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# Effect of Environment on Underwater Acoustic Communication Data Rates

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**ABSTRACT**

Underwater acoustic communication has several applications for civilians and defence. It is a challenging engineering problem, where large variability of ambient noise and highly variable channel characteristics limits the performance of communication system. In addition horizontal transmissions in shallow water is considered very challenging due to time varying delay spread and significant Doppler spread. An experiment was conducted to study the diurnal variability of underwater acoustic communication channel properties of the south west coast of India. Time spread and bit error rate for different ranges and depths are compared in this paper. Influence of prevailing sound speed profile on acoustic communication link is also discussed.

**Keywords:** Underwater Acoustic communication; Eastern Arabian Sea

## 1. INTRODUCTION

Emerging underwater system development scenario looks for efficient communication system for acoustically controlling robots to replace diver requirements, keeping underwater vehicle free from cable and enable to move freely and refine their range of operation. Basic problem encountered in ocean acoustic communications is the time-dependent, highly dispersive nature of the channel. Underwater communication systems encounter both forms of time and frequency variations in signal and the need is to design not only the single point-to-point links but also network configurations. Absorption at high frequencies, and ship noise at low frequencies, limits the usable bandwidth between, a few kHz to several tens of kHz, depending on the range. High-speed communications in ocean acoustic channel still remains a challenging technology. Past three decades have seen a growing interest in underwater acoustic communications. Continued research over the years has resulted in improved performance and robustness as compared to the initial communication systems.

## 2. BACKGROUND

The significant issue in selecting an underwater communication system is the real range and data rate available for a specific use. A system designed for deep-water may work poorly in shallow water (or when configured for too high a data rate when reverberation is present). Manufacturer specifications of maximum data rates are useful for establishing the upper performance bound, but often are not achievable, particularly in challenging acoustic environments. Users are resorted to purchase multiple systems and testing them in specific environments to identify the suitable model to their needs.

Transmission loss and noise are the principal factors determining the available bandwidth for an acoustic channel. Multipath occur due to reflections (predominately in shallow water), refractions and acoustic ducting (deep water channels), which create a number of additional propagation paths to the receiver. Due to differences in length of propagation paths they will arrive at different times. As the speed of sound propagation is very slow this delay spread is significant compared to electromagnetic waves in atmosphere. Ocean being dynamic, the reflecting surfaces have a relative motion and creating frequency variation. In addition to this, specific ocean phenomena tides, internal waves and ocean currents introduce Doppler shift from scatters[1]. The cumulative of all Doppler shifts is known as Doppler spread. Signal components of channels with large Doppler spread changes phase independently over time. This leads to constructive and destructive addition of signal components and shorten coherence time[2]. Thus the statistical characteristics of channel are highly environmental dependent and changes channel communication quality and throughput. Acoustic measurement from Indian waters also showed high Doppler spread effects[3].

Therefore physical layer parameters and their appropriate modelling during design are highly essential and unavoidable. For precise and quantitative performance predictions, at sea experiments are preferred to measure channel parameters while transmitting communication signals, as predictability of the channel is very difficult due to changing seasons and the influence of environmental factors which are difficult to quantify.

A sea experiment to study channel communication properties for a location off south west coast of India during winter season is discussed here. To analyse performance of communication signals a preferred choice is frequency shift

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keying modulation (FSK). Commercial modems also prefer FSK because of its robustness and implementation simplicity[4]. For a communication channel, bit error rate (BER) is used as a first hand information to estimate the achievable data throughput and reliability, time spread for FSK modulation is analysed here to understand the observed variability in BER.

## 3. EXPERIMENTAL CONFIGURATION

A four element vertical line array (VLA) was deployed with hydrophones at nominal depths of 10 m, 25 m, 45 m and 55 m attached to a moored buoy. Automated acoustic signals are generated in the frequency range of 1-10 kHz from projectors lowered at 10m depth from the ship. Four miniature data storage tags were also attached to record the depth of four hydrophones which reads depths mostly as of 9 m, 23 m, 43 m and 53 m. Typical results for 1.5 kHz and 3 kHz are presented here.

The FSK signals with a configuration of two frequency components spaced 100 Hz apart in the band at centre frequency of 1.5 kHz and 3 kHz were transmitted at data rate of 100 bits/sec. The data was transmitted as 24 bits/packet in each one second. Additionally M-sequence signal added to signal to characterise channel property and time synchronisation. These signals transmitted at ranges of 1600 m, 2500 m, 3400 m and 4700 m from the receiver at different times at a different location. Both transmitter and receiver were maintained at ocean depth less than 100 m. Later from GPS position the ranges are estimated as 1520 m, 2512 m, 3373 m, and 4674 m.

## 4. METHODOLOGY

Noise in the ocean is frequency dependent. The major factor affecting noise levels are noise from far field, self noise from own platform, intermittent noise from biological sources and rain. In some of the studies on channel properties[5] it has been observed that if the channel is not ambient noise limited, then there is no impact on performance by increasing the source level.

Bit errors are estimated depending on the actual or effective SNR or energy per bit to noise ratio. If there is more than one arrival, they will interfere producing a tone stronger or weaker than either of the individual arrivals. In shallow water significant multipath exists and hence the concept of 'signal plus multipath' is considered in this study[5]. The idea being that the 'true noise ($No_M$)' is a combination of ambient noise plus multipath. This methodology can accommodate multipath conditions for both signal and noise. In this paper for each received symbol, spectral levels are computed. From spectral levels on tone amplitude and off tone amplitude are obtained. The average of on tone amplitude and off tone amplitude of all symbols in packet is a direct measurement of true signal ($Eb_M$) and true noise ($No_M$)[5]. Here subscript M to denote multipath. However, to achieve the same bit error rate of that in deep water high SNR may be required in shallow water.

Multipaths combine at the receiver to give a resultant signal, which can vary widely in amplitude and phase. Each path has different attenuation, different phase shift and different propagation delay. Hence the received pulse is distorted and its energy is spread in time. Time spread values are estimated using[6]

$$T_s = \sqrt{\frac{4}{E_s}\int_0^{T_0} I(t)(t-t_{cg})^2\,dt}$$

where $T_s$ is time spread and $t_{cg}$ is centre of gravity of signal in seconds, $T_0$ is window time (1s) and $E_s$ is total energy. Centre of gravity of signal is calculated as

$$T_{cg} = \frac{1}{E_s}\int_0^{T_0} I(t)t\,dt$$

and total energy is calculated as

$$E_s = \int_0^{T_0} I(t)\,dt$$

## 5. RESULT AND DISCUSSION

Figures 1(a) and 1(b) shows the estimated BER values for measured ratio of $E_{bM}/N_{0M}$ for 1.5 kHz and 3 kHz respectively. Standard theoretical curve for FSK in a non fading additive white Gaussian noise (AWGN) is marked in blue line. Zero BER values estimated from the current experiment are seen on x-axis. Here higher BER for 1.5 kHz compared to 3 kHz is noticed and mostly lower BER belong to deepest hydrophone.

In Fig. 2, each vertical bar represents variation observed within 10 pings of each hydrophone and such bars are plotted as a group for each range. In each bar, the marker shows the mean value. Even though there is a difference in time spread within each group, 1.5 kHz at 1600 m and 3 kHz at 3.5 km and 4.7 km show little variation with respect to depth. In this geometry at this location, during the time of transmission, result shows for a low frequency 1.5 kHz is less affected at shorter range of 1600 m and higher frequency 3 kHz is less affected at longer ranges of 3.4 km and 4.7 km. It can also be noticed that at far ranges the deeper hydrophone error rates are less. This is evident in BER plots in Fig. 1.

BER percentage errors are included in Table 1. Here -* denotes no transmission and hence no BER value. It is estimated for all the bits send for that range in that frequency. Low BER rate discussed with Fig. 1 are also noticed in Table 1 for 3 kHz. In the case of 1.5 kHz lower rate of 0.41 per cent are

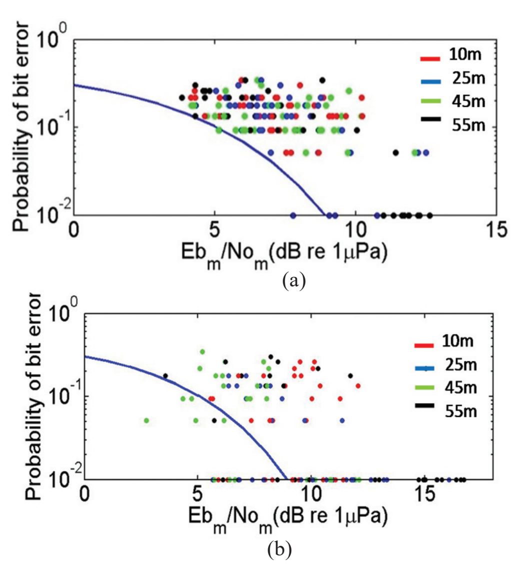
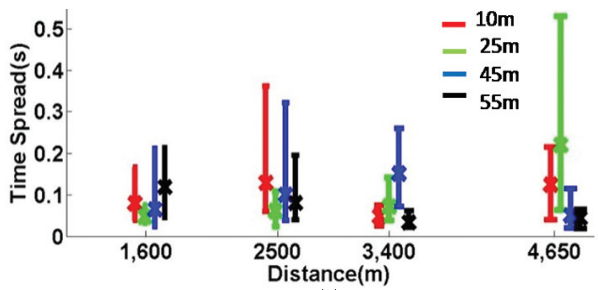
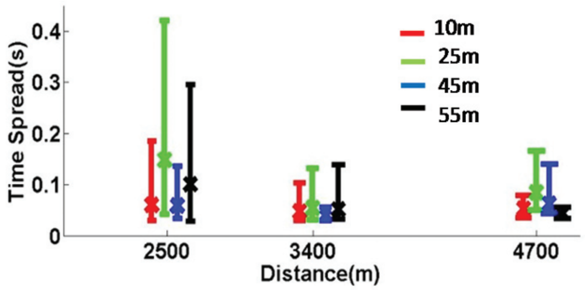



**Figure 1. BER of FSK signals at (a) 1.5 kHz (b) 3 kHz.**



(a)



(b)

**Figure 2. Estimated Time spread at different ranges for (a) 1.5 kHz and (b) 3 kHz.**

observed at 4700 m range at 55 m, while for 3 kHz half of the BER values are lesser than 2.5 per cent. Even though higher spread values are noted for 25 m depth hydrophone in Fig. 2, it can be noticed that the mean value doesn't change much from other hydrophone values. The minimum spread value and less difference between time spread values are seen at 3 km and 4.7 km ranges. Presence of steep duct observed just above the projector depth of 10 m is observed at these two ranges as shown in Fig. 3. The presence of this duct favoured ray bending and thus less interaction with surface for the transmitted signals at ranges 3km and 4.7 km compared to other ranges.

**Table 1. BER with range and frequency**

| Depth (m) | Range (m) | BER percentage | |
|---|---|---|---|
| | | 1.5 kHz | 3 kHz |
| 10 | 1500 | 15 | -* |
| | 2500 | 14.5 | 15.8 |
| | 3400 | 13.7 | 2.5 |
| | 4700 | 16.6 | 6.25 |
| 25 | 1500 | 4.1 | -* |
| | 2500 | 15.8 | 10.4 |
| | 3400 | 22.9 | 0.4 |
| | 4700 | 12.0 | 0.4 |
| 45 | 1500 | 12.0 | -* |
| | 2500 | 15.8 | 11.6 |
| | 3400 | 10.8 | 2.08 |
| | 4700 | 15.4 | 11.2 |
| 55 | 1500 | 19.1 | -* |
| | 2500 | 15.4 | 19.5 |
| | 3400 | 17.9 | 2.08 |
| | 4700 | 0.41 | 0 |

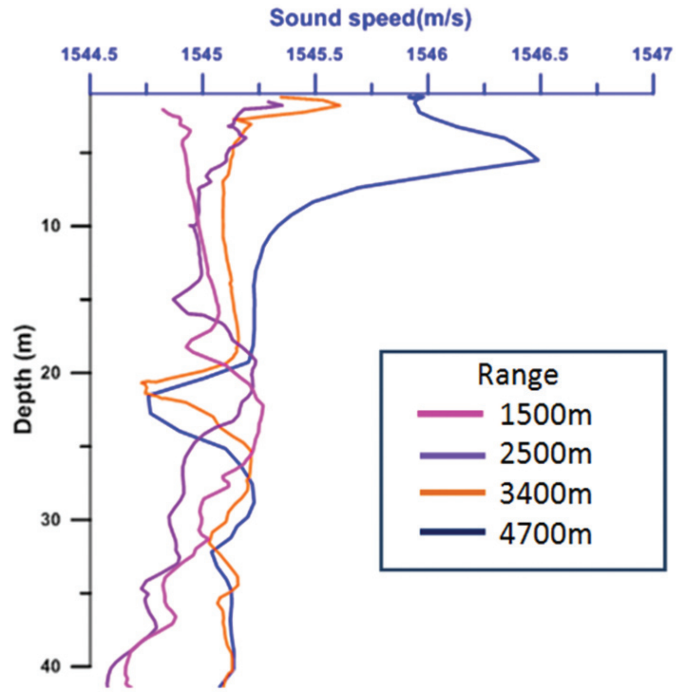



**Figure 3. Sound speed profile for different ranges.**

From M-sequence channel delay spread plotted for range of 3400 m in Fig 4. It shows 1.5 kHz has delay spread of approximately 40 ms and 3 kHz has 10 ms. 1.5 kHz has more spread than the one symbol duration (10 ms) and it more creates inter symbol interference than 3kHz.so we can observe more BER for 1.5 kHz than 3 kHz in Table 1.

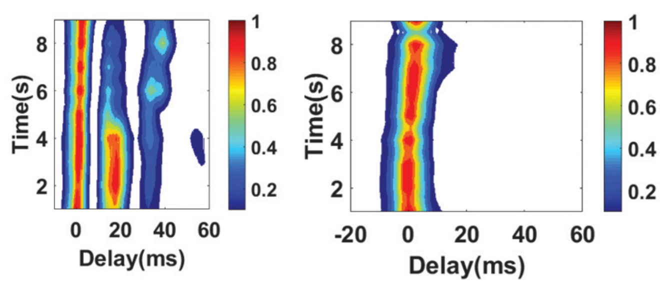



**Figure 4. Delay spread of 3 kHz signal and 1.5 kHz signal.**

## 6. CONCLUSIONS

The experiment has given an estimate on the reliability of acoustic communication links which can be established in real shallow ocean environment. At a data rate of 100 bps, the observed BER was as high as 22.9 per cent at a range of 3400 m and hydrophone depths of 25 m. But at the same depth, the BER was observed to be lower when the range was increased to 4700 m. This clearly is indicative of the massive role played by the sound-speed profile and multipath propagation in shallow waters. It was discussed that sound speed profile and resultant multipath propagation also explains the observation that, on the given day, the best performance was observed at a range of 4700 m when the hydrophones are at a depth of 55 m, while at shorter ranges and same depth, the performance was significantly lower. The time spread of symbols was estimated at different frequency-range-depth combinations and compared with BER. Here channel sound speed structure due to the prevailing thermocline conditions takes the lead role in establishing the link. So the key parameters for better performance are related to the source/ receiver geometry and the oceanography.

Accurate modelling allows the results to be generalised to other sites and environmental conditions, and it can be used in setting up acoustic communication link by determining optimal source/receiver placement. Further experiments under different environmental conditions need to be conducted to see the variability in the reliability of acoustic communication links.

## REFERENCES


1. Stojanovic, M. Acoustic underwater communication. *In* Encyclopedia of telecommunication. John Wiley and Sons, 2003.
   doi: 10.1002/0471219282.eot110
2. Beatrice, Tomasi; Giovanni, Zappa; Kim, McCoy; Paolo, Casari; & Michele, Zorzi. Experimental Study of the space-time properties of acoustic channels for underwater communications. *IEEE OCEANS*, 2010.
   doi: 10.1109/oceanssyd.2010.5603667
3. Nair, Nimmi R. & Roshen, Jacob. Observed spectral broadening of acoustic pulse in an underwater channel. *SYMBOL IEEE Ocean Eng.,* 2013.
   doi: 10.1109/ SYMPOL.2013.6701934
4. Kilfoyle, D.B. & Baggeroer, A.B. The state of the art in underwater acoustic telemetry. *IEEE J. Ocean. Eng.*, 2000, **25**, 4–27.
   doi: 10.1109/48.820733
5. Martin, Siderius; Michael, B. Porter; Paul, Hursky & Vincent, McDonald. The Kauai ExGroup.; Effects of ocean thermocline variability on noncoherent underwater acoustic communications. *In* JASA, 2007, pp. 1895–1908.
6. Van, Walree P.A.; Tegowski, J.; Laban, C. & Simons, D.G. Acoustic seafloor discrimination with echo shape parameters: A comparison with the ground truth. *Continental Shelf Res.,* 2005, **25**(18), 2273–2293.
   doi: 10.1016/j.csr.2005.09.002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