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Research Article

A Study on Multi-Path Channel Response of Acoustic Propagation in Northwestern Arabian Sea

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Abstract: Multi-path interference due to boundary reflection and variation of sound speed profile in underwater water acoustic communication pose the major barrier to reliable high-speed underwater communication system. Based on the sound speed profiles and the bathymetry data of northwestern Arabian Sea, Multipath impulse response profiles of the area have been obtained using Bellhop. The derived parameters like delay structure, effective transmit and receive angles suitable depths etc. from the obtained impulse responses have also been discussed. The impulse responses have been obtained for different scenarios of transmitter and receiver geometry to arrive at optimal configuration of wireless Acoustic communication/telemetry system for that area. This work can be used as a guide for the practical design of underwater acoustic wireless communication/telemetry system to be operated in this area which is critical to world oil exports.

Keywords: Acoustic communication, Arabian sea channel models, multi-path channel, under water underwater acoustic communication modeling

INTRODUCTION

With the increasing requirement of communication and ocean exploitation in the recent years, there has been a growing interest in the Under Water Acoustic (UWA) communications in various application areas such as telemetry, remote control, speech, or image transmission etc. Compared with EM environment, shallow and deep water acoustic channels are characterized by extended multi-path, limited bandwidth and spatial/temporal variability. Multipath propagation is of particular concern in horizontal underwater Acoustic Communication links, where it results in very long channel response spanning up to several tens of symbol intervals. This results in severe Inter Symbol Interference (ISI). The channel equalization is usually done to mitigate the effects of the ISI but as compared to most of the EM channels is excessively difficult. Spreading in time is mainly caused by multipath propagation (Giacomo *et al*., 2007) This Spreading can be modeled by the incorporating the effects of the boundaries i.e., sea surface and bathymetry into the propagation codes. Underwater acoustic communication simulation has become a very important method for assessment of new algorithms and scenarios. The simulation has qualities of flexibility, convenience and repeatability (Daniel *et al*., 2000). In order to assess and improve the performance of communication system, it is necessary to predict the characteristics of multi-path for some specific underwater channel. These multi-path parameters could be obtained from in situ experiments or acoustic propagation simulation. The multi-path parameters obtained from simulation can be used for channel coding and equalizers simulation research.

SOUND SPEED AND BATHYMETRY PROFILES

Sound Speed Profile (SSP) affects the propagation of sound wave significantly. The sound speed profiles of the north western part of the Arabian seas used in this study are obtained from various sources. The first source is the data bases of surveys conducted by researchers and oceanographers of the region (Prasanna *et al*., 1993; Iqbal *et al*., 2004; Wagstaff and Aitkenhead, 2005). The second source of data is World Ocean Atlas (2009) (www. nodc. noaa.gov). The world ocean atlas data base gives us the values of the sound speed profile for all the months at different geographical locations. The second important parameter that affects the multipath impulse profile is the bathymetry of that area where the acoustics communication is taking place. The Bathymetry data is taken from GEODAS (Geophysical Data System) database developed by the National Geophysical Data Center (NGDC) of United States of America (www.ngdc.noaa.gov) and data bases of SAGE software (Adrian *et al*., 2002) being used by Thales Underwater System and DSTO Australia. The sound speed profiles in

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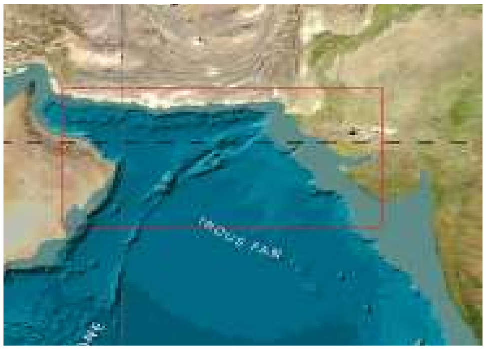

Fig. 1: General area under study

that area have typically sharp negative gradients. This makes the long range shallow water propagation difficult. The general area of the study is shown as Fig. 1.
The general bathymetry of the area is shown in the Fig. 2.

MULTI-PATH AMPLITUDE-DELAY ESTIMATION METHOD

In this study discrete multipath channel model approach is being followed. We assume that the channel is composed of a finite number of resolvable paths, the channel impulse response can be written in the form:

$$h(\tau_k) = \sum_k a_k (\tau_k) \delta (\tau - \tau_k)$$

Hence the received signal consists of k multipath components, with attenuations a_k and delays τ_k .Multipath structure is obtained using the Bellhop (Porter and Bucker, 1987) which implements the method of Gaussian beam tracing. Ray/beam tracing models have ability to construct a full time series for a broadband source with essentially no additional effort relative to a tonal calculation. Most of the other simulation methods handle a broadband source by representing it as a sum of tonal. The ray/beam process calculates the amplitudes and travel-times of all the echoes and can therefore calculate the received time series by summing up the paths taking in account the echoes, as well as Hilbert

transforms of the source waveform (Porter, 2011). Further, the ray/beam process uses attenuation values at the center frequency of the calculation. The major environmental parameters for the configuration are following:

- Frequency and beam pattern of the transmitter
- Sound velocity profile
- Bathymetry of the area
- Surface and bottom roughness
- Receiving and transmitting sensors positions

Bellhop has been used by many researchers for the simulation of channel properties with different degrees of success in terms of conformance with the actual scenario (Beatrice *et al*., 2010; Giacomo *et al*., 2007; Paolo *et al*., 2011). To obtain the multipath impulse response these steps are carried out. First of all the locations of the modems are selected and sound speed profiles and bathymetry at and between the points is established along with the sea bed properties. The parameters of transmitter and receiver like position, depth, frequency, beam pattern are provided. Some parameters of the bellhop code are then fed and simulation is started for the Amplitude - Arrival case. After this several simulation runs are performed to achieve convergence in the results.

TEST LOCATIONS AND RESULTS

There are three test locations where the Multi Path Intensity Profiles have been obtained .These include:

- The Rising continental shelf near Ormara
- Flat deep sea positions off the coast of Makran
- Shallow water near Karachi port

The absolute soft and plane boundary conditions were chosen for the sea surface and seabed was assumed

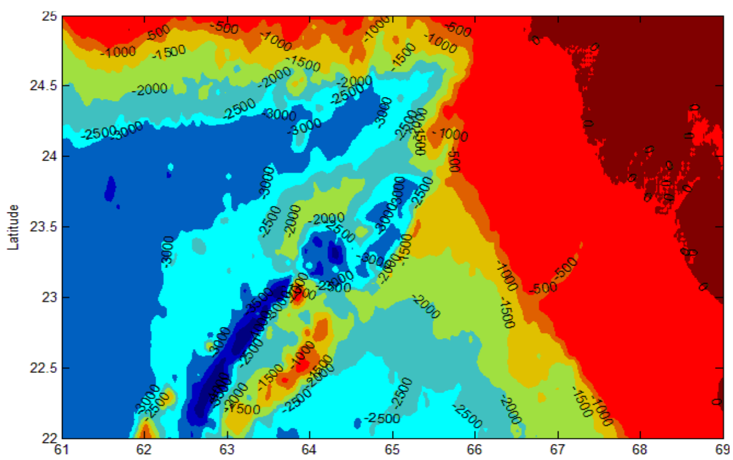

Fig. 2: Bathymetry of Area

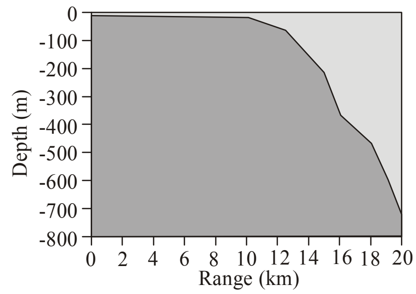

Fig. 3: Ormara Rising continental Shelf bathymetry

as acoustic elastic half space. Modem transmits at source frequency of 3.5 kHz. The transmitter and receivers modems were placed under surface at different depths and ranges details of which are given in the following paragraphs:

Ormara Rising continental Shelf: Ormara is an important harbor in the Makran coast and the Water depth increases dramatically with range. The latitude longitudes of modems are approximately 25° 10 N ,64° 42 E and 24° 59 N ,64° 41.9 E .The total range between the two points is about 20 km and the depth increases from 10 m to 722 m approximately . Bathymetries and sound speed profiles of the positions are given in the following figures (Fig. 3 and 4).

The modem was placed just under the surface. The received multi-path pulses structure is shown in Fig. 7, 8 and 9. The horizontal axis is the propagation time from the transmitter to the receiver. The following figure (Fig. 5) gives us the propagation paths of the transmission and suggests us to use the depth of around 400 m for the other modem to be deployed. This scenario also shows the unavailability of surface ducts otherwise assumed present in the shallow water channels because of the negative gradient of SSP. These negative gradients are typically found in that area. The year round data of Sound speed profiles, as shown in the Fig. 6, also indicate that any significant surface duct will be available in only months of January-February. This ray path also suggests that we have to use either a moored floating modem at a depth of 400 m at 20 km range or we could use a near bottom modem at about 18 km from the source to act as a hoping node for the next modem away in the range.

The channel Impulse response obtained from the simulation is given in the figures. The response, as shown in Fig. 7, has been obtained for the full ocean depth at the far end modem and shows the structure of the multipath impulse as a function of the depth and delay time. From the figure it is clear that at surface the arrivals are distinct in time and very separated but at the 300-400 m depth the bulk of the paths merge and thus create a strong signal.

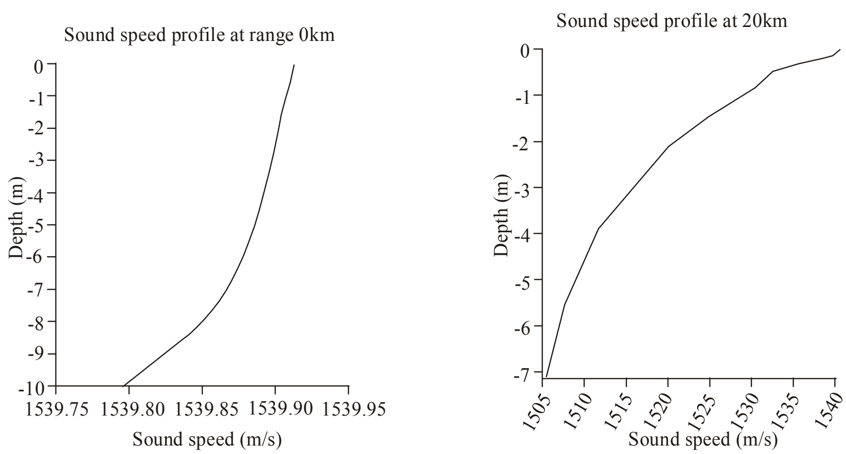

Fig. 4: Sound Speed Profiles at start and end Locations

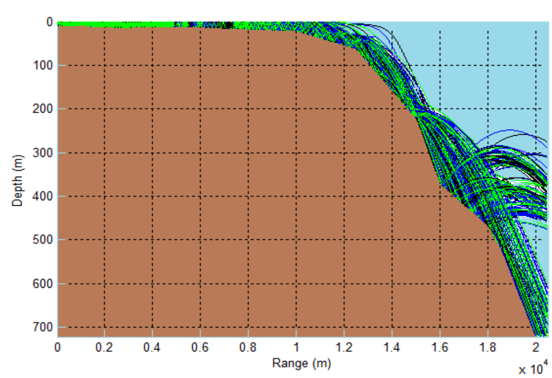

Fig. 5: Ray Paths for Ormara Rising continental Shelf

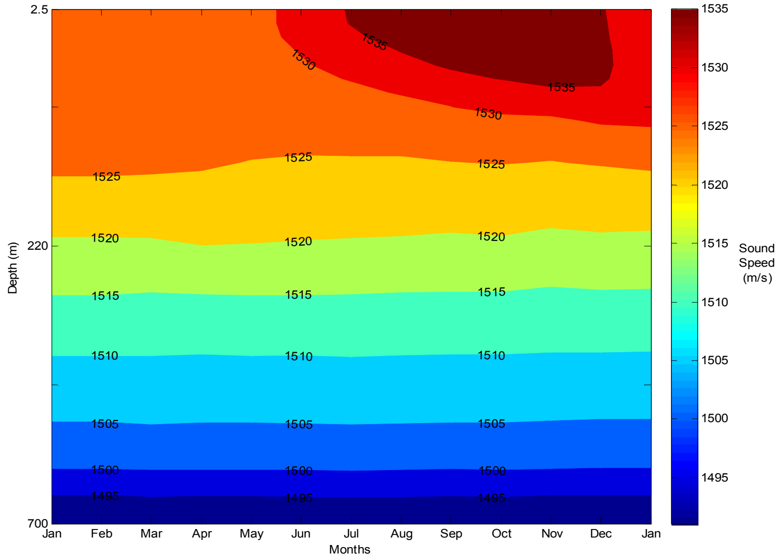

Fig. 6: SSP vs. Depth (year round)

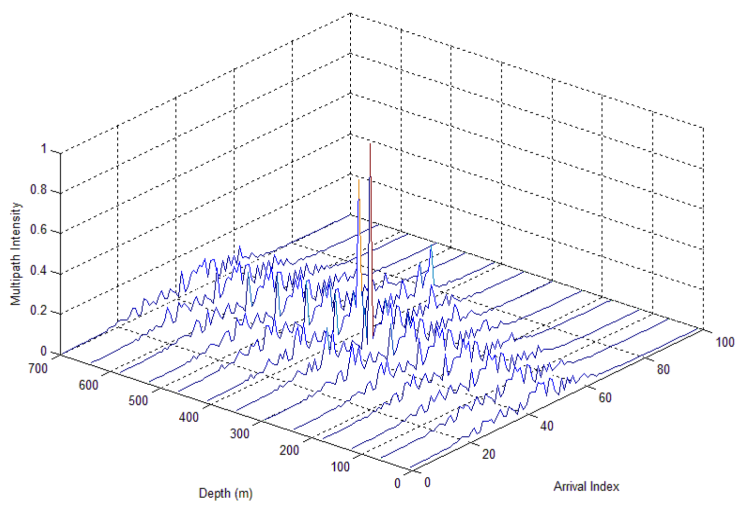

Fig. 7: Multi Path Profile with changing depth

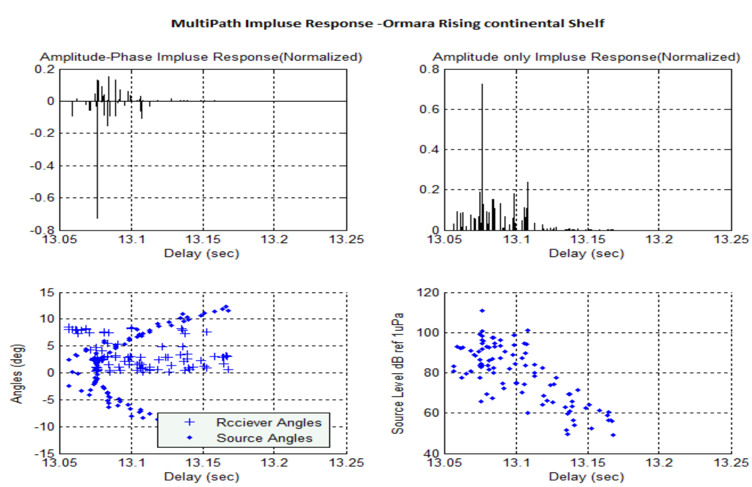

Fig. 8: Normalized Multi Path Profile Angles and received level

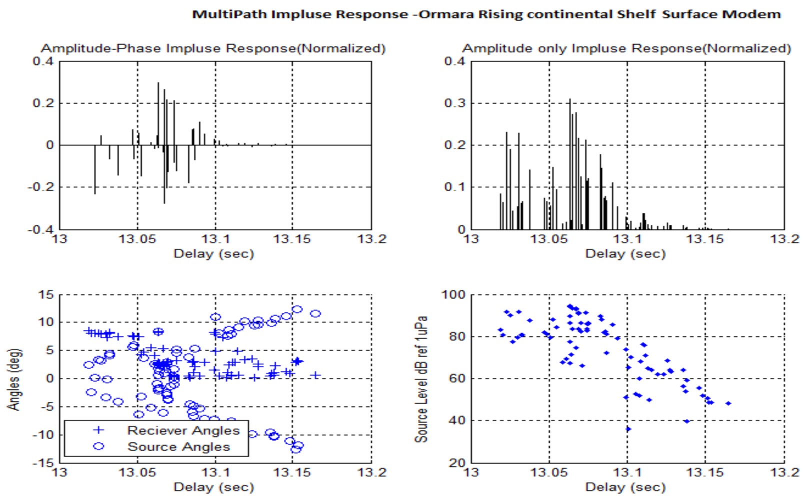

Fig. 9: Normalized Multi Path Profile Angles and received level

The following (Fig. 8) gives the Amplitudes and associated angles along with delay time for the paths of the communication for the modems when the far side modem is at 400 m depth. The fourth graph shows the source level prediction at the far end modem from a 40 watt 50% efficiency Omni directional transducer. The value can be used for arriving at the source levels needed here for reliable transmissions if the noise background and any processing gains for the modulation/signal processing schemes are known. This graph can be used to arrive at optimal settings of the parameters of the ualizer for this case. At this depth the channel behaves as impulsive and communication quality should be higher here. Also it is expected that the equalizer need not to be very complicated and hence reduce the overall complexity of the receiver.

The (Fig. 9) gives the Amplitudes and associated angles along with delay time for the paths of the communication for the modems when the far side modem is at 15 m depth. Immediately we notice that the Source level has dropped about 10-12 dB from the first case.

The channel response in both the cases shows that there are only a small fan of angles (-12 to 12º approximately) from the transmitter energy that is reaching the receiver. This means that the directivity of the transmitter is important factor in the modem design so that the energy budget of the modem is kept at minimum. In terms of the receiver angles (0 to 9º) the fan angle is also very narrow making possibility of using a sparse/less densely populated array a good choice. This should reduce the hardware cost and improve the overall energy efficiency. The receiver angles obtained in the simulation can be used in the design of spatial diversity gain algorithms.

Flat Deep Sea off the coast of Makran: This position is located near the Makran coast .We call this place in this study as Ormara deep sea channel. It can be used for the environmental monitoring and deep sea surveillance if proper network of sensors are installed here. The Water depth remains approximately 3400 m. The latitude longitudes of modems are 23°53.9 N, 61° 59.7 E and 23° 40 N, 61^0 58.1 E .The total range between the two points is about 25 km. Bathymetry and sound speed profiles of the positions are given in the Fig. 10 and 11.

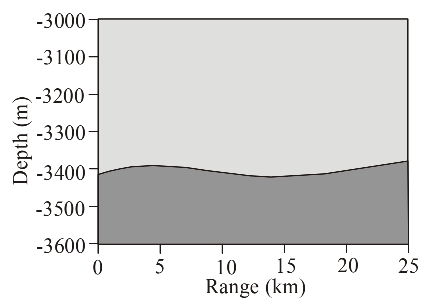

Fig. 10: Bathymetry of Deep Sea off the coast of Makran

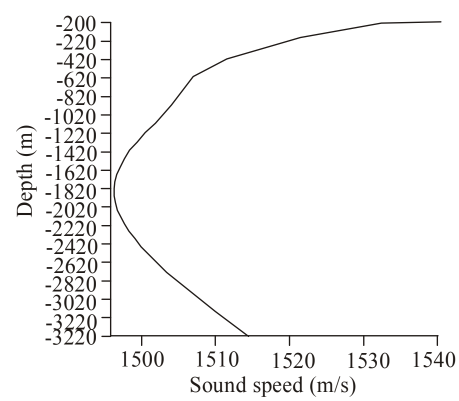

Fig. 11: Sound Speed Profile of Deep Sea Channel

The (Fig. 12) shows the energy concentration of the channel when the source modem is placed at 2000 m and 100 m depth. Here it is clear for the first case that the favorable depths for the hop modem should be around 1700~1800 m which is also the deep sound channel

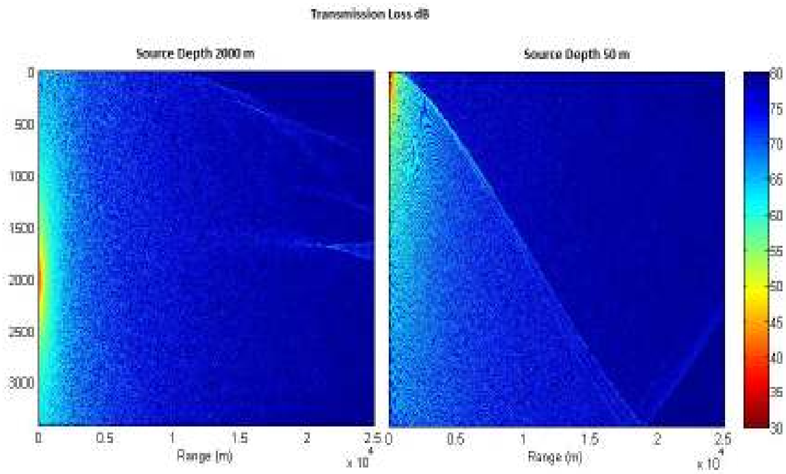

Fig. 12: Transmission Loss for DSC (left) and Surface modem (right)

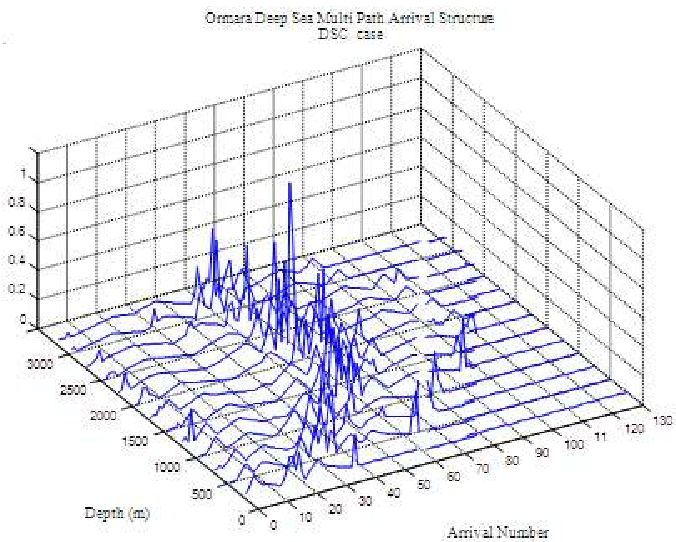

Fig. 13: Multipath profile with depth (Deep Sea Channel)

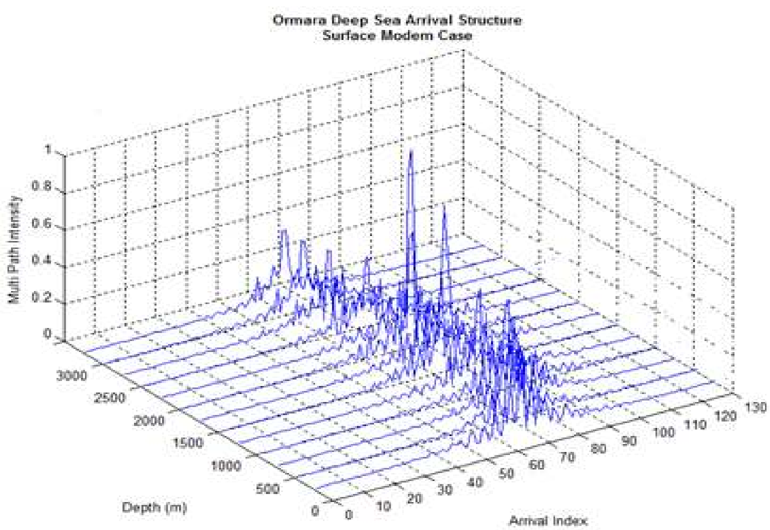

Fig. 14: Multipath Profile (Surface modem)

(DSC) depth. If the hop distance is reduced to 10-15 km then the modem can be placed at less than 500 m depth also. The favorable depths for the second case are around 2500 m.

The channels Impulse response obtained from the simulation when the transmitter modem is at about 100 m and at 1800 m are given below in Fig. 13 and 14.In these the channel response has been obtained for the full ocean depth from near surface to more than 3000 m.

The above figure shows the amplitude of the multipath impulse response and its change with respect to depth of the far modem. The multipath response of the simulation extends up to more than 50 seconds. The major response; however will not be so much extended as much of the response function has very low amplitude and will not be above the noise floor of the sea. The impulse response shifts its maxima to larger index of arrival as the depth is increased. This does not mean that delay increases. As a matter of fact the delay is at its minimum at that index, From the figure it is also clear that the maxima of the Multipath Impulse response is much higher for the greater depth as compared to shallow water's Multipath impulse response maxima. This is partially due to the negative gradient at upper water column and partially due to the DSC.

The Fig. 15 gives the Amplitudes and associated angles along with delay time for the paths of the communication for the modems when the far side modem is at 1800 m depth. The source and receiver angles in this scenario have a wider fan as compared to the previous example but again it is emphasized that the actual strong returns will be again be concentrated in less than +/- 30 degrees approximately.

The Fig. 16 gives the Amplitudes and associated angles along with delay time for the paths of the

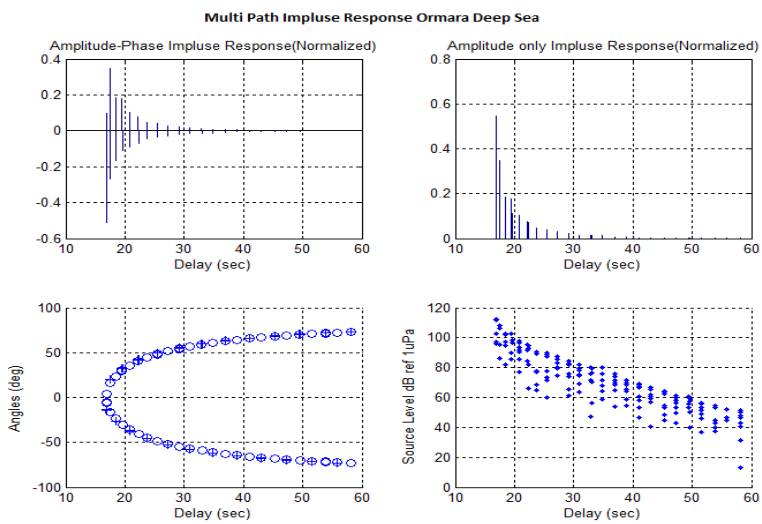

Fig. 15: Normalized Multi Path profile Angles and Received Level

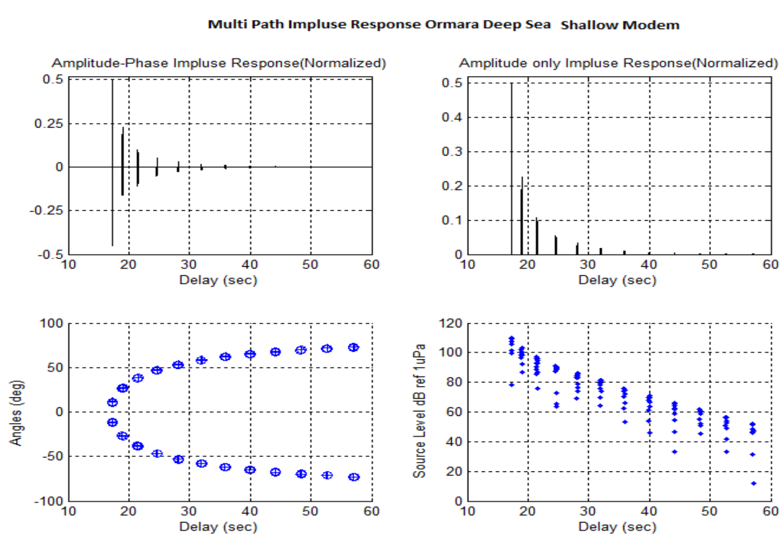

Fig. 16: Normalized multi path profile angles and received level

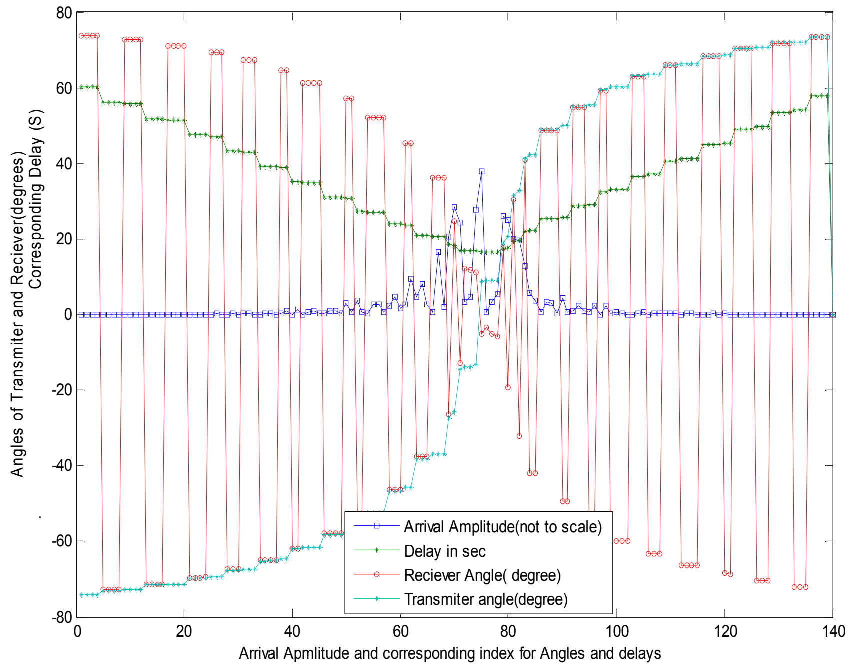

Fig. 17: Composite graphs for multipath Structure

communication for the modems when the far side modem is at 100 m depth. The Impulse response here is little bit sparse than the deep sea case but the source and receiver angles, source levels and structure are similar to the previous case.

The Fig.17 shows the most revealing features of the multipath such as the effective time spread and Relative Intensity of the different arrivals.

The delay of the multipath can be approximated by a quadratic function of arrival index while the impulse response has the shape of a Sinc function around the minima of the delay function. The receiver angles can be approximated by sine functions whose amplitude is modulated by an exponential like function. The transmitter angle function seems to be the one sided envelop of the receiver angle function.

Shallow water near Karachi: This position is located near the coast of Karachi .This place can be used for many functions. A Network of sensors if installed can be used for environmental monitoring, intruder detection, passive surveillance and host of other purposes. The Water depth remains approximately 120 m. The latitude longitudes of modems are approximately 24° 32.9 N, 66° 45 E and 24° 26.9 N, 66° 48.7 E .The total range between the two points is about 12.7 km approximately. Bathymetry and sound speed profile of the positions are given in the following fig. 18 and 19.

The channel Impulse response obtained from the simulation is given below in figs 20 and 21.

The Fig. 20 shows that the multipath response function is showing maximum at upper 10-20 m .This is

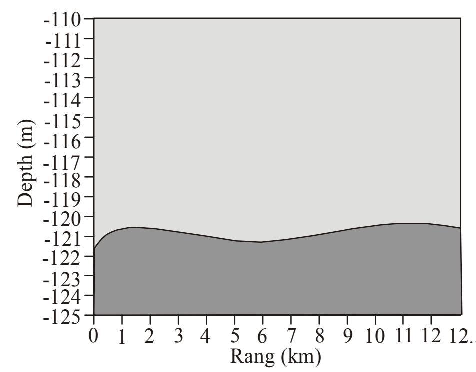

Fig. 18: Bathymetry of Shallow water near Karachi

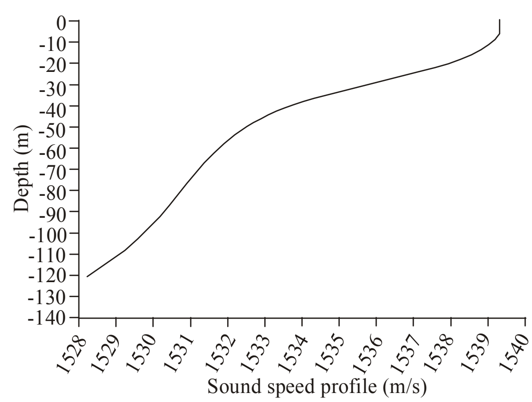

Fig. 19: Sound speed profile

because of the sound speed profile being slightly positive at that depth resulting in surface duct.

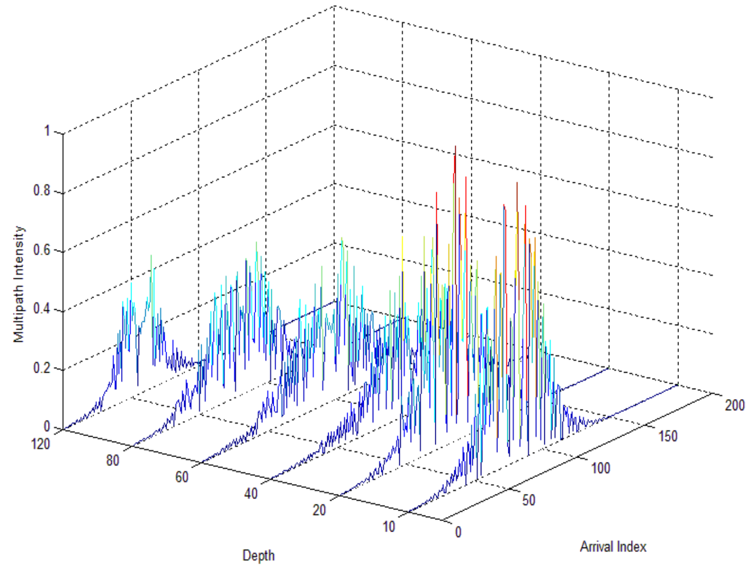

Fig. 20: MultiPath structure with depth

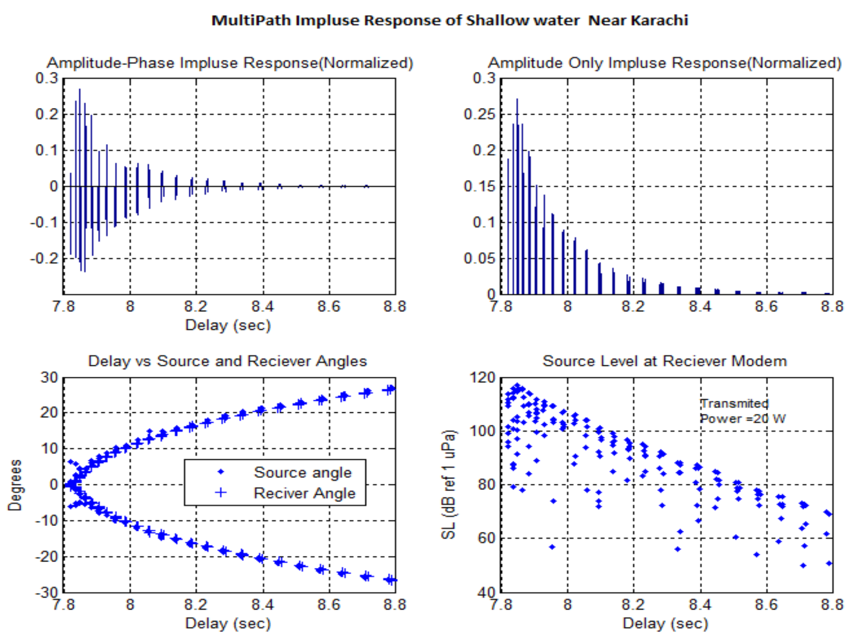

Fig. 21: Normalized multi path profile angles and received level

The above graphs clearly show that the channel time spread is although more than 900 m sec but the actual strong multipath components lie within 100-200 m sec. The best depth as seen from the first graph is in the upper 20 m. this dictates the use of floating modems near sea surface for this area. The simulation has been done for the case of different receiver depths.

CONCLUSION

In this study the static structures of the multipath impulse response of the some important locations of the northwestern Arabian Sea have been obtained and discussed. The type of communication schemes and data rates depend on the channel spread factor, which is influenced by the duration and structure of multipath. The multipath is useful for both system design and performance prediction. Starting from the observation that the areas of strong sound propagation for establishment of communication link can be predicted and easily characterized in terms of distance, depth and type by multipath characteristics, suitable relay/hop node positions and configuration can be achieved. Many of the processing algorithms can also be tuned from this kind of work.

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