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Research paper

Underwater channel design for diver communication

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Abstract

Underwater channels are usually considered to be very difficult media for communication purposes. There are many reasons that pull back us from considering these types of channels for communication purposes. Limited bandwidth, Doppler effect, multipath propagation etc are some of those reasons. These reasons limit the usage of underwater channel for wide range of applications.Optical waves, RF waves and acoustic waves are generally used. Among the methods, acoustic waves are used in most of the cases since less attenuation and scattering properties are offered by acoustic waves. There are many acoustic channel models existing but require some improvisations according to the diving application. An efficient acoustic underwater channel for diver communication is designed and implemented in this paper. Rayleigh channel model is considered in our algorithm that can deal with multipath propagation and Doppler effect with underwater specifications incorporated to it.This method gives a better result compared to OFDM and MIMO models. Further, a comparison between different modulation techniques like ASK, BPSK and QAM have been done. Results show QAM is a better modulation scheme for underwater environment.

Keywords: *Communication Purposes; Doppler Effect; Modulation Techniques; Multipath Propagation; Underwater Channel.*

1. Introduction

The Earth is known as a water planet since two-thirds of it is covered by water. The speedy developments in the underwater technology is a proof that underwater environment is no longer a terrific one.Underwater communication can now be considered as fast growing field with lot many applications. There are many applications in commercial as well as defense sectors. Medicinal applications are also notable. Many varieties of the sea weeds are now found out. Many more are yet to be discovered. If all these are discovered, this can be a big helping hand for our medical field. Diving is considered to be the prevalent technique for exploring the underwater world. The requirement for underwater wireless communication is increasing day by day. Oil extraction, scientific data collection from bottom stations of an ocean, surveillance of underwater areas where human intrusion is not practical etc are some among the applications. When considering the applications, it is important to note that most of the disaster detection can be taken place underwater. Tsunami, hurricanes, earthquakes, tornados, and even volcanoes can take place underwater. Because of all these disasters pressure and temperature in the atmosphere also varies. Resultant effects are observed in the surface also. An early detection of these disasters are possible which in turn can reduce many accidents. Commercial revolution has taken place as the underwater environment got explored more and more. Hence, various researches in the field of underwater wireless communication techniques have played a vital part in the inspection of oceans and other aquatic environments. Unlike the terrestrial communication, channels are very difficult to deal with. Underwater channels keep on varying with respect to time. It never stays stable. Underwater wireless networks are to be formed. But to form these networks and for efficient communication, is not an easy task. There are many hindrances that make people stay away from dealing with these kinds of channels. The serious impact of noise, limited bandwidth, Doppler Effect etc increases the difficulty in designing a channel. So, the communication that takes place underwater through a channel habitually unveil grave attenuation, multipath effect, frequency dispersion, and constrained bandwidth and power resources, etc. Considering these effects, normally underwater wireless channel is a tough and harsh channel to design. When facing these unique conditions in diverse underwater applications, many new challenges, which were not encountered in terrestrial wireless communications, are emerging in underwater acoustic, optical, and RF communications for future underwater wireless networks. Underwater acoustic channels are band-limited and resonating.Many experiments are carried out underwater. These experiments consider shallow region where depth is very less. When depth increases, challenges offered by the channel also increases. Apart from amplitude and frequency variations, phase variation also happens. The modulation scheme we use should overcome all such difficulties. So before designing a channel, we need to study about the environment, limitations, noises etc. these can be considered as the channel properties. It should include phase and amplitude variations, multi-paths, Doppler Effect etc. Acoustic waves propagate well in seawater and can reach a far distance. This is the main reason why we approach acoustic waves for most underwater wireless communications. Normally this is termed as underwater acoustic communication.

The maximum data rate a channel can possess is determined by its capacity. While we design a channel, we should keep in mind that our priority should be given to the increased throughput. The throughput has to be increased for better reception of the signal at the receiver. So, the channel capacity should get a higher value. In most of the cases, the channel capacity rate is high only in theoretical values. When it comes to the case of practical applications, the channel capacity is too little. It all depends on the power at transmitter and receiver, noise interpretations, obstacles and many other factors. In practice, additional constraints are imposed on the source spectrum by the bandwidth limitations of physically realizable transducers. Maximum data rate has many implications in practical view. We always require a channel that offers a better capacity but resistant to variations. Rayleigh fading technique offers a channel design for multipath propagation and effective resistance to the Doppler Effect.

In the last several years, underwater sensor network (UWSN) has found an increasing use in a wide range of applications, such as coastal surveillance systems, environmental research, autonomous underwater vehicle (AUV) operation, many civilian and military applications such as oceanographic data collection, scientific ocean sampling, pollution, environmental monitoring, climate recording, offshore exploration, disaster prevention, assisted navigation, distributed tactical surveillance, and mine reconnaissance. For the applications mentioned above, we can develop a distributed sensor network. If such a development can be achieved in a 3-D space, monitoring of the environment becomes less difficult. By the deployment of a 3-D distributed sensor networks, monitoring of a particular environment or area resembles to a local tactical surveillance method. The approach is then far better compared to the existing ones. So only remote sensing is least used now a days. People are more into underwater wireless sensor networks. To get a proper understanding of the underwater environment and various complexities related to it, sensor networks help.

If the communication of the sensor networks is done with the help of acoustic waves, then such type of sensor networks are named as underwater acoustic sensor networks (UWASNs). Signal transmission takes place when there is less attenuation and less hindrance offered for a signal. Wireless transmissions are very difficult in terrestrial communication. So when it comes to the case of underwater environment, the communication via wireless approach becomes much more difficult. In most of the cases, we don’t even have a direct line of sight (LOS). Apart from acoustic waves, we can use Electromagnetic waves and Optical waves for communication. Acoustic waves offer better transmission properties due to which they are considered for very wide range of applications. Wireless optical waves are usually used now days. But due to the scattering property and less distance coverage, these waves are not up to the mark. Comparatively, acoustic waves are less susceptible to attenuation and scattering. Due to these reasons, range it can cover is also more. But again we have so many limitations for acoustic waves. Propagation delay is one among them. The velocity of sound wave under water is 1500 m/s. Compared to the velocity of light above the surface,the velocity of sound under water is much less. So the propagation delay is very large. But signal degradation or attenuation offered is very less. This is especially true in thermally stable, deep water settings. The reflection of signals can adversely affect the propagation. Also refraction property is to be taken into account. Especially when the experiments are done in shallow water, which means depth is very less, then signal gets easily attenuated since temperature varies, and thermal stability is very less. Underwater noises are not always created under water.Turbulence created above the ocean surface due to wind can be transported underwater.

Free-space optical (FSO) waves are used for the wireless transmission. The main drawback of this method is its limitation in terms of the range covered.Water itself has an attenuation property. So if signals are transmitted through water, again transmission loss is more. Even the clearest water has 1000 times the attenuation of clear air, and turbid water has more than 100 times the attenuation of the densest fog. the future of the paper goes like this: Section II deals with the literature review for our work. In the section III, proposed work has been explained. Section IV explains simulation work done and the resulting outputs. Section V details about conclusion and the future scope.

2. Literature review

Modulation Analysis for an Underwater Communication Channel by Julio Diogo Miranda Xavier [1] gave a very perfect idea about the channel and the underwater characteristics. The paper itself is a survey report of the underwater channel and various characteristics and features of a channel. Along with this paper [2] gives an intelligent health monitoring system that monitors the health of a diver. But in that the authors used ASK modulation techniques which is no longer valid according to the work we did. But the paper paved a proper path to us that led us to get a better result. Underwater challenges and noises explained by the paper [3] were noted and accordingly we designed our features. Then the paper [4] dealt with the noise cancellation techniques that used so far and the introduction of a new NLMS technique which was important to consider. The underwater channel is itself so confusing that when we work with that we get a lot of reasons to stay back from it. But the paper Underwater Acoustic Communication Channels: Propagation Models and Statistical Characterization, a paper [5] by Milica Stojanovic and James Preisig takes the noise cancellation part into consideration. The background noise, although often characterized as Gaussian, is not white, but has a decaying power spectral density. The capacity of the channel completely depends on the distance. Our prominent aim is to increase the channel capacity. The main advantage of using acoustic communication is it works pretty well at lower frequencies. The constraints mainly faced were in the terms of bandwidth. Less bandwidth is offered underwater. Doppler Effect is also taken into consideration. As a result of Doppler Effect, shifting can take place. Eventually this results in the degradation of the signal. “Underwater measurements of heart rate” was a thesis paper [6] by HibiscaLiaw that describes very well about the heart beat rate for common man or a diver underwater. This paper dealt with not only experienced divers but also inexperienced people. The objective of this project is to develop a device that can monitor the heart rate and respiration of cetaceans. This would provide a way to quantitatively measure stress and determine the impact of human activity on cetaceans, especially for certain species that have been difficult to monitor in the past. There are many challenges to developing such a device, including determining the appropriate type of sensor, reducing the effect of flow noise, and designing an effective attachment method; this paper primarily focuses on determining the most suitable acoustic transducer.

Experiments were conducted to compare various acoustic sensors in detecting heart rate. The electronic stethoscope performed the best in the experiments, but the results showed that other transducers, such as accelerometers and pressure sensors, also performed well and could be successful options with further development. Data processing methods to identify heartbeats and characterize signals are also discussed in this paper.

3. Proposed work

The main features of the underwater channels are its multipath propagation, time varying nature, noise interference, Doppler effect, limited bandwidth etc.. These are the features that make the underwater channel a very challenging one to deal with. Here we are considering a Rayleigh channel with multipath propagation. Rayleigh fading is a statisticalmodel for the effect of a propagation environment on a radio signal, such as that used by wireless devices.

In Rayleigh fading model, the magnitude of the signal is considered to be varying. This variation is according to the Rayleigh distribution. In case of wireless communication through the environments where multipath propagation can occur and the area is tightly packed, in such cases Rayleigh fading model can be considered. It can be used for describing Tropospheric as well as Ionosphere signal propagation. In many of the cases, there is a lack of direct line of sight. If that is the case, then the propagation becomes difficult. Due to the urban development and highly hectic conditions, direct communication is not possible all the time. This is where we use Rayleigh fading models mainly. Even if we have multiple paths between the transmitter and receiver we have to send and retrieve back the signal. For this an effective channel is designed. Mostly the signal gets scattered and attenuated before it reaches the receiver and already transmitted from the transmitter. The central limit theorem holds that, if there is sufficiently much scatter, the channel impulse response will be well-modelled as a Gaussian process irrespective of the distribution of the individual components. If there is no dominant component to the scatter, then such a process will have zero mean and phase evenly distributed between 0 and 2π radians. The envelope of the channel response will therefore be Rayleigh distributed. Often, the gain and phase elements of a channel's distortion are conveniently represented as a complex number. In this case, Rayleigh fading is exhibited by the assumption that the real and imaginary parts of the response are modelled by independent and identically distributed zero-mean Gaussian processes so that the amplitude of the response is the sum of two such processes.

Here young's method for modelling a channel that deals perfectly with the underwater channel issues is adopted. A Doppler filter is designed for the process. The frequency considered was acoustic frequency range. It comes around 1-11 KHz.

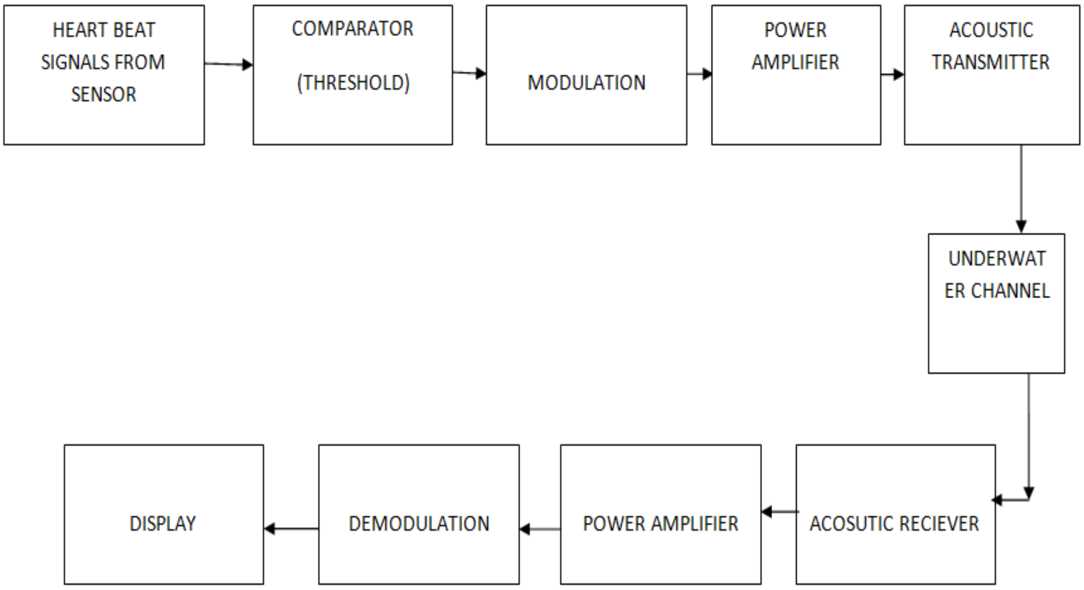

Fig. 1: Block Diagram of the Proposed Work.

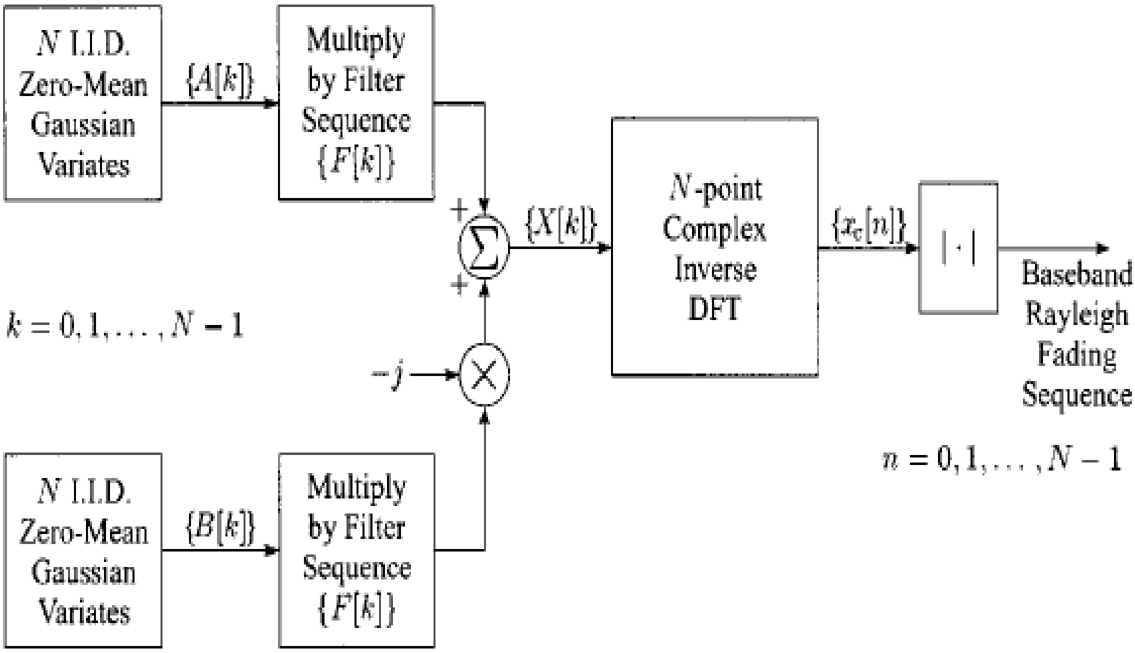

Fig. 2: Channel Model according to Young's Model.

$$F_M[k] = \begin{cases} 0, & k = 0 \\ \sqrt{\dfrac{1}{2\sqrt{1-\left(\dfrac{k}{Nf_m}\right)^2}}}, & k = 1, 2, \cdots, k_m - 1 \\ \sqrt{\dfrac{k_m}{2}\left[\dfrac{\pi}{2} - \arctan\left(\dfrac{k_m - 1}{\sqrt{2k_m - 1}}\right)\right]}, & k = k_m \\ 0, & k = k_m + 1, \cdots, N - k_m - 1 \\ \sqrt{\dfrac{k_m}{2}\left[\dfrac{\pi}{2} - \arctan\left(\dfrac{k_m - 1}{\sqrt{2k_m - 1}}\right)\right]}, & k = N - k_m \\ \sqrt{\dfrac{1}{2\sqrt{1-\left(\dfrac{N-k}{Nf_m}\right)^2}}}, & k = N - k_m + 1, \cdots, N-2, N-1. \end{cases}$$

Fig. 3: Doppler Filter Characteristics according to Young's Model.

4. Simulation

For the simulation process, Mat lab R2017b was used. First an ECG waveform was generated. This ECG waveform is considered to be that of a diver who is going deep under the sea. Abnormal as well as normal conditions are considered. The heart beat rate for a normal person underwater is 60 bpm. So above and below this limit is considered as abnormal heart beat. ECG waveform obtained using mat lab simulation is shown in Fig 3. Now we have the modulation techniques and the underwater channel design. Modulation techniques adopted are ASK, BPSK, QAM. Here we considered both single carrier as well as multi-carrier communications. Single carrier communication was designed with ASK first. The modulation and demodulation was done perfectly. This is shown in the Fig 2. Keeping all the specifications and model same BPSK modulation was done instead of ASK. This was much more effective. The results are given in figure 2.And to get a comparison between the modulation techniques and thus decide which modulation technique we should adopt for underwater conditions, BER vs. SNR plot was simulated. From the plot, clearly we can make out that BPSK gives a better result.

Now the second part of our implementation was multi-path propagation. We considered two channels. Different samples go through different channels. Which channel is the best was our aim to achieve. For this, we considered two channels and different samples going through them. The frequency taken was also different for both the channels to distinguish between them. Again BER vs. SNR was plotted. Here we took both BPSK modulation as well as QAM. 16-QAM was taken. Outputs through different channels, BER vs SNR plots of channels, their comparisons with different modulation techniques are given in the figures below. In the Fig 4, the ECG waveform of the diver is plotted. The frequency range adopted is 100 Hz. For single carrier transmission, we considered ASK for modulation. The modulation and the received output after passing through the single channel is given in Fig 5. For the same circumstances and channel conditions, we changed the modulation technique and then the observations were noted. Firstly we tried ASK, now BPSK modulation was tried out. The corresponding outputs are shown in Fig 6 and Fig 7.

The next step was to compare which is the best modulation technique for the single carrier transmission. The comparison is given in the Fig 8 showing the BER vs. SNR plot. From that it is clear that BPSK is giving a better result. But in the practical cases, we never get a single channel propagation condition in underwater circumstances. So we tried the multipath propagation techniques. For this, we compared the underwater channel with a Rayleigh fading channel. Based on this, we tried with BPSK as well as QAM. And as we considered multipath propagation, we considered two channels. Channel 1 is a path and channel 2 is another path. The corresponding outputs in channel 1 and channel 2 when we considered BPSK modulation is given in Fig 9 and Fig 10. The best channel among the two is selected from the plot considering SNR in the X-axis and BER in the Y-axis. This is given in the Fig 11. But by observing the figure, we are not able to find the best channel since there are intersections at several points. So we tried QAM modulation technique. The corresponding outputs of channel 1 and channel 2 are shown in Fig 12 and Fig 13 respectively. Again the best channel among the two is to be selected. So Fig 14 gives a comparison in terms of SNR vs. BER plot.The figure clearly says that channel 2 is the best. So the issue we faced when we used BPSK modulation has been tackled out.

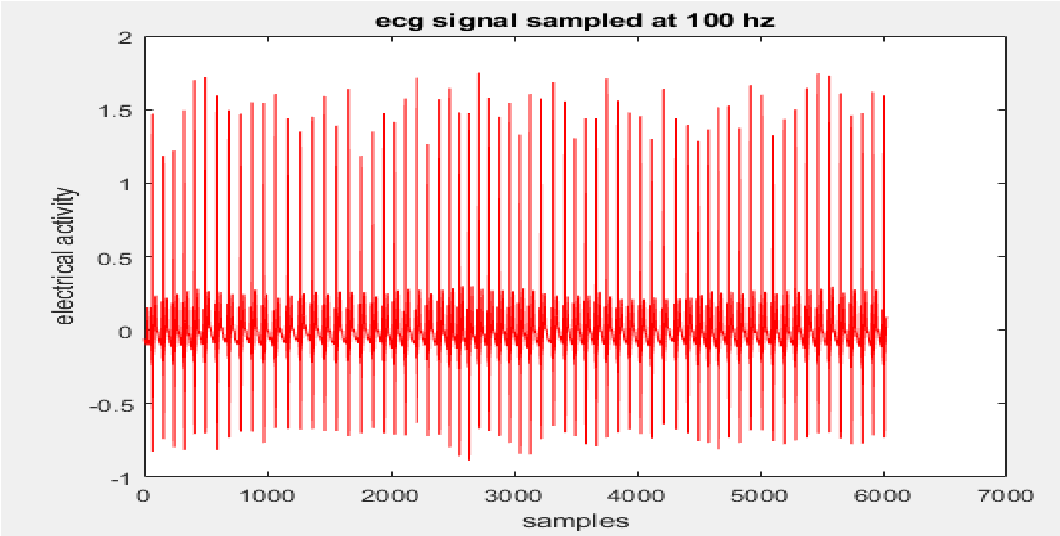

Fig. 4:ECG Waveform of the Diver.

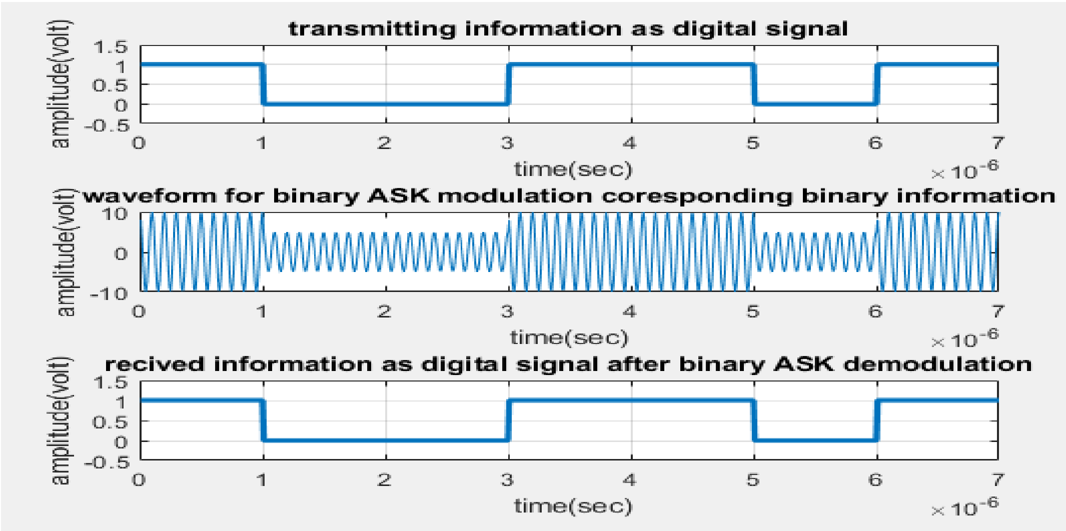

Fig. 5:ASK Modulation Considering A Single Channel.

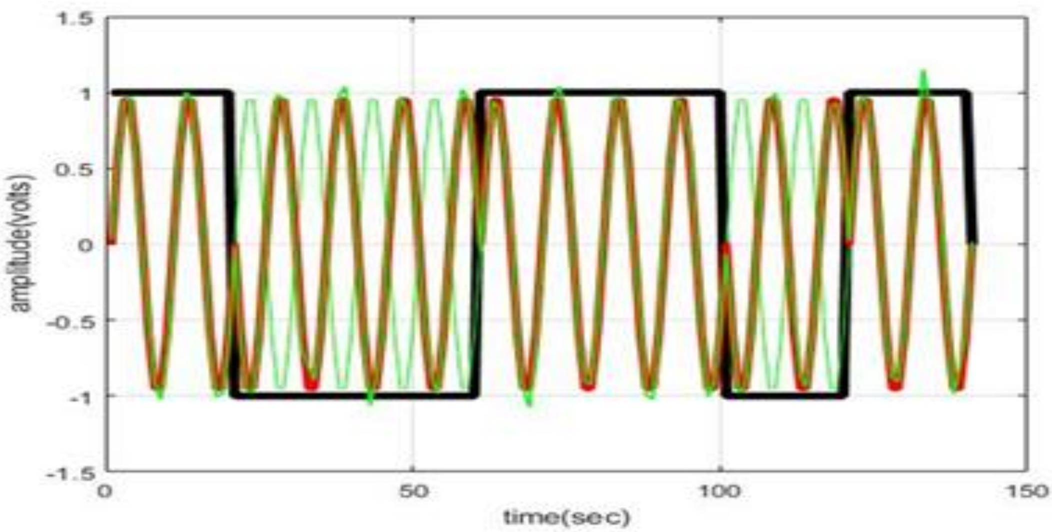

Fig. 6:BPSK Modulation Considering A Single Channel.

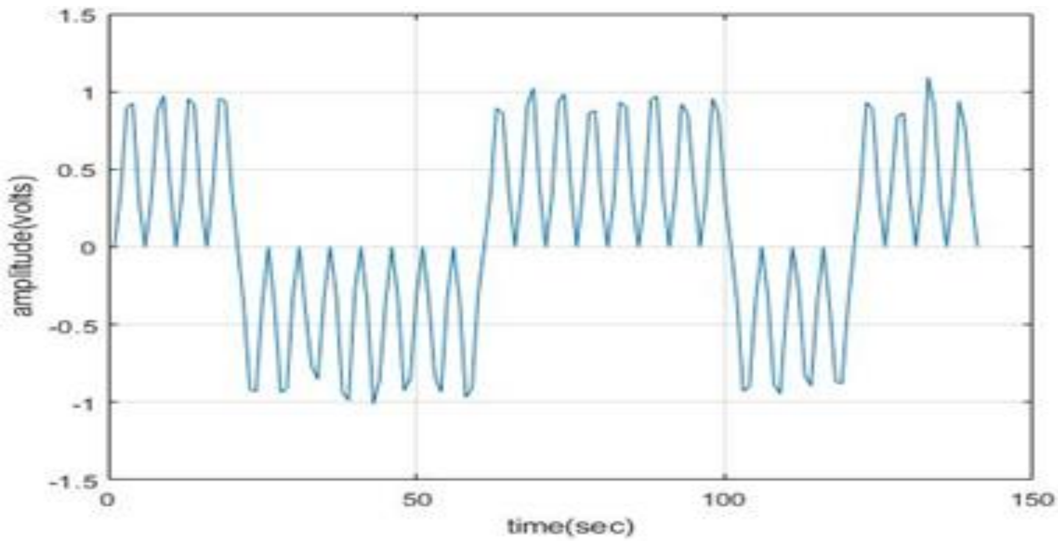

Fig. 7:BPSK Demodulation Considering A Single Channel.

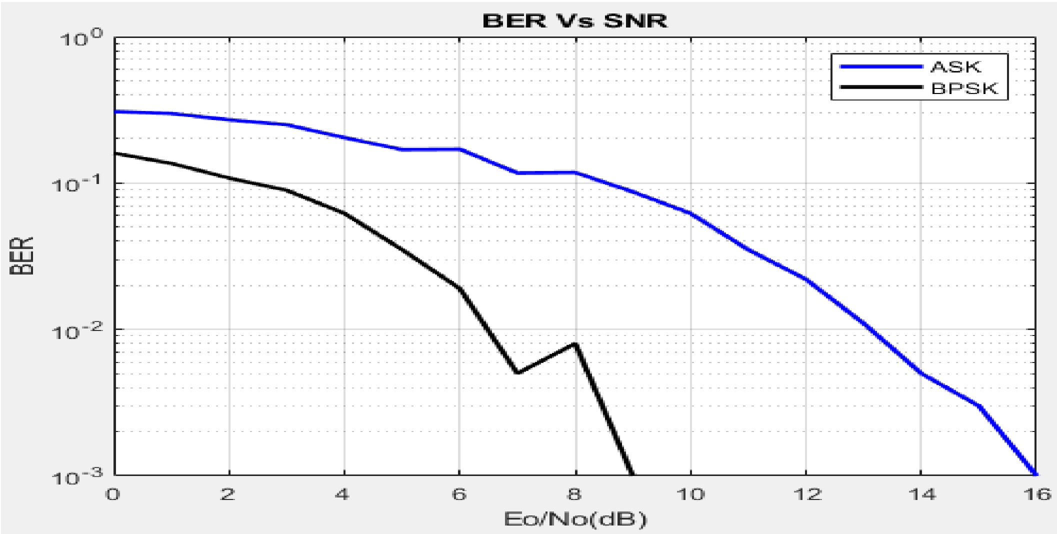

Fig. 8: Comparison (Single Carrier) BER vs. SNR Plot.

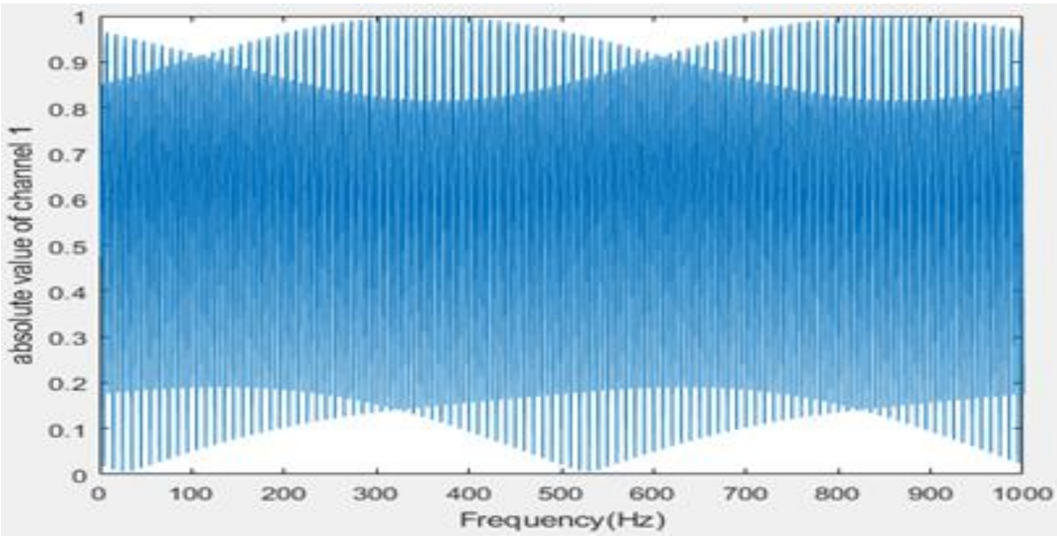

Fig. 9: Channel 1 Using BPSK Modulation.

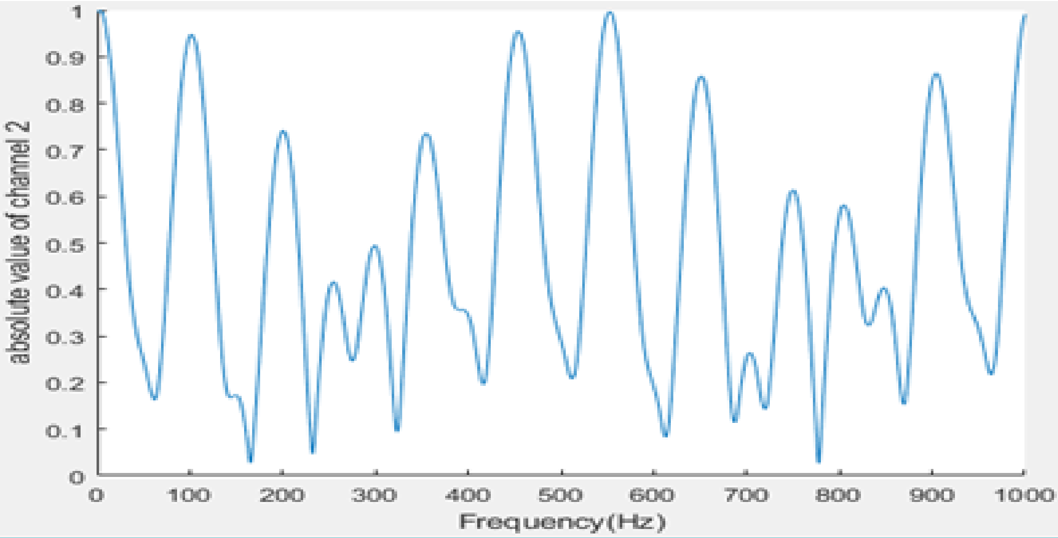

Fig. 10: Channel 2 Using BPSK Modulation.

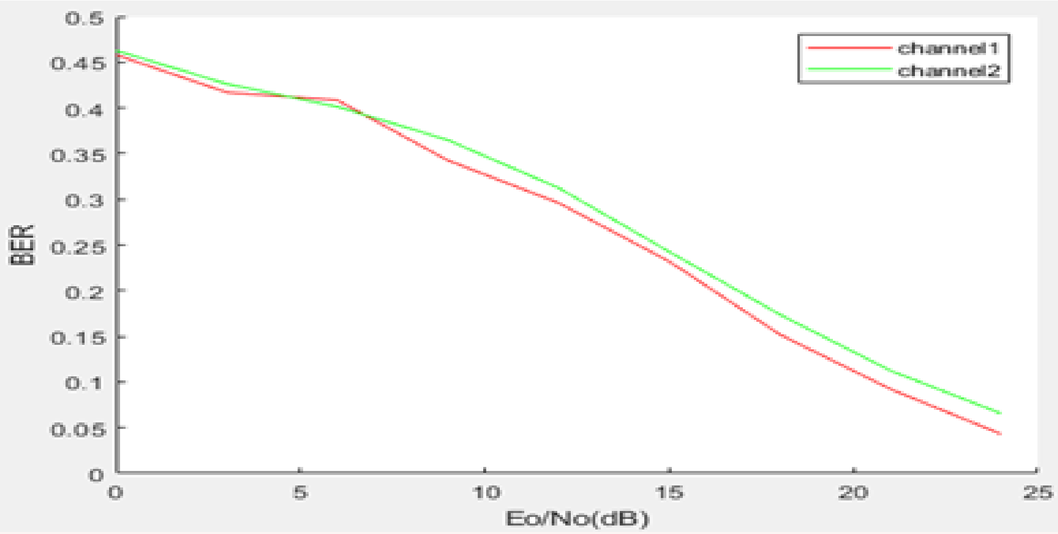

Fig. 11:BER Vs. SNR Plot for PSK Modulation.

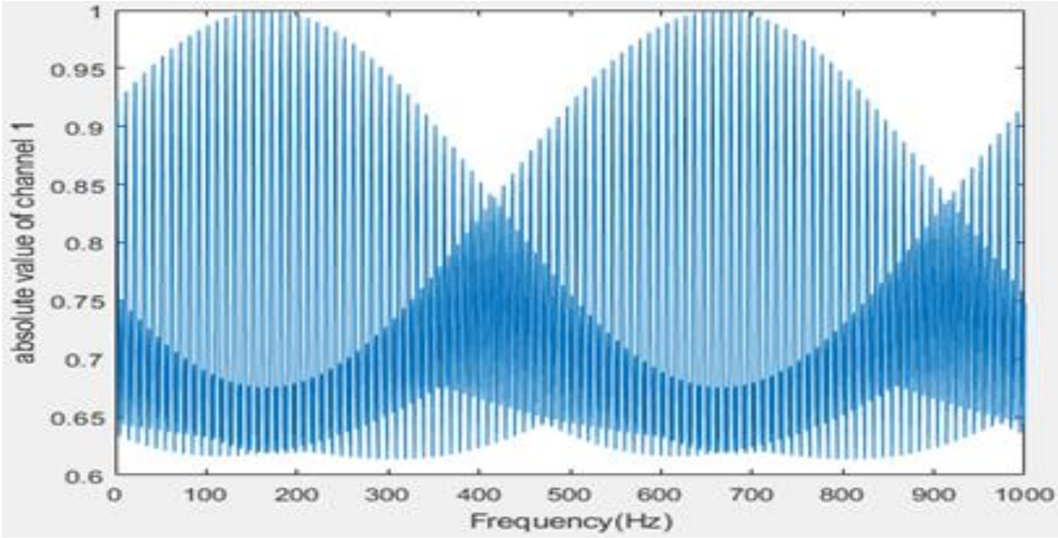

Fig. 12: Channel 1 Using QAM Modulation.

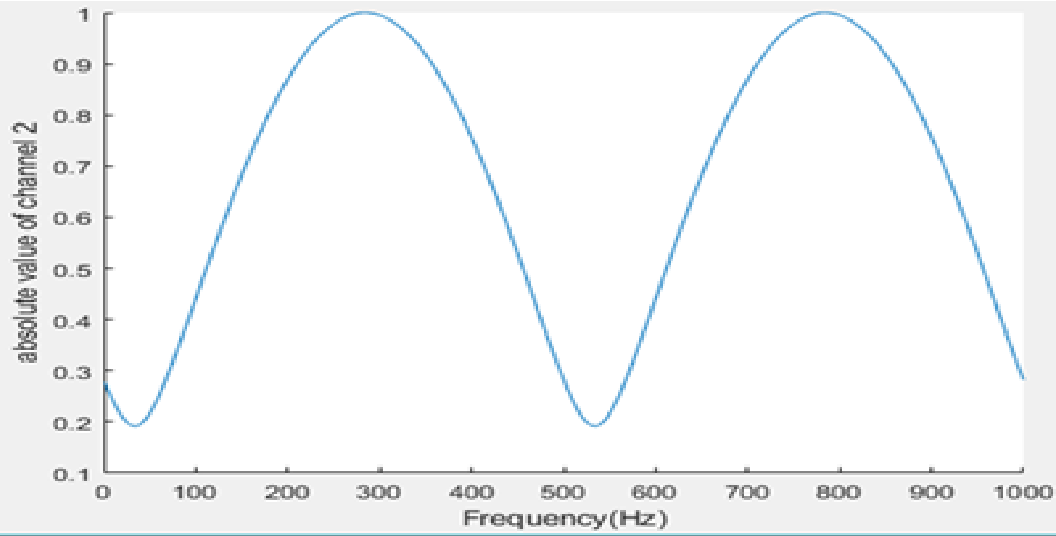

Fig. 13: Channel 2 Using QAM Modulation.

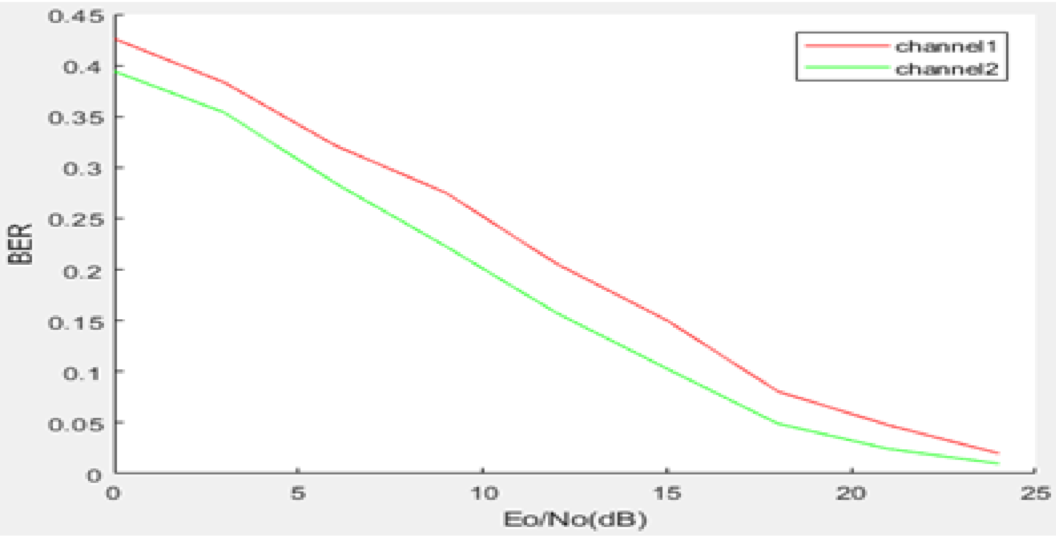

Fig. 14:BER vs. SNR Plot for QAM Modulation.

5. Conclusion and future scope

According to the work done so far, an efficient model for underwater channel is obtained. The simulation was done successfully. From the simulation results channel1 seems to be better in case of multi-paths. This is obtained by the BER vs. SNR plots. We considered two channels in the case of multipath propagation. The channels are taken as red and green. Red line shows the channel 1 and green line shows channel 2. In the first case, we used BPSK modulation and observed that both the lines intersect each other. So in that case we cannot say one channel is better than the other. In this case, we fail to distinguish the better channel or path among the two. But when we take the case of QAM, the two channels donot intersect. So we can distinguish among the channels and find out which channel offers better BER vs. SNR plots. In this case, green offers better result i.e. the channel 2. Since it offers less error rate compared to the other channel. Considering our results and comparing with the previous works on the underwater channel, the observations are given in the Table 1.

Table 1: Works Highlighted in Our Project in Comparison with the Previous Works

Sl. No.	Factors included in our work
1.	Single channel as well as Multi-channel propagation(we considered 2 in the latter case)
2.	Doppler Effect
3.	Comparison among different modulation techniques(ASK,BPSK,QAM)
4.	Selection of the best channel

Our work stands out from the previous works because we tried to approach Rayleigh fading channel as an underwater channel. Since no previous works did such an approach, we can't go for a comparison among the channels considered so far.

The noise cancellation part has to be taken for consideration. This can be done as a future work. And the practical implementation of the proposed system has to be done.

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