency (30 to 300Hz) because of these big antennas also required for this type of communication, thus affects the design complexity and cost. Optical wave also offers high data rate transmission. Nevertheless, the signal is rapidly absorbed in water and suffers from

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scattering effect. This will affect the data transmission accuracy. Acoustic wave is the most preferred signal used as carrier by many applications, owing to its low absorption characteristic for underwater communication. Even though the data transmission is slower compared to other carrier signal, the low absorption characteristic enables the carrier to travel at longer range as less absorption faced by the carrier.

A. Channel Characterstitics

1) NOISE: The noise sources in an UWA channels can be divided into ambient noise and man-made noise [4]. The ambient noise is caused by biological creatures, seismic phenomenon and movement of water such as waves. The ambient noise is being reduced as the frequency increases. For high frequencies the thermal noise can be very dominating, especially over 100-200 kHz, where the thermal noise increases with 20 dB per decade. Another source of ambient noise is water bubbles that can affect underwater communication. According to in the 10-20 kHz band the dominant noise source may be resonant air bubbles in the area near the surface. The resonant frequency f is given by the following equation

$$f = \left(\frac{1}{2\Pi r}\right)\sqrt{\frac{2\gamma P}{\rho}} \ldots\ldots\ldots\ldots\ldots(2)$$

$$10 \log N_s(f) \quad 40 \quad 20(s \quad 0.5) \quad 26 \log f \quad 60 \log(f \quad 0.03)\ldots\ldots\ldots(3) \qquad (5.2)$$

$$10\log N_w(f) \quad 50 \quad 7.5w \quad 20\log f \quad 40\log(f \quad 0.4)\ldots\ldots\ldots(4) \qquad (5.3)$$

$$10\log N_{th}(f) = -15+20\log f\ldots\ldots\ldots\ldots(5)$$

Here ρ is the ratio of specific heats; P is the ambient pressure and γ is the water density. The other source of noise is the man-made noise that may be caused by noise from ships, oilrigs and similar. This is especially an important noise source when UWA sensor networks (UWA-SN) is being used for 4D-seismic close to oilrigs. Ambient Noise can be modeled by a Gaussian noise with the empirical power spectral density (p.s.d) given in dB, μ per Hertz as a function of frequency (in KHz).

Where *s* is the shipping activity whose value always ranges from 0 to 1 for low and high activity respectively, *w* is the wind speed expressed in m/s. The overall p.s.d. of the ambient noise is noted *N*(*f*) and expressed as the sum of the four above mentioned noise components.

$$N(f) \quad N_t(f) \quad N_s(f) \quad N_w(f) \quad N_{th}(f)\ldots\ldots\ldots(6) \qquad \textbf{(5.5)}$$

2) LOSS: Transmission loss is caused by attenuation and geometric spreading for signals that are transmitted directly to the receiver. The geometrical spreading is caused by the movement of the wave-front, and for farther distance the wave front is spread over a larger area. There are in general two types of geometrical spreading in underwater acoustic communication: Cylindrical and spherical. Cylindrical spreading is typical for shallow water UWA communication and has only horizontal spreading. Spherical spreading is typical for deep water UWA communication and can be seen as an omnidirectional point source. Geometrical spreading will cause the acoustic intensity to decrease with increased distance.

The attenuation occurs because of absorption when acoustic energy is transformed into heat, and this will increase with both distance and frequency. The major factors for absorption are viscosity, thermal conductivity and other relaxation phenomena. Viscosity is the phenomenon of resistance against stress in a fluid. This is the major factor for absorption in freshwater. Thermal conductivity is another factor that affects the absorption in water. This effect occurs because volume changes creates heat that is being transferred away from the acoustic wave, and thereby reducing the energy in the wave.

Reflection loss from the water surface will under calm condition give almost no loss, but if there a lot of waves there may be some loss. Reflection loss caused by sound waves hitting the bottom will depend on the sediment in bottom and the angle of the incoming sound wave. Very often the sound speed will be higher in the bottom than in water and part of the energy will be transmitted into the sediment layers. How much of the sound energy will be lost in the bottom and not be reflected will also depend on the frequency. Since underwater communication for high data rate will use a quite high carrier-frequency the loss will be large.[4]

Air bubbles in the water will also affect the transmission heavily since the sound speed in air is much lower. Therefore under the

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right circumstances the air bubbles may almost block the sound wave passing through the bubbles.

3) Multipath and Delay: Multipath is a huge problem that might affect the communication severely, and will give inter symbol interference (ISI). How much the multipath will occur depends on many physical factors, but the depth depended sound velocity is most important. Fig.6 shows the depth dependent sound velocity that will give a bending of the sound rays in the horizontal direction. So, the choice of spacing size between the sensors needs to take this effect into account.

Another problem is that the depth depended sound velocity changes through the season and thereby change the multipath through the season making it harder to design the UWA-SN system. Multipath may lead to constructive or destructive interference. The received signal may be amplified or it may be reduced depending on the phase of different multipath. Multipath occurs because of reflection of waves from the surface and the bottom. The receiver will receive multiple signals, both direct, and reflected signals from the surface and the bottom. But there may also be several direct waves that may arrive at different times depending on how much the waves have been bend . Large time delay is caused by the fact that the sound speed under water is in the range of 1500 m/s, which is much lower than the speed of radio waves that is approximately 3*108 m/s. In terrestrial radio communication multipath and reflection will not be a problem since the delay is so little, but in UWA communication these delays may arrive very late and cause problem for the communication. This is further complicated by the fact that the delays may vary a lot.[1]

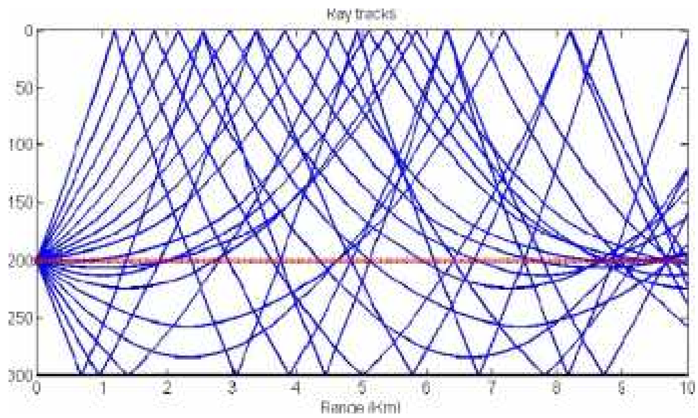

Fig.6: Bending of ray in depth

4) Sound Speed: Sound speed given by the bulk modulus and the density of the medium. In the ocean these factors depends on the water temperature, salinity and the depth of the water. The speed of sound waves is given by:

c = 1448:6 + 4:618T- 0:0523T2 + 1:25(S -35) + 0:017.
………………………………………………………..(7)
where T = temperature (in Centigrade), S = salinity (pro mille) D = depth (m)

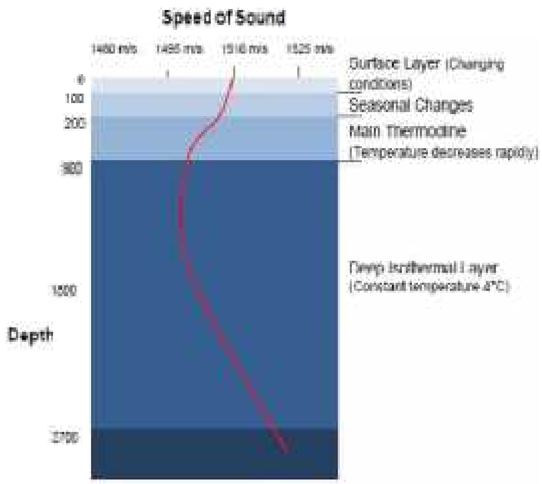

Fig.7: Sound speed profile in ocean

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The speed of sound is varying because the temperature, salinity and depth is varied. The layer near the surface will have a sound speed that varies with daily changes and seasonal changes in the temperature in the water. But also because of waves the water masse s will be changed and the sound speed will vary. Below the surface layer is the seasonal thermocline layer where the sound speed will decrease with depth because the temperature is decrease d with increased depth. Below thermocline layer is the deep isothermal layer where the temperature is almost constant, but the sound speed will increase with depth because of increased pressure.[2]

So between the main thermocline and the isothermal layer the sound speed will reach a minimum and this will create a sound channel. This sound channel has the ability to transmit low frequency signals very far.

V. SIMULATION RESULTS

The MIMO-OFDM scheme with IDMA is simulated for varying different parameter and a 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.

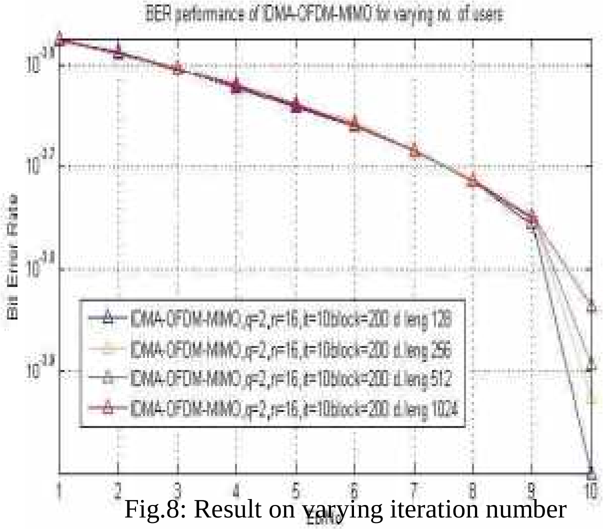

Fig.8: Result on varying iteration number

The above simulated graph 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. 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.

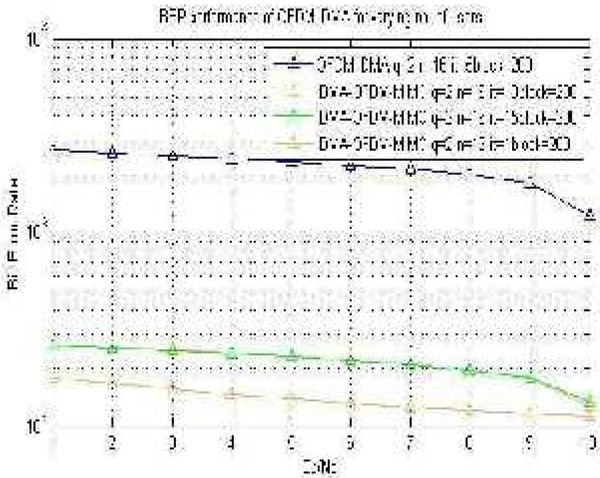

Fig.9: Result on varying data length

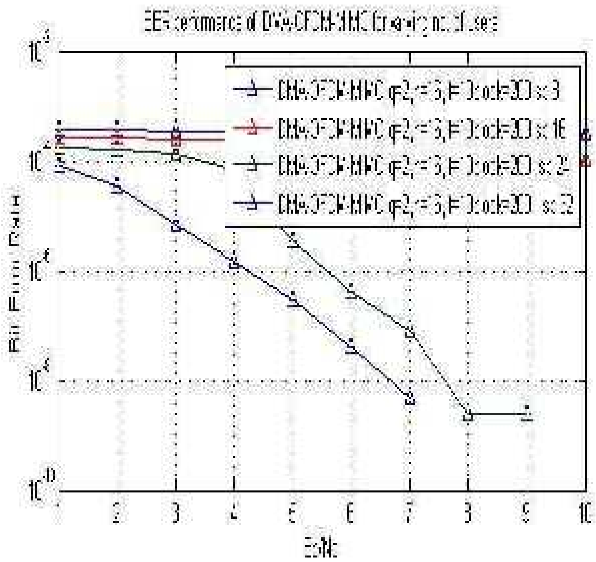

Fig.10: Result on varying spreading length

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.

VI. CONCLUSION

In this paper, MIMO-OFDM and IDMA scheme is studied for the underwater communication. The OFDM scheme is described thoroughly, the pros and cons of OFDM also listed. MIMO scheme is explained, the transmitter architecture and different type of detection methods described with their mathematical equation. Also the algorithm of MMSE detection method is developed that is used in simulation. This paper contains the characteristics of the underwater channel. The underwater channel is modeled in mathematical form. In last contains the result OFDM-MIMO with IDMA scheme is simulated for varying the different parameter like iteration number, data length, block length and spreading length. On the basis of these stimulated result a optimum value of different parameter has been taken. The optimized simulated result shows the better BER performance in comparison to MIMO-IDMA scheme.

VII.ACKNOWLEDGMENT

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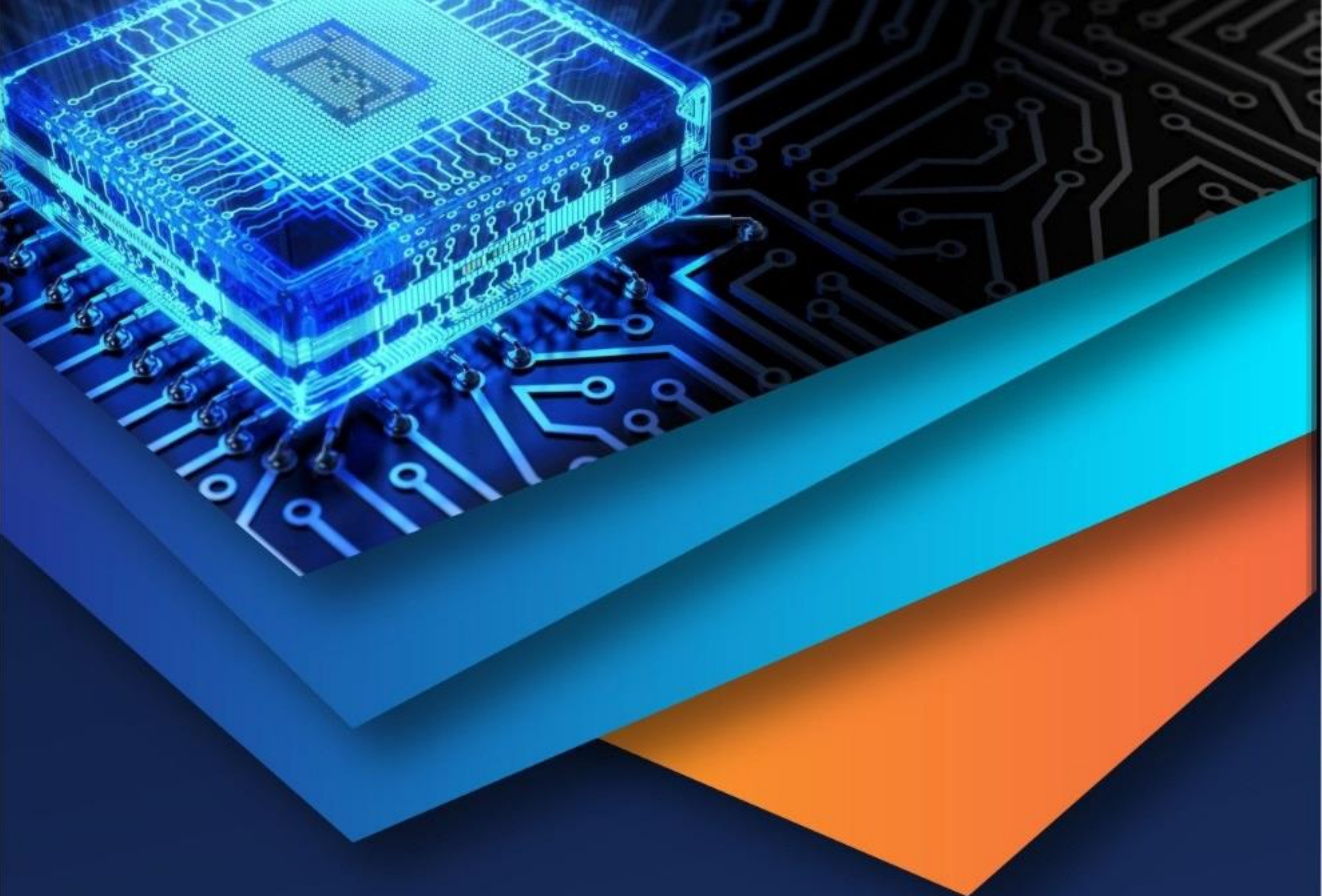

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