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MIMO-OFDM and IDMA Scheme in Underwater Communication

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Abstract— **Under water acoustic communication has been growing rapidly from last few decades due to its application i.e. in oceanography, marine research and defense. There is big need of underwater communication technique to explore oceans but it is not as simple as in air. It is quite different from air communication. Electromagnetic waves, optical fiber or coaxial wire cannot be used in underwater because of its limitation. However it is still challenging to communicate in underwater because of the different parameters of channels such as fading, bandwidth limitations, multi-paths or refractive properties of sound channel. That's why there is only one reason to use acoustics waves but the bandwidth of its signal is very low. Due to low speed of acoustic waves, fading problem occurs. We require high spectral efficiency for superior communication i.e. data rate is high and fading is low. For minimizing this problem we have been used MIMO-OFDM scheme with IDMA. MIMO is the technique in which we use multiple antennas at the transmitter and the receiver side. We use same channel for sending and receiving more than one data signal. Thus by using this technique the data rate is increased and OFDM save the bandwidth and avoids fading.**

Keywords- **MIMO, IDMA, ISI, CDMA, FDMA, TDMA**

I. INTRODUCTION

For sending signal over wireless channel in last years OFDM becomes a familiar multi-carrier modulation technique. The reason is behind the popularity of OFDM is its ability to reduce the bandwidth and attenuate the multipath interference. First of all, OFDM scheme has been used to implementing digital video broadcasting (DVB) system and digital audio broadcasting (DAB) system.[1] Secondly it has been used as the basis for the air interface for the new broadband wireless access (Wi-Max) standard IEEE 802.16. With this system we can get more popular applications & requirements for a better performance are becoming higher. OFDM technology can be used in two types of environment i.e. 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.[2] However in wireless communication, it is called 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 have been discussed. DCT is another technique to obtain orthogonal signal and it also save the bandwidth and decrease PAPR. Comparisons between conventional FDM scheme and OFDM scheme have been also done that demonstrate the OFDM scheme is bandwidth efficient.

II. OFDM (Orthogonal Frequency Division Multiplexing) SCHEME

A. *Introduction of OFDM Scheme*

OFDM scheme is used to develop wide high speed data in wide band over a large number of sub channels of low data speed in narrow band. In conventional frequency division multiplex (FDM) systems, sub channels are distinct in the frequency domain by guard band, therefore they do not inhibit with each other but it is inefficient use of frequency, all sub channels are overlap with each other in OFDM system. Due to overlapping, bandwidth is used very systematically in OFDM without creating the inter-carrier interference and the subcarriers are orthogonal in time domain that the separation of signal is done easily at receiver side.

OFDM technology is used in two ways, i.e. wired communication and wireless communication. The wired communication is called digital multi toned (DMT). DMT is the main technology used for all the XDSL (digital subscriber lines) systems. DMT provide high-speed data service through existing telephone networks. However in wireless communication it is called as OFDM. A guard band is introduced to avoid interference in conventional FDM (Frequency Division Multiplexing), but this is incompetent use of bandwidth while in OFDM all the carriers overlapped.[3]

The difference between OFDM and FDM is shown below.

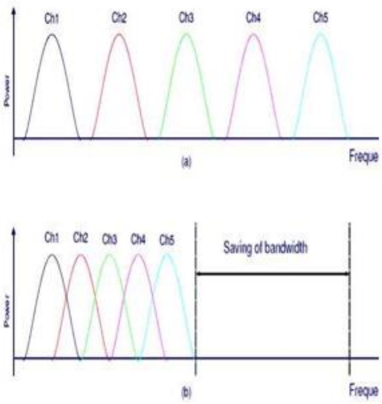

Fig.1: Difference between FDM and OFDM scheme

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 Xi[k] is first converted serial to parallel bit. After that IDFT of parallel stream data is taken that assures the orthogonality between all parallel bit streams. Basically the work of FFT is to multiply the different parallel stream with sinusoidal carrier signal of different frequency. If m and n are integer then sin(mt) and sin(nt) will be orthogonal to each other.

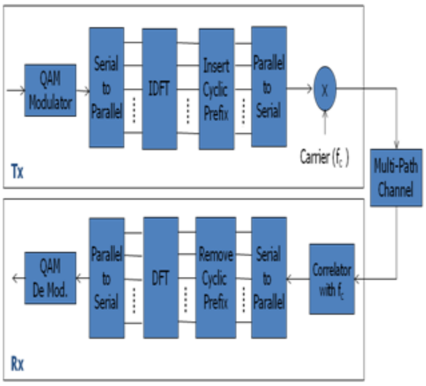

Fig.2: Block diagram of OFDM

The signal is again transformed into serial data and transferred by the channel, by using FFT. The signal that is transferred to channel can be written in mathematical form as follows:

$$\tau(t) = {}_{n=1}\Sigma^{N} m_n (t) \sin (2\pi nt)\ldots\ldots\ldots.(1)$$

The above equation is equivalent to FFT where m (t) is the message signal and n is any integer. The serial data is again converted into parallel stream at the receiver side and applied to IDFT block. The data is again converted into serial stream at last block and after decoding, the original message signal obtained. DFT and IDFT are invertible to each other so it can be used at both sides either at transmitter or at receiver.

DCT (Discrete Cosine Transform) can be used in the place of FFT (Fast Fourier transform), to produce the orthogonal signals because the computational speed (as only real calculation is required) and implementation area is decreased by DCT. OFDM is a better technology for underwater acoustic communication based on DCT, because the bandwidth required is half for DCT system as compare to DFT, having same numbers of subcarriers. DCT have a good factor of energy concentration and spectral compression which help to improve the performance of channel estimation. This OFDM system also gives better noise immunity and BER performance and higher peak-to- average ratio (PAPR).

B. Advantages of OFDM Scheme

OFDM has a numbers of advantages. Orthogonal subcarriers subdivide the available bandwidth into a number of narrow sub-bands. Transmit signal can be easily generated by subcarrier signal orthogonality, through an inverse fast Fourier transform(IFFT), also easy equalization via a scalar gain per subcarrier, easy separation of the transferred data symbol at the receiver side via a fast block and easy adoption of Multiple Input Multiple Output (MIMO). Adaptive modulation schemes can be given to subcarrier bands to increase the bandwidth efficiency and transmission rate to the peak point. The problem of carrier & symbol synchronization simplify by a unique structure of OFDM.

III. MIMO (MULTIPLE INPUT MULTIPLE OUTPUT) SYSTEM

The multiple elements employ at the transmitter end and the receiver end is known as multi-input multi-output (MIMO) wireless communication. This technology fortifies significant improvements in capacity, spectral coherence and link reliability. In Under Water communication, the MIMO is suitable, because by adding multiple receivers & transmitters the declared gains are achieved. Additionally, there is no need to be increased the bandwidth and transmission powers.

A. MIMO transmitter architecture

In VBLAST encoder the message bits first divide 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. This scheme has bit rate is bN_t. In VBLAST when interleaver is combined with channel coding, the VBLAST becomes HBLAST.

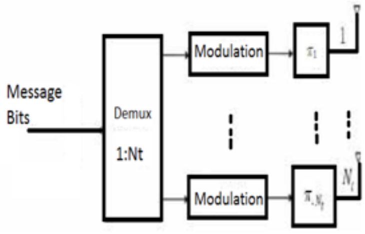

Fig.3: HBLAST

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

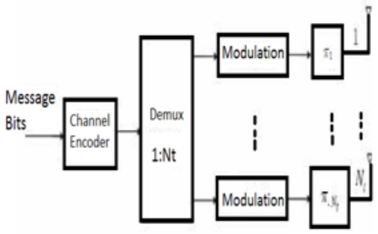

Fig.4: VBLAST

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 scheme all the layers are encoded by a single channel code. The SCBLAST architecture is shown in fig (5).

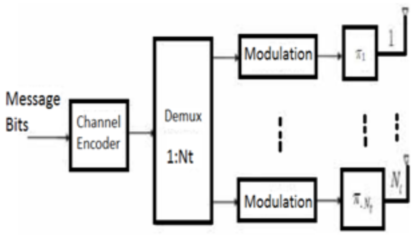

Fig.5: SCBLAST

B. Detection Algorithm

The optimal technique is used to detect when blast signal is maximum but there is a disadvantages of optimal technique as the number of states of channel and transmit antenna increases, the complexity of system grows. This is the reason that it cannot be used practically.

There are other two techniques i.e. Minimum mean squared error (MMSE) and zero force (ZF) technique. Zero force technique is less complex. ZF technique states that, when layer is detected, interference coming from undetected layers is suppressed. The MMSE technique, settlement between noise reduction and interference suppression is obtained. 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 power of noise 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 mentioned for MMSE.

IV. UNDERWATER CHANNEL

The underwater acoustic (UAV) channel and terrestrial radio channel have different parameters. The underwater acoustic channel is much better than radio channel. These are the parameters which affect the UWA channel i.e. noise, multipath, attenuation loss, variable delay and Doppler spreading. This makes underwater acoustic communication more difficult. In wireless communication we commonly use three types of carrier wave for underwater. The communication can be done at higher frequency and bandwidth by using electromagnetic wave. The limitation is due to high absorption/attenuation that has significant effect on the transmitted signal. Long distances are travelled by radio frequency waves but at very low frequency (30 to 300Hz) because for this type of communication we need big antennas. These big antennas affect the cost and make the design more complex. High data rate transmission is also provided by optical wave. However, the water absorbs the signal and signal suffers from scattering effect. Data transmission accuracy will be affected by this scattering effect. The low absorption characteristic allows the carrier to travel at longer range as less absorption accept by the carrier. In many applications signal of Acoustic wave is used as carrier, due to its low absorption characteristic for underwater communication.

A. Channel Characteristics

*1) **Noise***

The noise sources in an UWA channels can be divided in two parts i.e. ambient noise and man-made noise. The ambient noise causes biological creatures, movement of water such as waves and seismic phenomenon. The ambient noise reduces as the frequency increases. The underwater communication can be also affected by ambient noise whose source is water bubbles. The thermal noise can be very affecting, for high frequencies especially over 100-200 kHz, where the thermal noise increases with 20 dB per decade. According to this the 10-20 kHz frequency band the dominant noise source may be deep air bubbles in the area near the surface.

The resonant frequency f is given by the following equation

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

$10\log N_t(f) = 17 - 30\log(f)$ (3)

$10\log N\,s\,(f) = 40 + 20(s - 0.5) + 26\log(f)\ 60\log(f + 0.03)$ (4)

$10\log N\,w\,(f) = 50 + 7.5w^{1/2} + 20\log(f) - 40\log(f + 0.4)$ (5)

$10\log N\text{th}\,(f) = -15 + 20\log$ (6)

Here ρ is the ratio of specific heats; γ is the water density and P is the ambient pressure (2). The other source of noise is the manmade noise that may be causes noise from ships, oilrigs and similar. Manmade is an important noise source when UWA sensor networks (UWA-SN) is used by 4D-seismic close to oilrigs. Ambient Noise can model as a Gaussian noise with the empirical power spectral density (P.S.D) measure in dB, μ per Hertz as a function of frequency (in KHz).

Where w is the wind speed (m/s), *s* is the shipping activity whose value always ranges from 0 to 1 for low and high activity respectively. The overall P.S.D of the ambient noise is noted as *N* (f) and expressed as the sum of the four above mentioned noise components (3) (4) (5) (6).

$N(f) = N\,t\,(f) + N\,s\,(f) + N\,w\,(f) + N_{th}(f)$ (7)

Equation (7) is power spectral density of ambient noise.

2) *Loss*

The transmission loss is caused by attenuation and geometric spreading for signals that are transmitted directly to the receiver. The movement of the wave-front causes the geometrical spreading and for farther distance the wave front is spread over a larger area. There are two types of geometrical spreading in underwater acoustic communication:

Spherical and Cylindrical: Spherical spreading is used for deep water UWA communication and it could be an omni directional point source. Cylindrical spreading has only horizontal spreading and is used for shallow water UWA communication. Acoustic intensity will be caused by geometrical spreading to decrease with increased distance.

When acoustic energy is transferred into heat, the attenuation takes place because of absorption and this will increase with both distance and frequency. Viscosity, thermal conductivity and other relaxation phenomena are the major factors for absorption. For absorption in fresh water, viscosity is the major factor.

Viscosity is the phenomenon of resistance against stress in a fluid. The absorption in water is affected by thermal conductivity is another factor. This effect occurs when heat is created by change in volume 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 some loss may be if there a lot of waves are present. Sound waves are hitting the bottom causes for reflection loss will depend on the sediment in bottom and the angle of the incoming sound wave. Always the power of speed will be higher in the bottom than in water and part of the energy will be transmitted into the sediment layers. The losses of sound energy occur in the bottom and how much energy will not be reflected is also depend on the frequency. Since for high data rate underwater communication will use a quite high carrier-frequency the loss will be large. The transmission will be also affected by air bubbles in the water heavily since the speed of sound in air is much lower. Therefore under the right conditions the sound wave passing may almost block by the air bubbles. [4]

3) *Multipath and Delay*

The communication severely may be affected by multipath and it creates inter symbol interference (ISI). It depends on different physical factors that how much the multipath will occur but the depth depended sound velocity is most important factor. 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 supervise constructive or destructive interference. It depends on the phase of different multipath that the received signal may be amplified or it may be reduced. Reflection of waves from the surface and the bottom creates multipath. Both the signals, direct and reflected signals will be received by the receiver from the surface and the bottom. When the waves have bend /tilt then they appear at the discrete times. The speed of sound under water is 1500 m/s, which is much lower than the speed of radio waves that is approximately $3*10^8$ m /s, causes the large time delay. In terrestrial radio communication, the delay is so little so multipath and reflection will not be a problem but in UWA communication these delays may arrive very late and cause problem for the communication. This is promoted by the fact that the delays may vary a lot. [5]

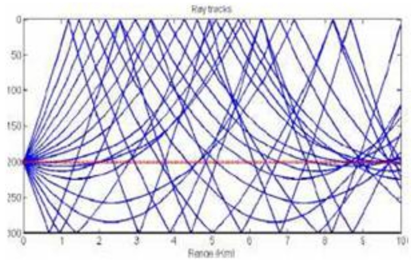

Fig.6: Bending of ray in depth

4) Sound Speed:

The bulk modulus and the density of the medium give speed of sound wave. 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:

$c = 1448:6 + 4:618T - 0:0523T2 + 1:25(S - 35) + 0:017$ (8)

T denotes temperature (in Centigrade), D denotes depth (in m) and S denotes salinity (in pro mille). (8)

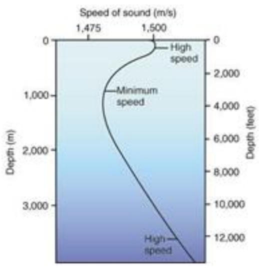

Fig.7: Sound speed profile in ocean

The temperature, salinity and depth is varying due to this the speed of sound is also 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. The masses of water also will be changed and the speed of sound will vary due to waves. Below the surface layer is another seasonal thermo cline layer where the temperature is decrease d with increased depth but the speed of sound will decrease. Below thermo cline layer is the other deep isothermal layer where the temperature is almost constant, but due to increased pressure the speed of sound will increase with depth.

So between the main thermo cline and the isothermal layer the speed of sound will reach a minimum level and this generate a sound channel .This sound channel transmit low frequency signals very far.

V. SIMULATION RESULTS

The MIMO-OFDM scheme with IDMA is simulated for varying different parameter and an optimized result is obtained. The scheme is firstly simulated for multipath environment. 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.

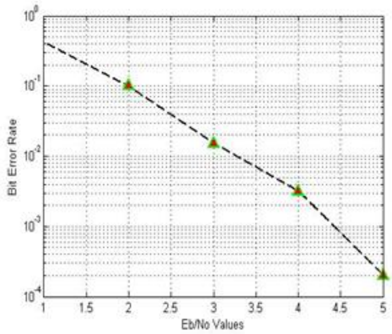

Fig.8: BER on Multipath at varying SNR

The above simulated graph show that this scheme gives the good result on less values of E_b/No, it is quite visible that almost 10^{-4} error rate achieved at 5 value of E_b/No.

Next this scheme is simulated for same data length 512 and block length 200. And we have simulated the model for direct path.

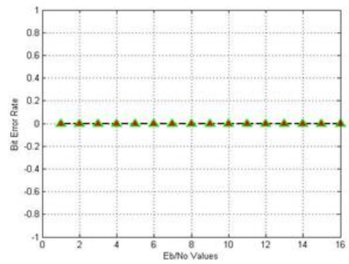

Fig.9: Direct Path BER

For the direct path scenario, the BER rate is negligible and no error whatsoever in transmitting and receiving the data bits. If E_b/No is increased than also BER remain constant which shows that for direct path IDMA results in almost zero BER no matter how much we increase.

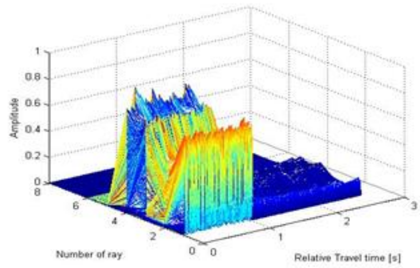

Fig.10. signal propagation in Acoustic channel

In fig 10, the signal propagation in underwater channel implemented using mathematical equation is displayed.

The wave generates while transmitting the data in the multipath mode.

VI. CONCLUSION

In this paper, MIMO-OFDM and IDMA scheme is studied for the underwater communication. The OFDM scheme is described deeply, 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 a mathematical form. In last contains the result OFDM-MIMO with IDMA scheme is simulated for varying the different parameter like Multipath and Direct Path. And from both the scenario simulation it is being concluded that IDMA in underwater communication performs better in both direct and multipath. As in direct path the BER is almost negligible and in multi path also its performance is quite impressive.

VII. ACKNOWLEDGMENT

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