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Research Article

Climatical Characterization of Northern Arabian Sea for OFDM Based Underwater Acoustic Communication

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Abstract: The effects of climatic changes on the Underwater Acoustic (UWA) communication are addressed here with the aim to evaluate the performance of proposed scheme in the whole year specifically for the north Arabian Sea. Oceanic channel is a most challenging medium for the design of underwater wireless communication as it offers various unwanted degradations in terms of frequency-dependent attenuation, multipath spread, long path delays, etc. Multipath spread having extended delay spread further deteriorates the communication packet (s) and in result, mutilation of entire signal, i.e., Inter-Symbolic Interference (ISI) is occurred. Detailed analysis for the interaction of sound wave with the water mass is essential for the design of Underwater Acoustic (UWA) communication. In particular, at varying temperature and warm surface site like Ormara, Pakistan (north-western region of Arabian Sea), where a very strong seasonal dependency may be observed due to climatic changes. OFDM, being the most feasible communication scheme and well suited for underwater environment is utilized in this study for the effect's monitoring. In this study, we are presenting the effects of climate on the selected region of North-west Arabian Sea and validating our work on Zero Padded (ZP) OFDM scheme for UWA communication. Relevant meteorological and oceanic data are obtained from open source buoy ARGOS ID 2901374 and Global ARGOS marine atlas (Worldwide tracking and environmental monitoring by satellite). For each of March, June, September and December we find a temperature and salinity with respect to the depth and subsequently calculate the sound speed in the specific channel. Bellhop ray tracing program is used to obtain the receiving path's amplitudes and delays for respective channel modeling and ZP OFDM based communication system. Simulation results explain the effects of climate in the transmission and endorse that ZP-OFDM is a viable choice for high-rate communications in these types of oceanic channel. In this way system level design of the underwater acoustic wireless communication/telemetry can be optimized for the most prevailing channel conditions.

Keywords: Bellhop ray tracing, channel modeling, multipath spread, Orthogonal Frequency Division Multiplexing (OFDM), Underwater Acoustic Communication (UWAC)

INTRODUCTION

The aquatic channel is an intrinsically difficult channel for acoustic communications and has been an area of interest for researchers, engineers and practitioners alike. Acoustic wave transmission to communicate wirelessly underwater hold snumerousapp lications,includinggathering of scientific data from remote sites, pollution control, climate monitoring, detection of various objects, transmission of images to distant places, etc. Wireless information transmission is also useful for surveillance and other military applications, as well as Autonomous Underwater Vehicles (AUVs) which could serve as mobile nodes in future Underwater Wireless Sensor Networks (UWSNs). The UWA channel is in general much more hostile for any communication as it offers time varying multipath propagation, limited bandwidth as the signal attenuates and drops as a function of distance and frequency and the slow speed of sound underwater. The overall effects ofthese factors make a channel of very poor quality and high latency (Rehan *et al*., 2011; Rehan and Qiao, 2012).

The characteristics of oceanic channel may vary from a point to point link and even at a fixed position, temporal variations ranging from seconds to seasons can be observed. In order to incorporate these deviations in the current UWA communication scheme(in terms of climatic variations), relevant statisticsare required that will enhance the quality and flexibility of the system. These statistics may include environmentalfactors like temperature, salinity, wind speed of sea surface, internal tides, etc. Acoustic transmission is mainly depended upon the speed of sound wave propagation, which is entirely relied on the temperature and salinity profiles of the UWA channel. Determination of the changes of these factors by experimentation is very expensive, time-consuming and

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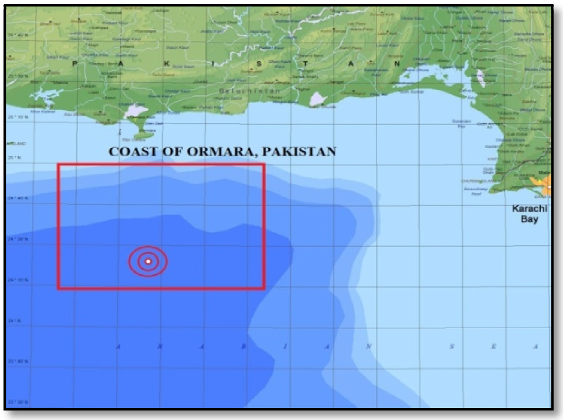

Fig. 1: Site map of selected UWA channel

restricted procedure (Heidemann *et al*., 2012). This is the reason why numerous research study (Xie *et al*., 2009; Guerra *et al*., 2009; Frisk, 1994; Jensen *et al*., 1994; Etter, 2003; Stojanovic, 2007; Chitre, 2007; Etter, 2012; Xie *et al*., 2006) are being carried out for the modeling of UWA channel with the aim to design a communication system having more accuracy and robustness. One efficient way is to get relevant literature/ statistics from various online sources like from ARGOS real-time data buoys and performs channel modeling steps for the specific oceanic region. Thus, considering various channel conditions and dynamics of the acoustic propagation, any communication scheme can be developed with enhance capabilities and adaptability approach. Moreover, to acquire the good communication capabilities of any channel, acoustic propagation model at the specified frequency band is essentially required. Acoustic propagation model by means of ray theory is a common practice for the researchers which offers a high-frequency approximation to the sound field and based on different arrivals of acoustic ray paths. The ray theory model in general is valid for the condition when the spatial variation is more dominant as compared to the wavelength, i.e., usable for frequencies ≥5 KHz (Jensen *et al*., 1994).

In this study, we are considering North-western region of Arabbian Sea near a coast of Ormara, Pakistan, as seasonal variations are very much revealing in this area, the site location is shown in the Fig. 1. Scientific data is collected from ARGOS buoy id 2901374 and Global ARGOS marine atlas for extracting climatic dependencies of sound speed profiles. ZP OFDM is utilized here for the validation of this scheme on modelled multipath channel. The changing sea surface due to blowing wind is an important factor in determining channel dynamics and respective Doppler shifts. However, this study neglects such complications and concentrates on effects of climate on sound speed profiles. Conversely, this study is also used for performance evaluating of ZP OFDM based communication scheme on static multipath channel of Arabian sea obtained on a quarterly basis, i.e., from June 2011 to March 2012.

The main objective of this study is to present the performance evaluation of ZP-OFDM based scheme forUWA communication in various climatic conditions of north Arabian sea. For the execution of this task, we have generated channel models near the coast of Ormara, Pakistan and data is acquire through Argos floats's ID 2901374 and global Argos marine atlas.

SEASONAL VARIABILITY OF THE ENVIRONMENT

In this section, we look at the effect of seasonal variation in the temperature, salinity and respective sound speed profiles near Argos float 2901374. Figure 2 and 3 show the recorded salinity and temperature profile obtained from this buoy. The channel characteristics is modelledusing a highly efficient two-dimensional acoustic ray tracing program, i.e., Bellhop that inputs environmental data and bathymetry of specific region and produces the travel time and amplitudes of the multiple paths reflected from surface and bottom boundaries of the ocean. Using MATALB, Bellhop.exe (i.e., based on the theory of Gaussian beam) is executed and multipath induced model together with sparsing function are further utilized for the designing of robust UWA communication. Porter (2011) and Rodrguez (2008) also explained the importance of a Bellhop ray tracing algorithm pertinent to the provision of other parameters like ray coordinates, Eigen-rays and transmission loss (coherent, incoherent or semi-coherent).The temperature and salinity with respect to the pressure in deci-bar (i.e., depth) are obtained quarterly from June 2011 to March 2012 using both Global Argos Mairne Atlas and float 2901374. The bathymetry, i.e., depth profile of the UWA channel, is another important factor, which will be used to estimate the multipath spread for acoustic communication. The Bathymetry data is available in a GEODAS (Geophysical Data System) database developed by the National Geophysical Data Center (NGDC) of United States of America (http://www.ngdc.noaa.gov/) and also be taken from Google Earth software (www.earth.google.com).

Area under study is located within 23° 58' to 24° 02' N and 63° 58' to 64° 02' E near coast of Ormara, Pakistan, that makes UWA channel channel of length 9.6 Km with maximum depth of 3.2 Km and 54 m floor depth deviation as shown in Fig. 4. Using the following mathematical expression derived by Mackenzie (1981) Sound Speed Profiles (SSPs) are calculated from the salinity, temperature and depth profiles:

$$C = 1448.96 + 4.591t - 5.304 * 10 - 2t^2 + 2.374 * 10 - 4t^3 + 1.340\,(s - 35) + 1.630 * 10 - 2d + 1.675 * 10 - 7d2 - 1.025 * 10 - 2t(s - 35) - 7.139 * 10 - 13td^3$$

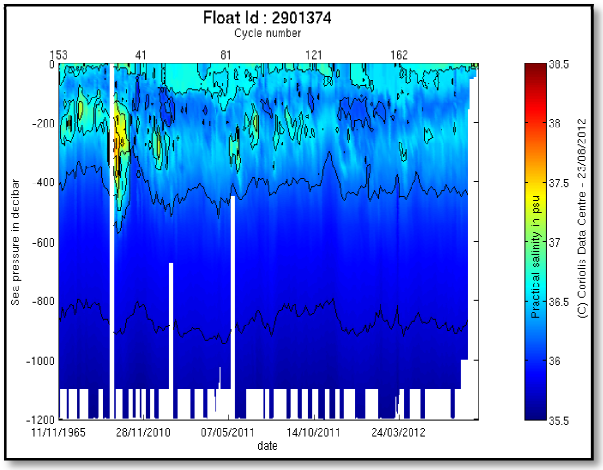

Fig. 2: Recorded salinity for Argos floats 2901374

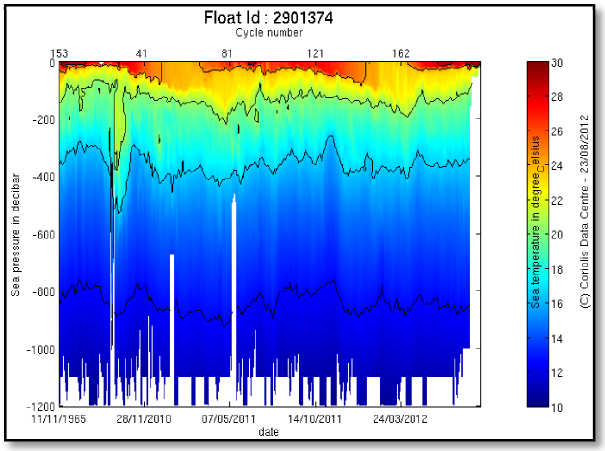

Fig. 3: Recorded temperature for Argos floats 2901374

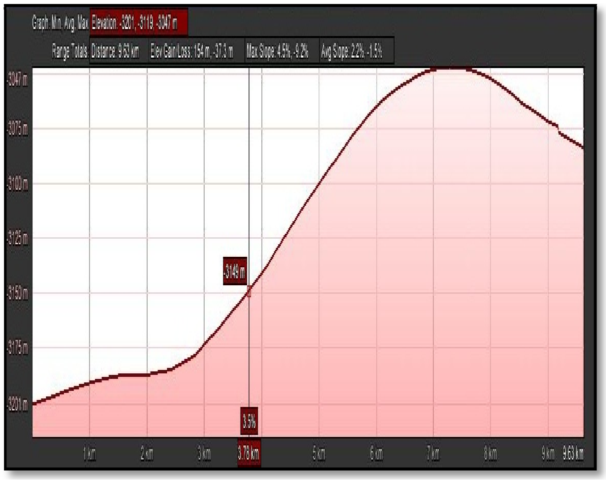

Fig. 4: Bathymetry profile of the selected region

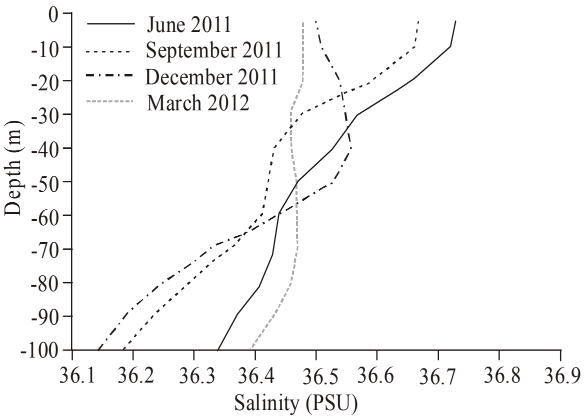

Fig. 5: Salinity profile of the selected region (100 m depth)

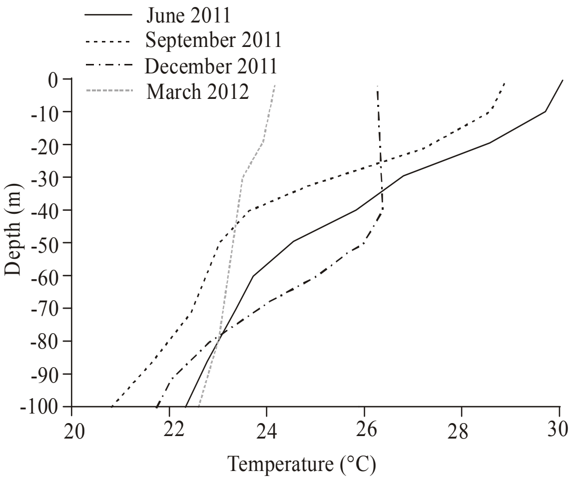

Fig. 6: Temperature profile of the selected region (100m depth)

where, salinity (s) and temperature (t) profiles of the selected region with respect to depth (d) are obtained in quarterly basis from June 2011 to March, 2012 and displayed (till 100 m depth) in the Fig. 5 and 6 respectively. The calculated SSPfor June, September, December 2011 and March 2012 are shown in Fig. 7a to d.

From Fig. 8, it is evident that the sound speed profiles in June and September have mostly a negative sound speed gradient due to warmer (sun exposing) surface whereas, in December and March the conditions are different. In these months (during December to March), it is observed that the upper isothermal/positive gradient layer extends to its maximum depth of approximately 100-120 m. As the most depended factor in the sound speed calculation is temperature (Urick, 1983; Brekhovskikh and Lysanov, 1982; Waite, 2002), the effect of the temperature for the sound speed variability is limited to upper part of the ocean depth. Below about 500 m, all the world's oceans are at about 0°C. The positive gradient in the deep isothermal region is solely due to the pressure (depth) effect.

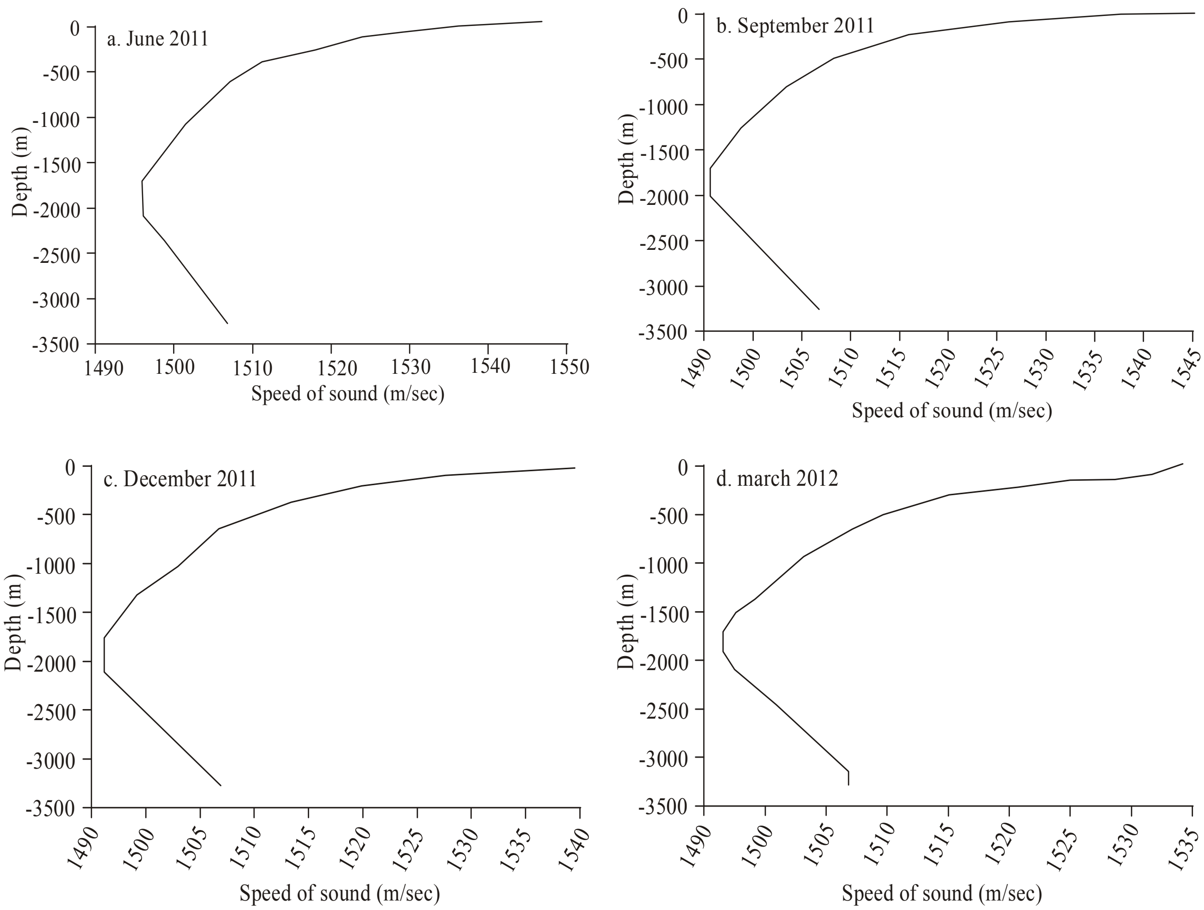

Fig. 7: Sound speed profile the selected region from June 2011(a) to March 2012 (d)

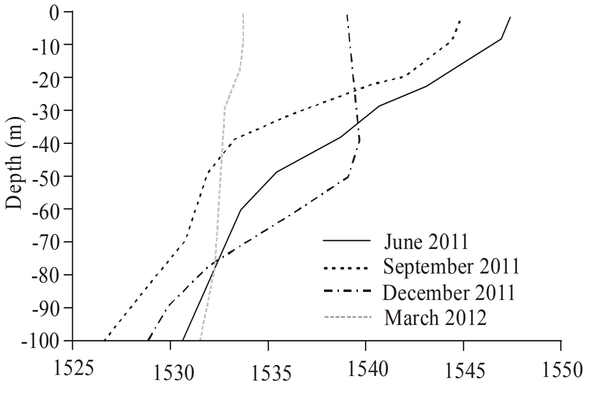

Fig. 8: Combine sound speed profile (100m depth) June 2011to March 2012

In addition to the aspects of SSP, the transmission loss also changes in connection with the climatic variations and affects the over system performance in terms of BER. Transmission loss variation can also be exploited in our favor if we set low levels of transmission for the months when the transmission loss is less. Thus, it can be revealed from aforesaid details that the SSP will generate similar transmission loss in winter season like December/March while, remaining months has a similar loss response as that of June. Therefore, the effect of these seasonal variations (dominant on the surface layer) needs to be experienced and cater in the UWA communication system design. This leads us to select a shallow depth modem at 15 m. As shown in the next section of this study the channel behaves almost as impulsive and communication quality should be higher here all year round.

ENVIRONMENTAL INFLUENCES ON GENERATEDCHANNEL MODELS

For the generation of channel models on quarterly basis, Environmental Files (ENV) are created that includes details of SSP, maximum floor depth, the depths of source (transmitter) and collector (receiver), range and the number of beams to be transmitted. MATLAB program is written to runBellhop.exe that needs the number of beams to be transmitted to test channel behavior. Beam tracing is similar, in principle, to ray tracing but only considers the paths of finite width beams rather than infinitesimal width rays. Using

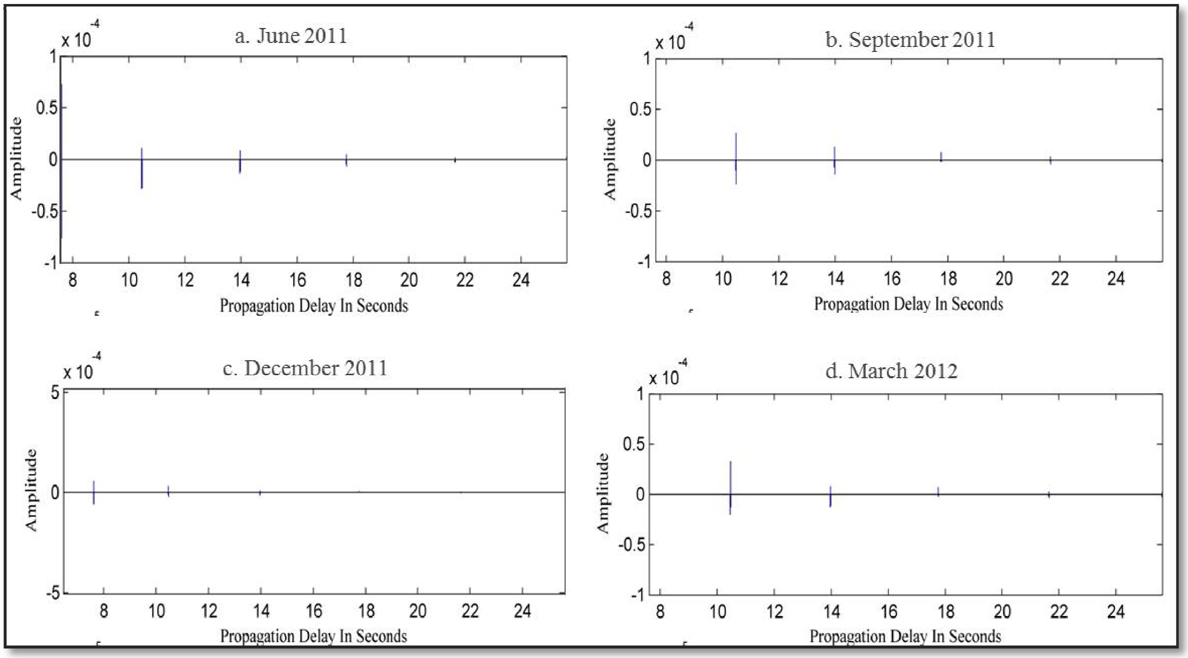

Fig. 9: Channel multipath responses without sparsing

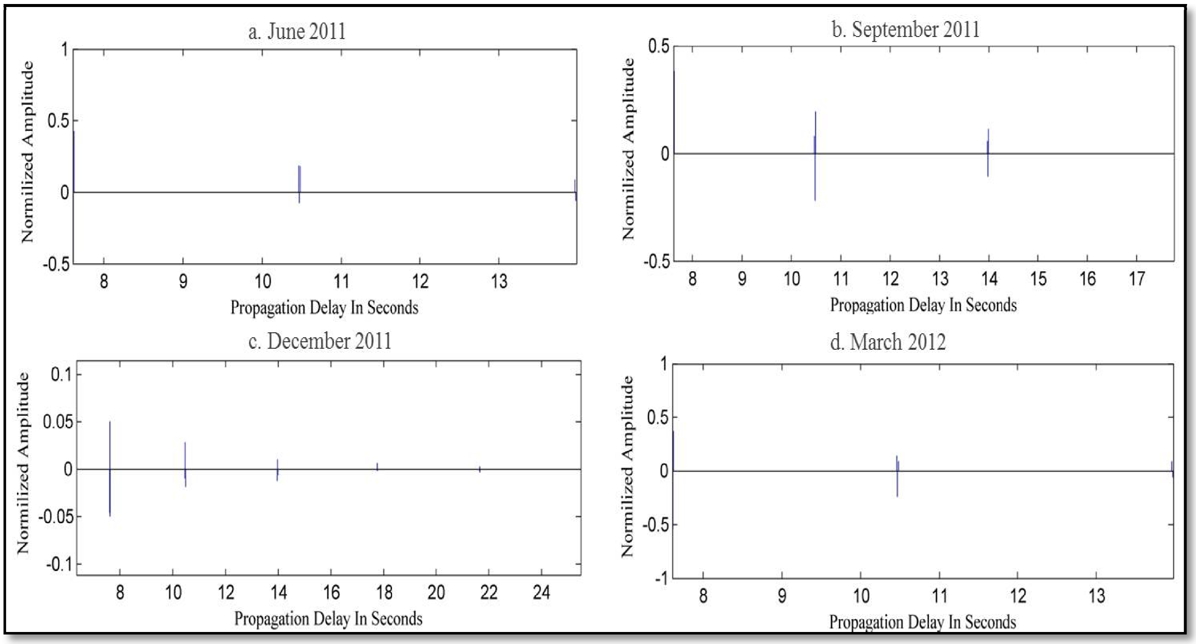

Fig. 10: Sparse multipath channel responses

Gaussian intensity profile or geometric beams, Bellhop beam tracing program can produce the same result as a standard ray trace method. In order to find channel impulse response, propagation time and amplitudes of the multiple paths are obtained that explains the reflection phenomena from the surface and bottom boundaries of the ocean. Each path of any acoustic channel can be assumed to act like a low-pass filter and hence the overall impulse response cans be written as:

$$h(\tau,t)=\sum_{p=0}^{K} h_p(t)\delta\big(t-\tau_p(t)\big)$$

If some of the coefficients $\mathrm{h_p}(t)$ are zero or relatively very small, the corresponding estimates can (and should) be discarded. By doing so, the problem of dimensionality is reduced to the one dictated by the physics of propagation and not by the number of subcarriers. Out of the *K*, *J* coefficients are selected as those, whose magnitude is greater than some threshold (i.e., 5% of maximum in our case). Hence, sparse channel impulse response $h_s(t)$ is obtained optimally by truncation in magnitude:

$$h_s(\tau, t) = \sum_{p=0}^{J} h_p(t)\delta\left(t - \tau_p(t)\right) \quad (1)$$

The transmitting modem is placed just under the sea surface at 10 m and the receiving modem is placed at 15 m depth at about 9.6 km from the start position. Channel vectors obtained from bell hop beam tracing program are further used in the simulation of OFDM based UWA communication. Original and sparse channel impulse responses on a quarterly basis (i.e., from June 2011 to March 2012) of the selected region near a coast of O'Mara are shown in Fig. 9 and 10 respectively. Considering original channel impulse, various paths of the beams can be clearly observed that makes the channel more complex and resistant against any UWA communication. On the other hand, sparse channel reduces the complexities of channel by avoiding insignificant amplitudes and consideration is only given on those multi-paths whose magnitudes are greater and equal to the 5% of the maximum amplitude pulse. Sparse channel model is used in ZPOFDM based UWA communication system.

From the figures, it is revealed that the channel behaves in quite a similar manner during March and June and offers minimum multipath spread. The same spread is significantly more and visible in the sparse channel models during other months. Moreover, deletion of many unwanted paths is clearly viewed that makes channel models more ideal for OFDM based communication even in the presence of non-uniform Doppler distortions and high noise activities, which we will consider in future study.

ZP OFDM FOR UWA COMMUNICATION

Multicarrier modulation in the form of Orthogonal Frequency Division Multiplexing (OFDM) has proven robust and best suited in underwater environment because it offers low complexity design of receivers that can deal with highly dispersive channels. This technique divides the available bandwidth into several sub-carriers. The frequency spacing of the carriers is chosen in such a way that the modulated carriers are orthogonal and do not interfere with one another as shown in Fig. 11. The idea of OFDM scheme for UWA communication is encouraging as it is a suitable method to deal with the strong multipath having long delay spread and offers high transmission rate with more bandwidth efficiency. The multipath induced signal from the modeled channels arrives mainly from the sea surface and process on the receiver side.

In the ZP OFDM based scheme, let T and T_g symbolize the symbol time and guard interval respectively. The total time OFDM block can be written as:

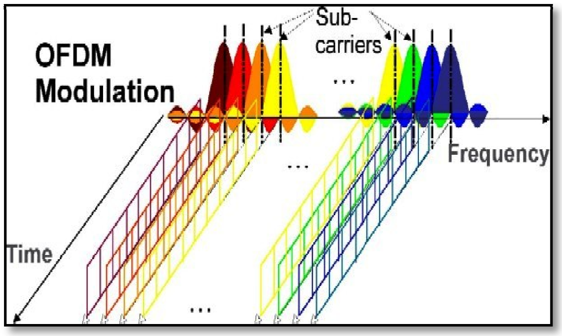

Fig. 11: OFDM modulation scheme

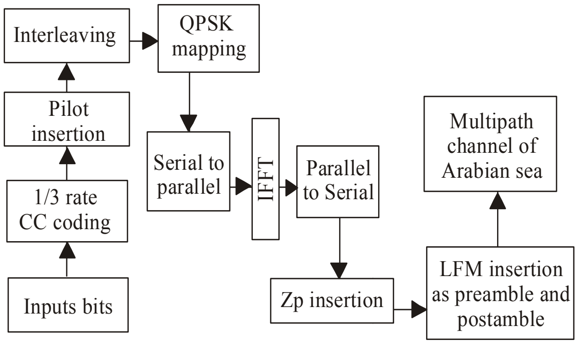

Fig. 12: Block diagram of implemented OFDM transmitter

$$T_{total} = T + T_g$$

The transmitting signal in pass-band can be written as:

$$s(t) = s_a(t) + s_g(t)$$

where, $s_a(t) = Re\left\{\sum_k \left[d[k]e^{i2\pi k\frac{t}{T_{total}}}\right] e^{i2\pi f_c t}\right\}$, for $t \in \{0, T\}$ is the expression for OFDM symbol, $d[k]$,denotes the information symbol to be transmitted on k^{th} subcarrierand, $s_{g(t)} = 0$ for $t \in \{T - Tg, T$,represents zero padding operation during guard interval time. So, we can write complete expression for ZP-OFDM transmitting signal as:

$$s(t) = Re\left\{\sum_k \left[d[k]e^{i2\pi k\frac{t}{T}} g(t)\right] e^{i2\pi f_c t}\right\} \quad (2)$$

where, g(t) = 1 for $t \in \{0, T\}$ and $g(t) = 0$ $otherwise$

After multipath sparse channel with gain h_p, from (1), the receiving signal in baseband satisfies $\tilde{z}(t) = Re\{z(t)e^{i2\pi f_c t}\}$ and can be written as:

$$z(t) = \sum_{p=0}^{J} A_p\{\sum_{k\in K}[d[k]e^{i2\pi k\Delta f(t_p)}\, g(t_p)] \times ei2\pi afktp+nt \quad (3)$$

where, $\tilde{z}(t)$ is the passband version of receiving signal, $t_p = t - \tau_p$ and n(t) is channel noise. In Fig. 12, block

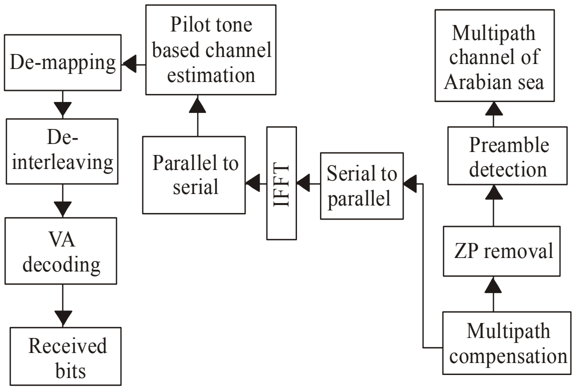

Fig. 13: Block diagram of implemented OFDM receiver

diagram of considered model of OFDM transmitter is shown.

In the receiver side, multipath is compensated from the received signal $z(t)$ using guard interval of duration T_g. The length of T_g should be greater than the maximum delay of p^{th}path τ_{max} for proper mitigation of multipath. The compensated signal $y(t)$ is then in form of:

$$y(t_c) = \sum_{c=0}^{J} A_c\{\sum_{k\in K}\left[d[k]e^{i2\pi k\Delta f(t_c)}\ g(t_c)\right] \times ei2\pi afktc+vt \qquad (4)$$

where, $t_c = t - \tau_p + T_g$ is time such that, $y(t_c) = y(t)$(i.e., compensated signal) for $T_g \geq \tau_p$, $A_c = A_pJ - A_pN$is an amplitude (N is number of compensated paths) and $v(t)$ is a noise component respectively. Moreover, after the removal of a ZP guard interval, LS channel estimation is carried out in a frequency domain. In a Fig. 13, block diagram of an implemented model of OFDM transmitter is shown.

Received compensated signal in frequency domain is expressed as:

$$y_n = fft[y(t)]\ = H(n)d[n] + u(n)\mathrm{q} \qquad (5)$$

where, $H(n)$ is the channel frequency response and $u(n)$ is the noise component. The coefficients of $H(n)$ can be related to the discrete baseband channel parameterized by $L + 1$ complex-valued coefficients as:

$$H(n) = \sum_{l=0}^{L} h_l e^{i2\pi ln/K} \qquad (6)$$

We use K_p pilot symbols as pilots having equal spacing within K subcarriers. Ignoring noise component, the frequency domain LS channel estimation is carried out as:

$$H(p) = \frac{Y_p}{D_p} \qquad (7)$$

where, $Y_p = y_n(p)$, $p \in K_p$ and D_p is the known pilot symbols.

Using linear or any suitable method of interpolation $H(n)$ can be found for all information subcarriers K_s per symbol. Accordingly, data bits for n^{th} subchannel are obtained as:

$$D(n) = \frac{y_n(n)}{H(n)}\ , n \in K \qquad (8)$$

PERFORMANCE EVALUATION ZP OFDM ON THE SELECTED CHANNEL MODEL

For the simulation of OFDM based UWA communication near coast of Ormara, the selected bandwidth is $\mathrm{B.W.} = 6$ KHz and the carrier frequency is $\mathrm{f_c} = 7$ KHz. ZP (zero padded) OFDM of 1024 subcarriers with the guard interval of $\mathrm{T_g} = 42.66$ ms per OFDM symbol is used. The subcarrier spacing and OFDM symbol duration are therefore $\Delta\mathrm{f} = 5.86$ Hz and $\mathrm{T} = 170.66$ ms, respectively. Convolution coding of rate $^1/_3$ with constraint length of 14 and generator polynomial of (21675,27123) is applied within the data stream for each OFDM block. The 9.6 Km channel range is selected with the depths of transmitter and receiver respectively are 10 m and 15 m. Number of equally spaced Pilot bits is selected using:

$$K_P = {}^{K}/_{4} = 64\ bits/symbol$$

IFFT/FFT length of 8192 is used and QPSK mapping using MATLAB built-in command modem.pskmod and modem.pskdemod is implemented with the aim to obtain the appropriate results. Channel estimated impulse responses on first (blue) and last (green) i.e., 45th symbols obtained from the least square method for all four-channel conditions are shown in Fig. 14a to d. The plots explained almost similar channel responses estimated on first and the last symbols in all seasons that further endorsed the robustness of an OFDM scheme with LS- estimation. As observed generated in a channel model, the effects are clearly visible and low amplitudes as produced in December 2011 can also be seen in the estimation plot.

Scatter plots of demodulated (QPSK) receiving bits are shown in Fig. 15a to d respectively for the seasons from June 2011 to March 2012. Response from scattered plots explains that the decision points are more prominent for channel model generated in December and in September. However, for remaining case, especially in June, decision points are little bit blurred. Using similar configurations and same communication scheme, the decision points are

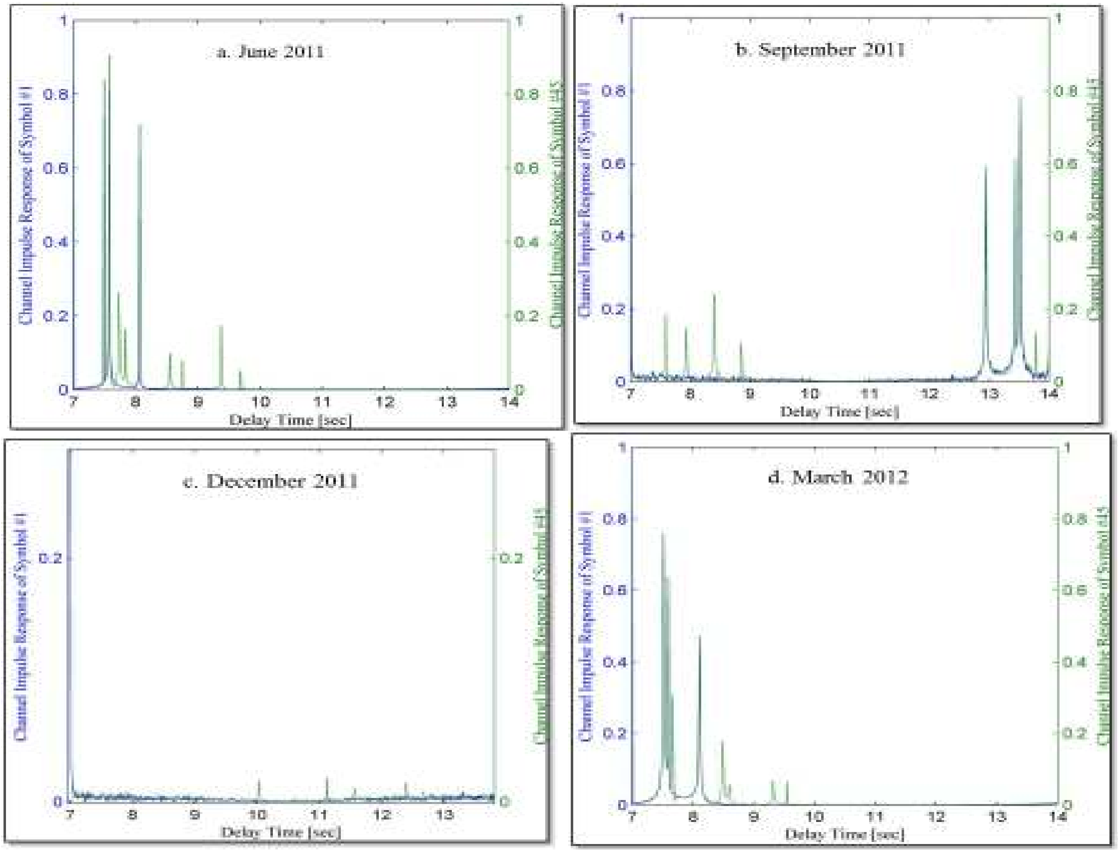

Fig. 14: Estimated channel (a. June 2011 to d. March 2012s)

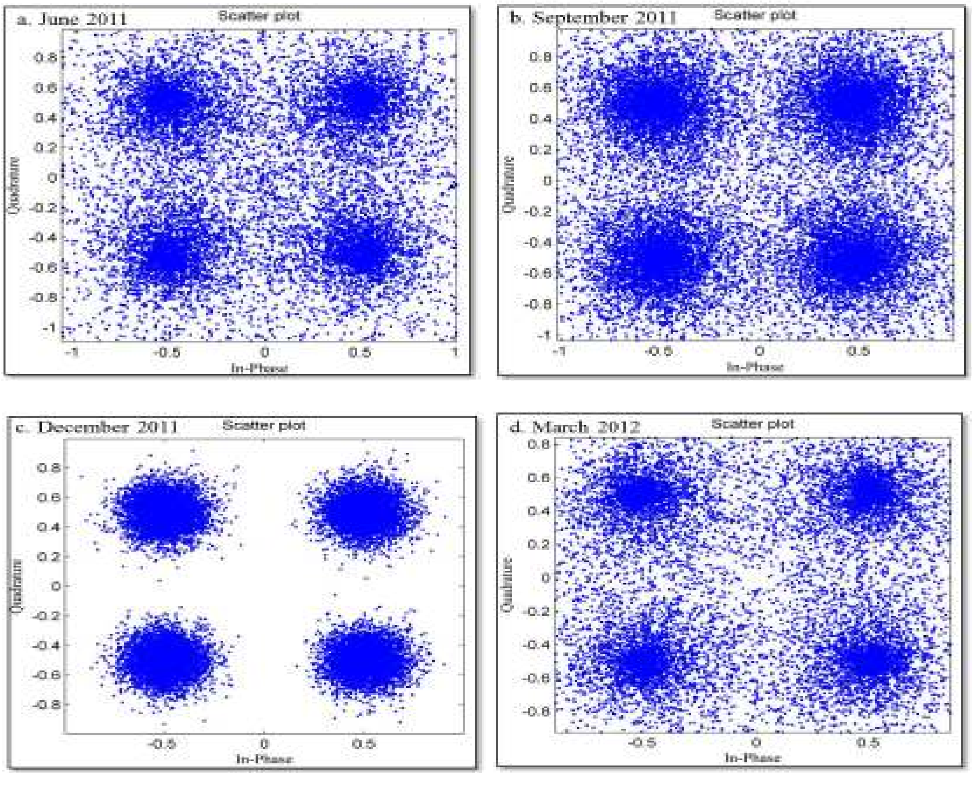

Fig. 15: Scatter plot (a. June 2011 to b. March2012)

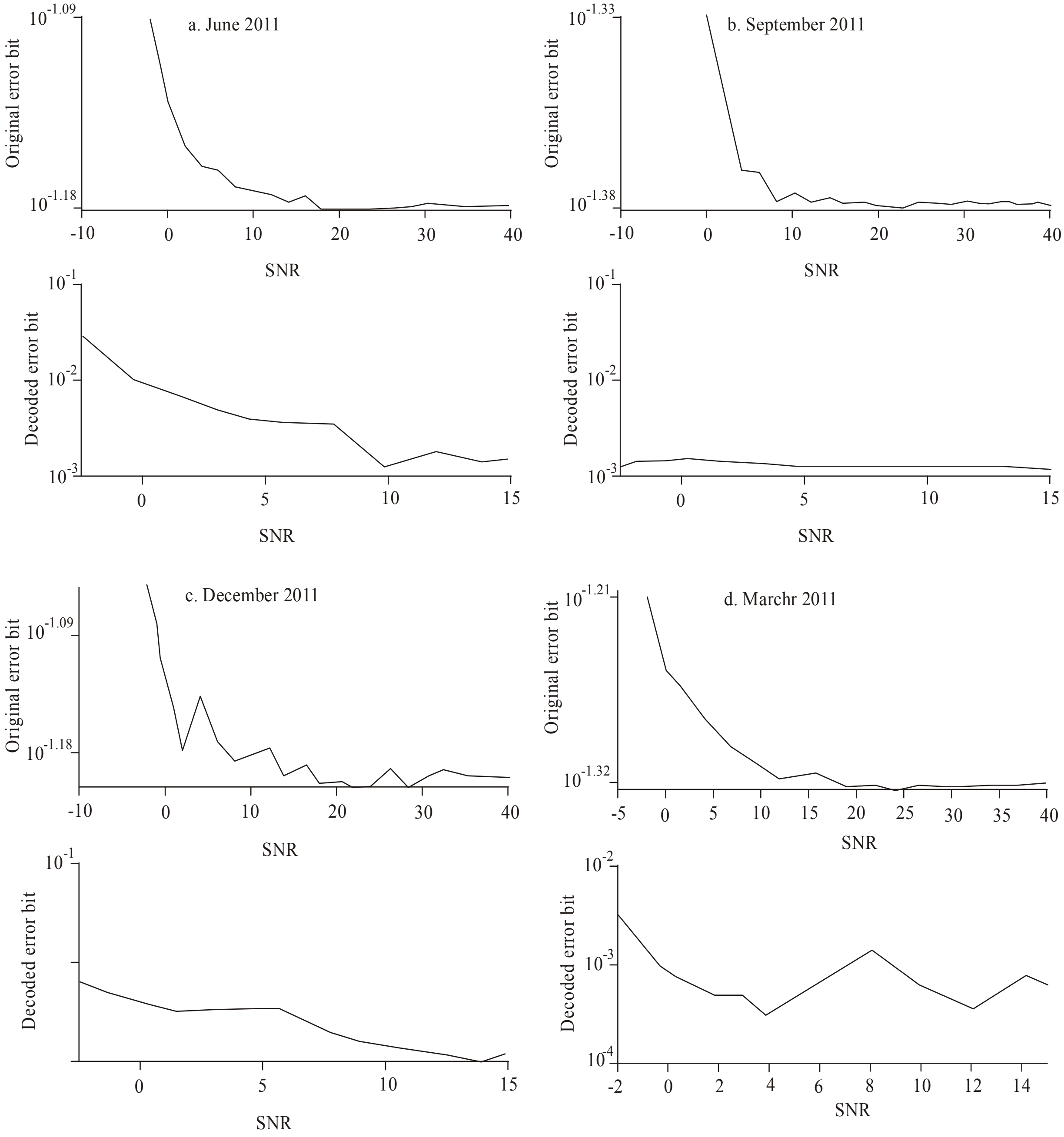

Fig. 16: SNR vs BER plot (a. June 2011 to b. March 2012)

different for different season and make able to decide the better understanding for the robust design. The plots suggested the selection of a season for better communication is between Septembers to March.

In Fig. 16a to d, show the BER performance (raw and coded) for the selected region of Arabian Sea, hard VA decoding is carried out here. From these simulation results, we get the evident for the robustness of OFDM scheme on with respect to the climatic variations and specifically for the coded BER of the order of.10^{-2} have been achieved near to 0 $dB\ SNR$ in three (March, September and December) of seasons. In this algorithm, BER performance can be improved with more receiving element through multi-channel combining.

CONCLUSION

In this study, we have presented the performance evaluation of ZP-OFDM based scheme for UWA communication and tested on generated channel models. The study is carried out with aim to observe the effects of seasonal climatic variations in the ocean, for this purpose, we have selected the North-western region of Arabian, near a coast of Ormara, Pakistan. Argos floats's ID 2901374 and global Argos marine atlas are utilized for data acquisition. Channel models generated through a Bellhop ray tracing program are properly highlighting the effects of the seasonal variations. From the simulation results of ZP OFDM scheme, it is revealed that OFDM based communication is one of the robust technique that has a capability to mitigate the effects of underwater multipath completely, specifically; it will provide best results during the months of September and March for the selected region. The designed can also be adapted with respect to the climatic changes. The same results can also be utilized to determine the maximum possible range at which the transmitter and the receiver can be able to communicate at a given source level. Therefore, this study is an initial step in feasibility study for deployment of underwater acoustic sensor network and telemetry solution in that area. Dynamic channel condition modeling (due to wind and platform motion), with the aim to compensate the Doppler induced signal will also be carried out inner future for more accurate validation/verification of communication prior to the experimental work. Future study will also focus on both experimental and analytical results for verification/ validation of current simulations.

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