Performance Evaluation of Spread Spectrum Communication System in some Key Locations of North Western Arabian Sea

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Underwater acoustic communications, Arabian Sea, channels, Direct-Sequence, Spread-Spectrum

ABSTRACT

Multi-path interference due to boundary reflection and variation of sound speed profile in underwater acoustic channel pose a major barrier to dependable underwater acoustic communications. Based on actual data of northwestern Arabian Sea, multipath impulse response profiles of the area were obtained previously. These channel models are used in spread spectrum communication simulation described in this paper. The transmitted signals, which consist of frames of multiple spreading sequences, are modulated using coherent phase shift keying. The use of multiple pseudo noise sequences (PN) in a single frame allows one to achieve robust communication with a relatively simple receiver structure as compared to traditional single spreading sequence approach. This long code multiple sequence approach also helps in realizing low probability of intercept(LPI) communication. On the receiver side, a rake type receiver collects the energy present in multiple propagation paths after synchronization and Doppler compensation. Channel estimation necessary for the correct working of rake receiver is done together with a Doppler tracking that allows an adaptation to the instantaneous shift. The performance of underwater acoustic communication scheme has been evaluated by simulation. Bit error rate (BER) has been used as a performance metric and effects of different channels, types of noises, data rates, chip rates etc. have been evaluated. The results indicate that such communication systems overcome multipath channel distortion and can perform at low signal to noise ratio. This work can be used as a lead for the practical design of underwater acoustic DSSS communication/telemetry system for this area.

تقييم الأداء لنظام اتصالات الطيف المنتشر في بعض المواقع الرئيسية لشمال غرب بحر العرب

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الكلمات الدالة

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المُستلخص

يشكل التداخل متعدد المسار بسبب انعكاس الحدود وتغيرات سرعة الصوت في القنوات الصوتية تحت الماء تحديا كبيرا على اعتمادية الاتصالات الصوتية تحت الماء. استناداً على بيانات فعليه لشمال غرب بحر العرب، تم الحصول مسبقا على استجابة نبضة المسار المتعدد للبحر. أما نماذج هذه القناة فقد تم استخدامها لمحاكاة نظام اتصالات الطيف المنتشر الموصوف في هذه الورقة. تم نمذجة الإشارات المرسلة والتي تحوى إطارات التسلسلات المتعدد باستخدام تبديل إزاحة الطور المنسجم. يسمحُ استخدام تسلسلات الضجيج الزائف في إطار وحيد باستخدام اتصالات متينة ذات بنيه مستقبل بسيط نسبياً، وذلك إذا ما تم مقارنتها بطرق تسلسل الانتشار الوحيد التقليدية. تساعد طريقة التسلسل الوحيد المتعدد طويلة الرمز أيضا على تحقيق اتصالات آمنه. يعمل طرف الاستقبال مستقبل من النوع الجامع على جمع الطاقة الموجودة عند مسارات الانتشار المتعدد وذلك بعد التزامن وتعويض دوبلر. تم عمل تقدير القناة من اجل مستقبلاً مجمعاً ويعمل صحيحاً بجانب تتبع دوبلر والذي يتأقلم مع الإزاحة اللحظية. استخدمت المحاكاة لتقييم أداء طريقة الاتصالات الصوتية تحت الماء، حيث تم تقييم تأثيرات مختلف القنوات، وأنواع الضجيج، ومعدلات البيانات، و معدلات بت تسلسلات الانتشار، ...الخ. كما أعتمد معدل خطأ البت كمقياس أداء. أوضحت النتائج تغلب مثل هكذا أنظمة الاتصالات على تشويه القناة متعدد المسار ويمكن أن تعمل عند نسبة إشارة إلى ضجيج منخفضة. يمكن استخدام هذا العمل كموجّه لتصميم عملي لأنظمة الاتصالات الصوتية تحت الماء والقياس عن بعد الخاص بها.

Introduction

Underwater acoustic communication is a key enabling technology for ever-increasing requirement of ocean exploitation. There has been a growing interest in the underwater acoustic communications in various application areas such as telemetry, remote control, speech, or image transmission etc. One way of establishing communication between two remote underwater sites is to connect a receiver and a transmitter with a cable. This solution has several disadvantages when one is attempting underwater communication: It is expensive, maintenance and repair is difficult, and the drag from the cable can be a problem if one of the platforms is small and mobile (e.g., an autonomous vehicle). Another way is to use the wireless communication to propagate the signal containing information. Electro-magnetic waves are used for this purpose in air and in space, but they propagate poorly in water (Waite, 2002), and the attenuation is 40dB/km for light with frequencies in the blue-green region where an attenuation minimum exists (Shifrin, 1983;Dyer, 1995). At very low frequencies, acoustic waves are able to propagate in the ocean over distances extending to several hundreds of kilometers, and even at 20 kHz the attenuation is only 2-3 dB/km. The attenuation of acoustic waves is roughly proportional to the square of the frequency (Dyer, 1995). Therefore using acoustics for underwater communications is a preferred choice.

Spread spectrum communication demonstrates its potential as an important tool in underwater acoustic communications for the applications requiring utilization of full available bandwidth and networking of various sensors (Freitag *et al,* 2001). Direct-sequence spread spectrum signaling uses phase coherent signals, where the information symbols are coded/multiplied with a code sequence (Proakis, 2001). The signals are processed at the receiver using the code sequence as a matched filter to extract the information symbols (Stojanovic *et al,* 1989; Sozer *et al,* 1999).

There are two main advantages of DSSS signals. First advantage is possibility of multiple access communications between the different users using different code sequences that are almost orthogonal to each other (Tsimenidis *et al,* 2001). The other main advantage that this technique presents is its ability to perform LPI/LPD communications due to use of low signal levels. In the multiple access communication, the focus is on separation of user messages by mutual interference suppression. This is achieved by assigning different spreading codes to different users that have very small cross-correlation. For the latter, the focus is on the signal enhancement for the intended receiver using the processing gain of the matched filter.

The performance of underwater acoustic communication systems is dependent upon channel characteristics including multipath, spatial coherence , temporal coherence, Doppler effects and ambient noise. Multipath propagation is one of the significant sources that degrade the underwater acoustic communication system performance (Baggeroer, 1984 ; Kilfoyle & Baggeroer, 2000). In the DSSS communications inter chip and inter symbol interference caused by multipath arrivals is a major source of error. Many processing algorithms including Rake receiver (Sozer *et al,* 1999), passive-phase conjugation(Zhang & Dong, 2012) ,decision feedback equalizer (DFE) and extended Kalman filter based estimator have been used to achieve precise symbol synchronization and channel equalization with different degrees of success in different channels (Iltis & Fuxjaeger, 1991; Stojanovic & Freitag, 2000; Blackmon *et al,* 2002; Freitag & Stojanovic, 2004).

In order to mitigate the complications mentioned above, we chose multiple sequence direct sequence spread spectrum with PSK modulation. The aim is to develop a low complexity low data rate communication scheme. The use of multiple pseudo noise sequences allows one to reduce narrowband interference arising from other users and self-interference due to multipath propagation paths. The solution employs phase coherent modulation and it is based on the assumption that the channel does not vary significantly during one transmission frame interval. On the receiver side, we perform Doppler compensation, synchronization and channel estimation using synchronization sub-frames. After this, a rake receiver combines the multipath energy to exploit the multipath diversity. Use of synchronization signals usually reveals the existences of the communication signal in the environment so the probability of detection and intercept increases. The synchronization sub-frames described in this scheme are also DSSS signals that cannot be distinguished from the information carrying signals without prior knowledge of the spreading sequences. Hence, this scheme preserves the desired low probability of detection and intercept (LPI/LPD) characteristics of spread spectrum signals. In this paper, we do Multipath combining via rake type structure. Channel estimates are achieved using synchronization sequences. In this way, satisfactory error rates at low SNR levels are possible.

This paper is organized as follows. Test locations are described in the second section. The third section describes BPSK-DSSS background along with transmitter and receiver used for the DSSS communication system in this paper. Transmitter frame structure is also described in this section. Results of performance analysis are provided in section that follows and the conclusions are given in the last section.

Material and Methods

(1) Test Locations

The test locations are chosen from the point of view of the most common topographical features encountered for underwater telemetry deployment. Generally, one finds that the telemetry nodes/ links nearest to shore are located in shallow water with flat bathymetry. At some distance from the shore, continental slope starts and the channel then has sloping bathymetry. After the sloping channels, deep and relatively flat ocean channels are encountered. Because of the above mentioned reason the three test locations mentioned below have been selected and channel multi path response profiles have been obtained .These include:

(a) Shallow water near Karachi port.
(b) The sloping continental shelf near Ormara.
(c) Flat deep sea positions off the coast of Makran.

Some of the details of these can be found in (Gang, Ismail, & Aatiq, 2013)

The first test location is near Ormara, which is an important harbor in the Makran coast and the water depth increases significantly with range. The latitude longitudes of modems are approximately between (25^0 10' North ,64^0 42' East) and (24^0 59' North ,64^0 41.9' East) .The total range between the two points is about 20 km and the depth increases from 10m to 722m approximately.

The second test position is located near the Makran coast. This is a deep and flat channel and the Water depth remains approximately 3400 m. The latitude longitudes of modems are 23^0 53.9' North, 61^0 59.7' East, and 23^0 40' North, 61^0 58.1' East .The total range between the two points is about 25km

The third test position is located near the coast of Karachi, which is the largest coastal city of the area. This is a shallow flat channel. The Water depth remains approximately 120 m. The latitude longitudes of modems are approximately 24^0 32.9' North, 66^0 45' East and 24^0 26.9' North, $66^0$48.7' East .The total range between the two points is about 12.7 km approximately. The test locations are shown in Figure (1,a,b,c).

Figure 1 (a): The 1st Test Location Near Ormara
(25^0 10' North ,64^0 42' East) and (24^0 59' North ,64^0 41.9' East)

Figure 1 (b): The 2nd Test Location Near Makran Coast
(*23^0 53.9' North, 61^0 59.7' East, and 23^0 40' North, 61^0 58.1' East*)

Figure 1 (c): The 3rd Test Location Near the Coast of Karachi
(*24^0 32.9' North, 66^0 45' East and 24^0 26.9' North, $66^0$48.7' East*)

Figure 1, a; b; c: The Chosen Three Test Locations
(a: *Near Ormara*; b: *Makran Coast*; & c: *the Coast of Karachi*)

The Channel response functions are given below in Figures(2-4) . Figure (3) given below represents the multipath spread of the sloping continental shelf channel at Ormara. Here the channel although has a lot of multipath but the depth of the modem is chosen so that the paths combine at that depth and a strong signal is received. Figure(4) is of the flat and deep-water channel response whiles the Figure (2) is of shallow water flat channel response. In all the figures (2, 3 & 4) below, x-axis is the delay time (in millisecond or seconds) and the y-axis represents the observation number of the normalized intensity of the channel multipath response. These show the normalized value of $h(t,\tau)$ in log scale for better dynamic range presentation of the channel. The quantity $20*\log10\ |h(t,\tau)/\max(h(t,\tau))|$ for the channel at the location has been plotted.

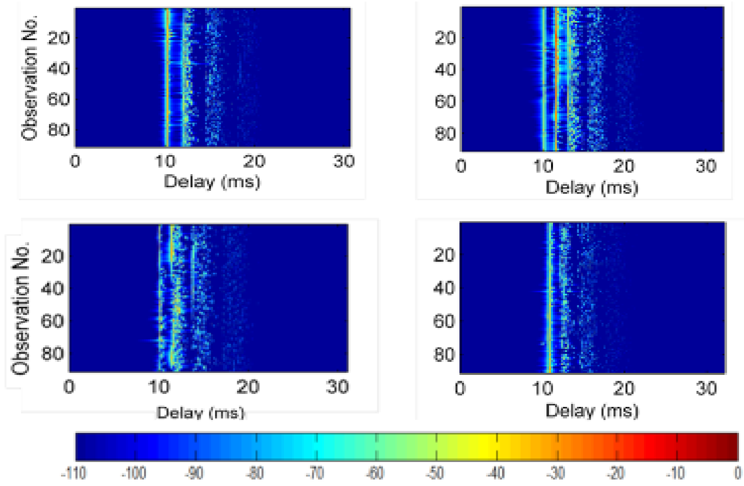


Figure 2: Channel Response Function in
for Karachi Flat and Shallow Sea

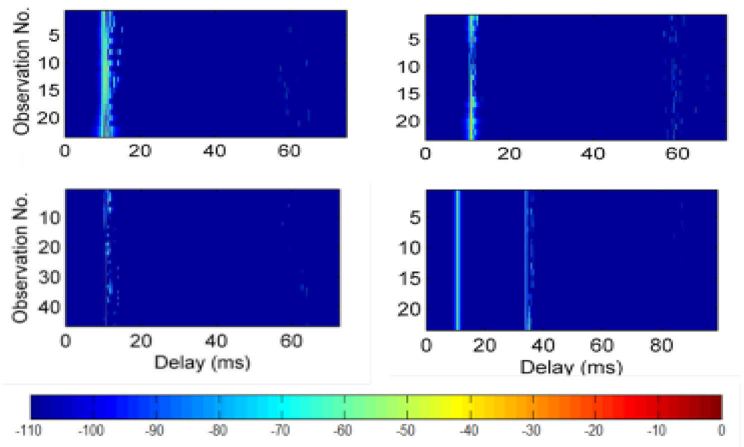


Figure 3: Channel Response Function
for Ormara Sloping Continental Shelf

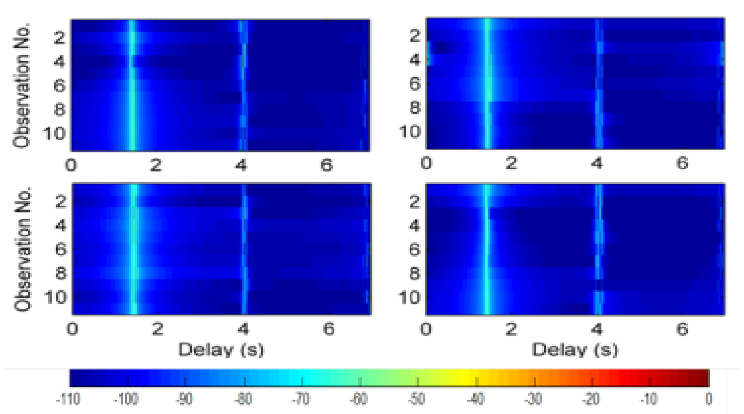


Figure 4: Channel Response Function for
Deep Flat Sea Positions off the Coast Of Makran

(2) Transmitter and Receiver System

This section illustrates the basics calculations of phase-shift-keyed (PSK) direct-sequence spread-spectrum (DSSS) communications in multipath fading environment. The channel model considered here is discrete multipath channel model. We assume that the channel is composed of a finite number of resolvable paths, the channel impulse response can be written in the form;

$h(\tau_L)=\sum a_L(\tau_L)\delta(\tau-\tau_L)$ **(1)**

Hence the received signal consists of L multipath components, with attenuations a_L and delays τ_L. The data signal $b(t)$ is a sequence of rectangular pulses each of duration T whose l^{th} pulse has amplitude b_l, for $lT< t < (l + 1)T$. The data $\{b_l\}$ is a sequence of random variables, whose each element can have a value of +1 or -1 with equal probability. The signal is then spread by the waveform $c\ (t)$.given by;

$c\ (t) = c_i p(t-iT_c)$

where; $iT_c<t < (i+1)T_c$ **(2)**

Where c_i is the binary code spreading sequence and $p(t)$ is a rectangular chip waveform satisfying;

$p(t) = 1 \quad for\ 0 <t<T_c$

$p(t) = 0 \quad otherwise$

If the transmitter power is P , carrier frequency f_c and the phase angle of the PSK modulator is θ. The transmitted spread-spectrum signal $s(t)$ can be expressed as

$s(t) = Re\{u(t)exp(j\ 2\pi f_c\ t)\}$ **(3)**

where; $u(t) = \sqrt{2Pb(t)c(t)exp(j\theta)}$

The output signal $y(t)$ produced by the multipath channel consists of L paths and may be modeled as the sum of attenuated, phase-shifted and delayed versions of the input signal $s(t)$.Thus it may be expressed as;

$$y(t) = \sum_{n=0}^{L} Re\{g_n u(t-\tau_n)exp(j2\pi f_c\ (\ t-\tau_n)\} \quad \textbf{(4)}$$

Where the complex gain coefficients g_n, are given as;

$g_n= A_n exp(j\theta_n)$ for $n =1\ to\ L$ **(5)**

for the n^{th} delayed path. Here A_n and θ_n represent the attenuation and phase shift incurred from the multiple paths while τ_n is the n^{th} path delay relative to the first path. The variables τ_n , A_n and θ_n are usually mutually independent random vectors.

The output of the channel $y(t)$ is combined with additive zero mean white Gaussian noise $n_o(t)$ having standard deviation $N_o/2$ to produce the received signal r(t).

r(t)= $y(t)$ +no(t) **(6)**

The receiver correlates this signal with the modulated code sequence given by (√2/T) c(t) $Cos(2\pi f_c t)$ and integrates over the N- bit duration which is equal to the length of the sync sequence in bits. The receiver output becomes sequence in bits. The receiver output becomes;

$$Z= \sqrt{\frac{2}{T}}\int_0^{NT} r(t)c(t)\cos(2\pi f_c t)dt \quad \textbf{(7)}$$

On substituting the expression for the r(t) this becomes;

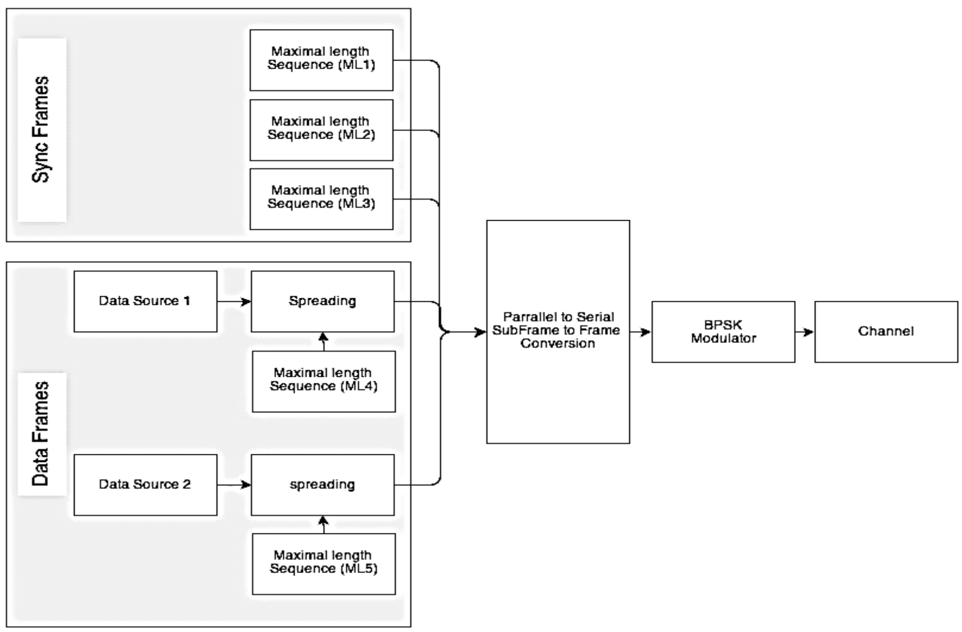
$$Z=\sqrt{\frac{2}{T}}[\int^{NT} [\sum_{n=0}^{L} Re\{Anexp(j\theta n)u(t-\tau_n)exp(j\ 2\pi f_c(t-\tau_n)\}$$

$$+ n_o(t)] * c(t)\cos(2\pi f_c t)]dt \quad \textbf{(8)}$$

This is compared with some threshold to determine the code acquisition and hence the demodulation and dispreading of the signal being received is done. It is pertinent to mention that in this paper three sync sequences are used without data modulation i.e. {b(t)}={ 1} for all t. The output for these is used for calculation of start data marker. The transmitter and receiver systems that have been used in this are described as follows

(2.1) Transmitter

The transmitter system is very simple. The system starts with a data source sequence, which is spread by a chipping sequence. The chipping sequences being used are long code sequences (Karkkainen, 1995). Both m-sequences of 255 length and gold sequences of 2047 length can be used in this simulation. For a fixed channel length, the gold sequence will require faster chipping rate and hence more bandwidth. Five sequences are used in each transmitted frame. There are two sequences being used for spreading the data sub-frames. The synchronization sub-frames use three remaining sequences .In applications that require low probability of intercept, initial synchronization must he acquired without the aid of special signal preambles. In other words, acquisition must be performed directly on the DSSS signal, which, for the time allocated to acquisition, is modulated using all-ones data stream (Stojanovic & Freitag, 2003).These sequences are not modulated by data. Appending sync sequences has been demonstrated previously in literature but the structure is very different and uses only one part of one sequence with silence (Sozer *et al,* 1999). This essentially lowers the overall energy in the correlator output at receiver and hence the sync is lost at comparatively higher SNR (Duke, 2002). Also the extended multipath channel can possibly corrupt the sync as only a portion of the original long code is used as sync. The transmitter frame is then sent to BPSK modulator and finally to the multipath channel. The decision to utilize phase coherent modulation is because of the fact that these provide efficient use of the limited bandwidth available in underwater channels. Figure (5) shows the block diagram of the transmitter section used in this paper as well as the transmitter frame. The details of the system can be referred to in (Gang *et al* , 2013)



Transmission Frame				
Sync Sub Frame C1	Sync Sub Frame C2	Sync Sub Frame C3	Data sub frame D1	Data sub frame D2
Maximal Length Sequence ML1	Maximal Length Sequence ML2	Maximal Length Sequence ML3	Maximal Length Sequence ML4	Maximal Length Sequence ML5
256 Chips	256 Chips	256 Chips	8 bits Data on 256 Chips	8 bits Data on 256 Chips

Figure 5: Transmitter Block Diagram and Transmission Frame

(2.2) Receiver

The receiver section mainly comprises of two sub-sections. The first deals with the sync sub-frame and has the job of finding the channel response for the frame .This also locates the start and end of the data for the data sub-frames. The multipath indexes are found by comparing the received versions of the modulated sequences. The received sync sequences in modulated form are correlated with the stored modulated sync sequences and the correlation vectors are stored for comparison.

Firstly, the correlation vectors for sync sequences are sorted in descending order and then the indexes as well as values of the first n taps are selected. These values are then compared for each sync sequence. The index of the sync sequence that has maximum value is selected as a marker for start and end data in the data frame as we know the position of the data frames with respect to sync frames from our knowledge of the transmitted frame. In this way we ensure that the unambiguous maxima of the correlation is captured for the start data and end data calculation in the data de-spreading operation that follows in the receiver. As we are using more than one sync sub-frame, so the acquisition process becomes more robust.

After the acquisition has taken place, we demodulate the data sub-frames after combining the paths with appropriate weights and phases. This is done for utilizing the multipath diversity found in the channel and increasing the SNR of the signal being demodulated.

Finally, the de-spread operation takes place and transmitted data is recovered. The flow chart of the receiver is given in the figure (6a) while an example sync frame correlation output signal is given in figure (6b). Figure (6c) and figure (6d) give the estimate of the channels given by the receiver (test location1and 3) at -20 dB SNR.

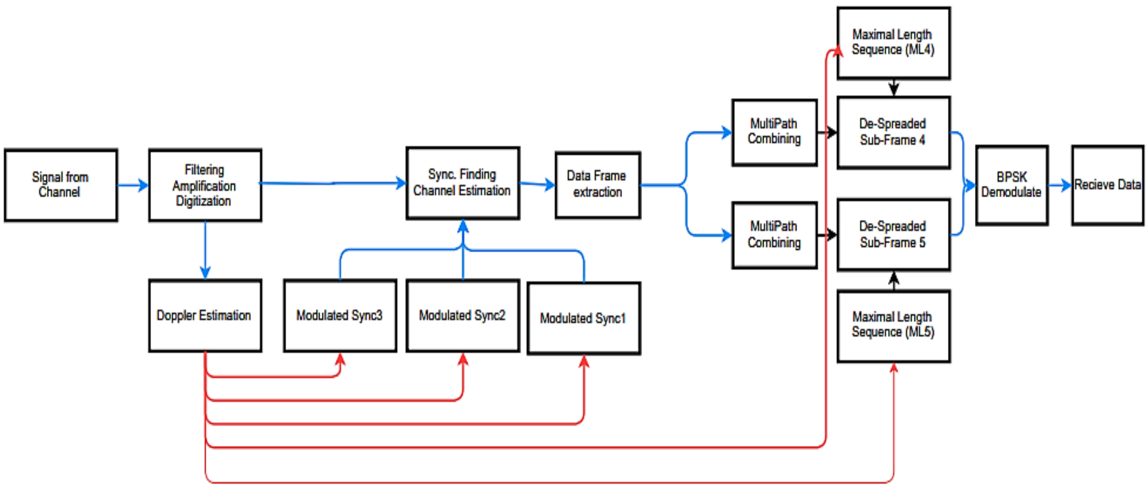


Figure 6 (a): Receiver Flow Chart

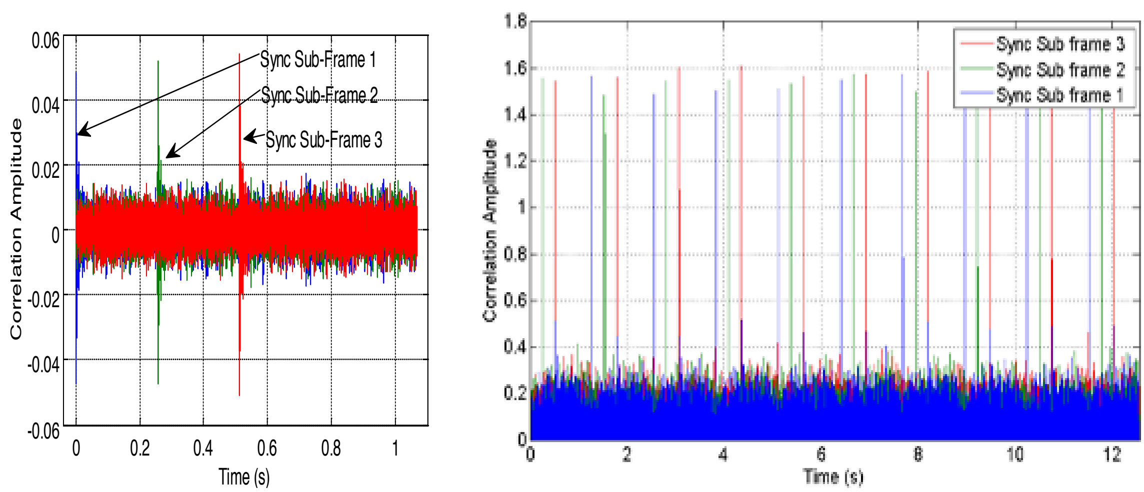


Figure 6 (b): Sync Sub-frame Correlation Out put for (left) One Frame and (right) Multiple Frames

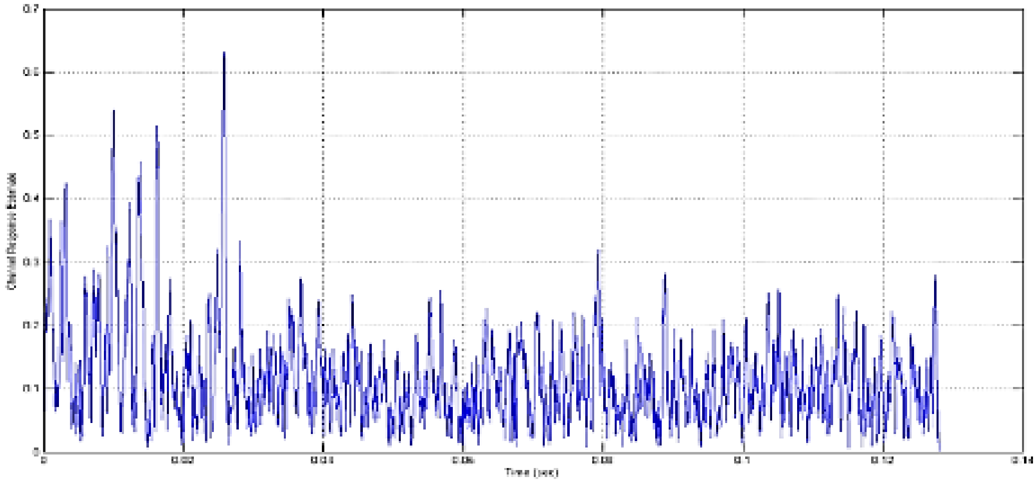


Figure 6 (c): Channel Response Estimate at Test Location 1 (SNR<0)

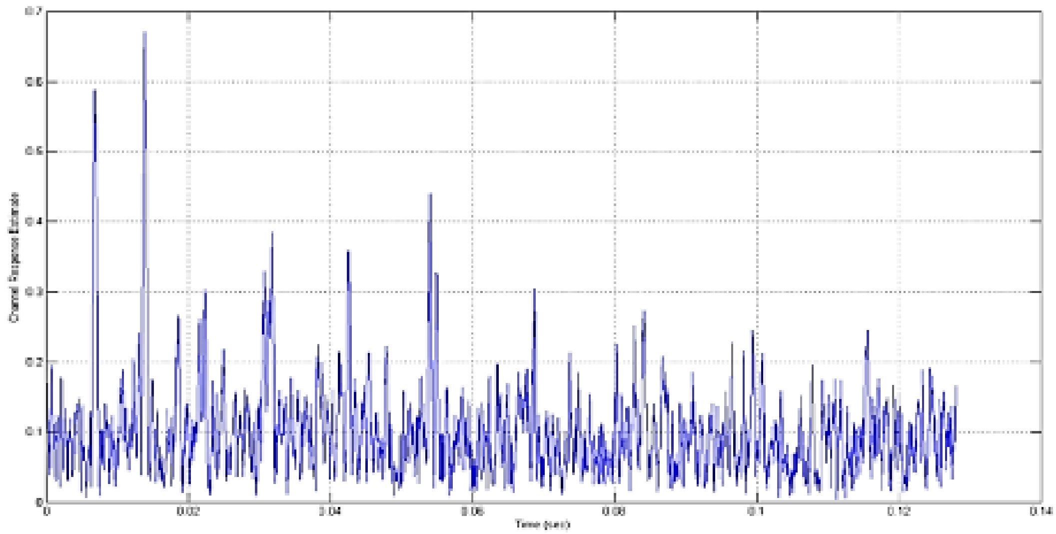


Figure 6 (d): Channel Response Estimate at Test Location 3 (SNR<0)

Figure 6, a; b; c; d: The Flow Charts of the Receiver & the Estimate of the Channels Given by the Receiver

Results and Discussion

Many results have been obtained by simulation for the channels mentioned above. The main performance metric has been bit error rate. SNR, channel type, chip rate, bit rate, and types of the additive noise present in the environment influence the bit error rate. The effects of using different code sequences have also been evaluated. The gold 2047 and maximal length 255 have been used for this purpose. The loss of synchronization problem at low SNR has been identified also for the case of approximately SNR < -20 to -18 dB for the m-255 sequence case. In the case of gold 2047 sequence the loss of synchronization occurs at much lower SNR (typically < -35 dB) at the cost of increased processing time and bandwidth. When the synchronization cannot be achieved consistently, BER is high. It is only above -15 dB SNR in the case of m-255 sequence and -30 dB SNR in the gold 2047 sequences that we lock onto the data in signal at which point the error rate drops quickly. These are described in details in the preceding paragraphs. The acquisition frame statistics for the case of m-255 sequence can be estimated from the graphs in figure (7) and figure (8) .

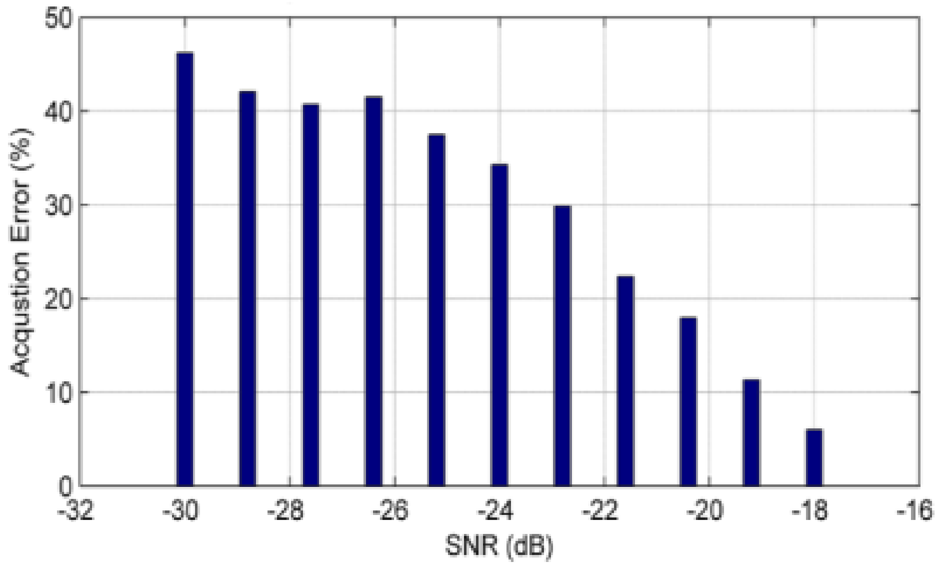


Figure 7: Errors in Acquisition of Sync for Data Sub-frame 1

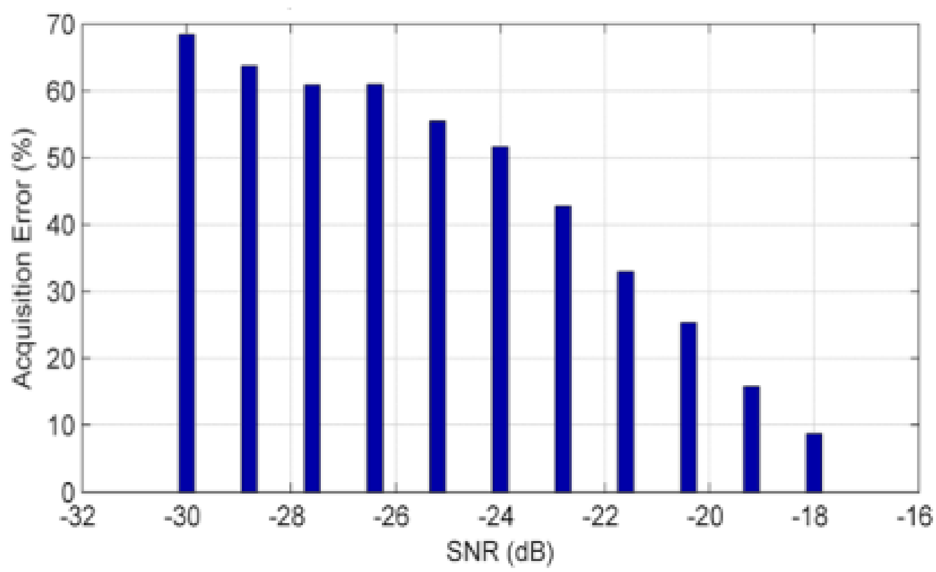


Figure 8: Errors in Acquisition of Sync for Data Sub-frame 2

(1) Bit Error Rate of Channels with SNR

Bit Error Rate (BER) of the proposed scheme is evaluated at different SNR for the m-255 sequence. Figure (9) tells us the efficiency of the scheme in combating the detrimental effects of the multipath channel for the underwater acoustic communication. 16 bits per frame are used in this simulation at a chip rate of 1 KHz and the sampling frequency is kept at 48 kHz. Modulator carrier frequency is 7 kHz. From figure (9), it can be seen that for the deep flat channels the BER is less then corresponding shallow water channels. This trend continues for the results given in next subsections also.

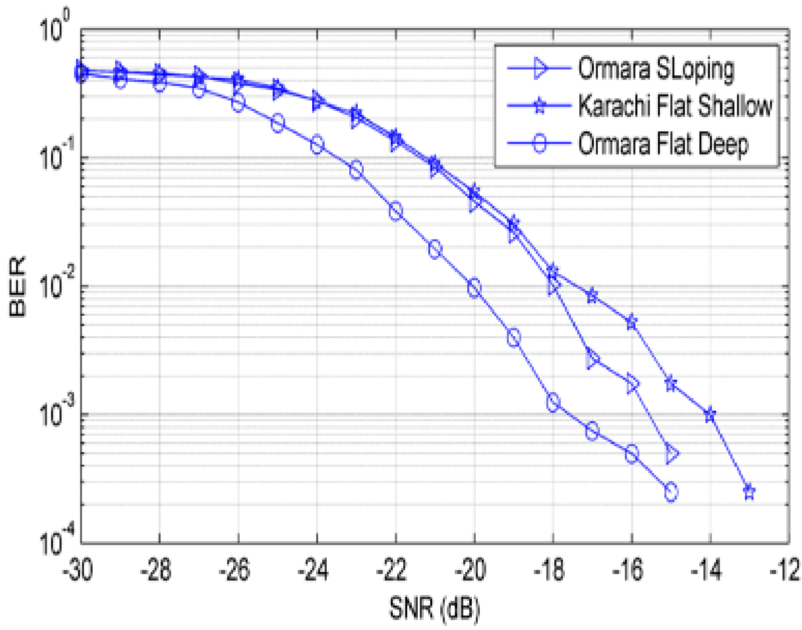


Figure 9: BER of Channels at Different SNR

(2) Effect of Data Rate

In DSSS, the spreading of the signal bandwidth occurs at baseband by multiplying the baseband data pulses with a chipping sequence. This chipping sequence is a pseudo-random binary waveform with a pulse duration of *T* and a chipping rate of $R_C = 1/T_C$. Each pulse is called a chip with chip interval T_C. For a given information symbol of duration T_S and a symbol rate of $R_S = 1/T_S$, the duration of each chip is much less than the pulse length of the information symbol (i.e., $T_S >> T_C$) and R_C is much higher than the symbol rate R_S. Usually the numbers of chips per symbol are an integer number. The ratio of chips to symbols is called the processing gain *k*. Here $k = R_C/R_S$. The chip rate is kept constant at 1 kHz and the data length is increased from 8 bits to 32 bits per data sub-frame for simulating the effect of the reduced chip per bit. This, in other words, is an effort to increase the data rate while keeping the chip rate constant hence reducing the processing gain of the system. The BER of the scheme for this scenario has been given in the figure (10).

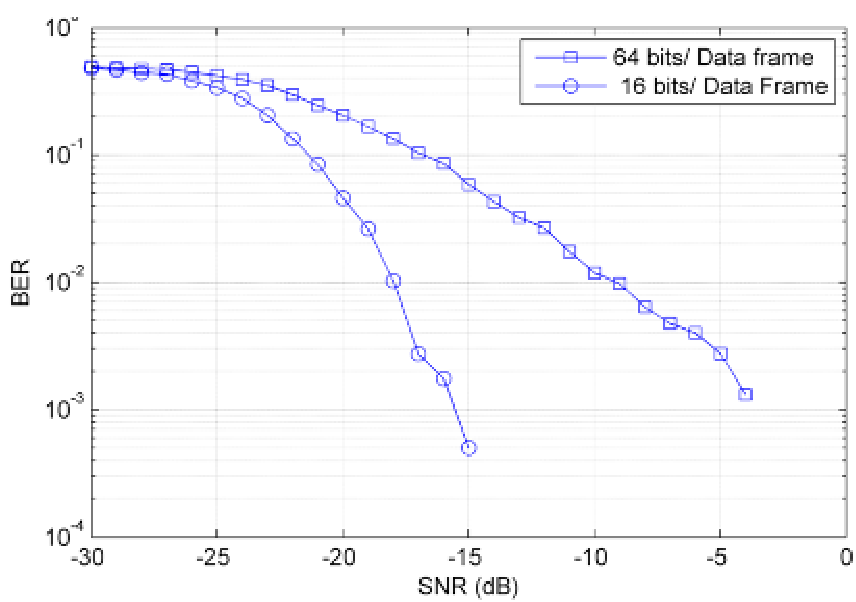


Figure 10: Effect of Increasing Bits per Chip

(3) Effects of Multipath Combining

The multipath combining has been simulated and its effect on overall BER of the scheme is given in figure (11).

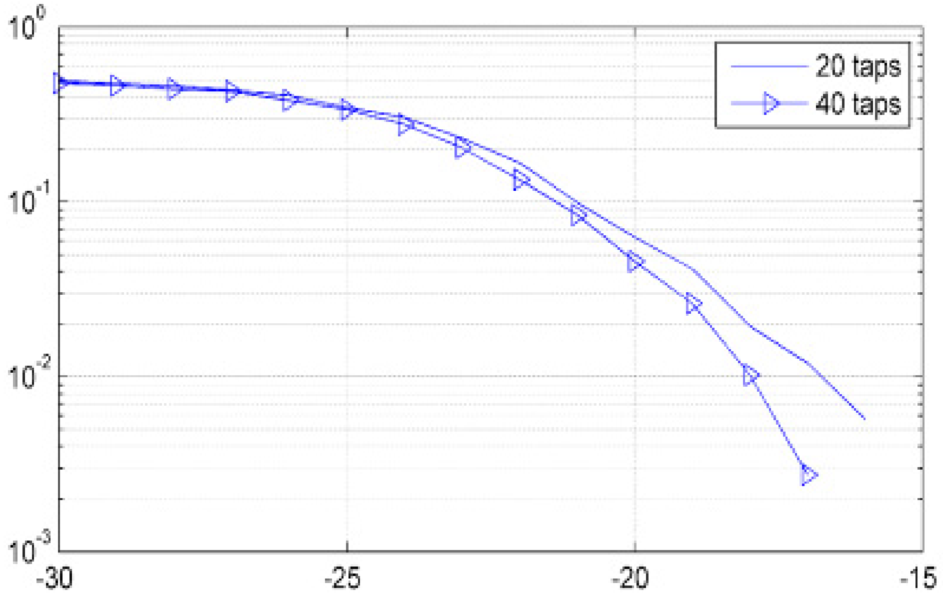


Figure 11: Effect of Number of Multipath Taps on BER

As more and more signals are combined after amplitude and phase correction, the overall SNR at the input of the demodulator increases and hence the bit error decreases. The limit to this is reached when the tap weights become too little. At that stage, the noise starts to add up and hence no more increase in SNR by multipath combining is possible beyond this limit. Multiple runs of the simulation reveal that limit to be around 70 taps for the sloping channel of Ormara.

(4) Effect of AWGN, Colored and Actual Measured Noises

The additive distortion in the form of noise is always present in any communication system. This corrupts the data and hence the error rate is increased. In this simulation, three kinds of Noises are introduced with varying SNR for performance evaluation of the scheme. The first is the flat Gaussian noise. Then in the second case, the noise is filtered to make it colored and hence it resembles the actual noise present in the oceans. Figure (12) shows the spectrum of the colored noise.

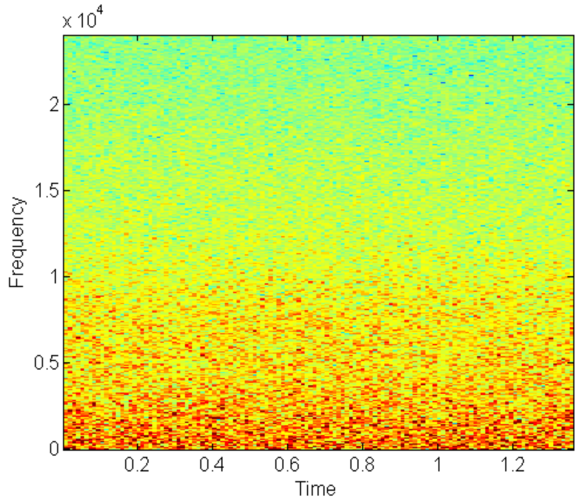


Figure 12: Spectrum of Simulated Ocean Noise

The third type of noise is actual measured ambient noise using a towed array of 32 hydrophones. This array was drifting, so some amount of flow noise along with manmade and marine noise is also present as seen in Figure (13).

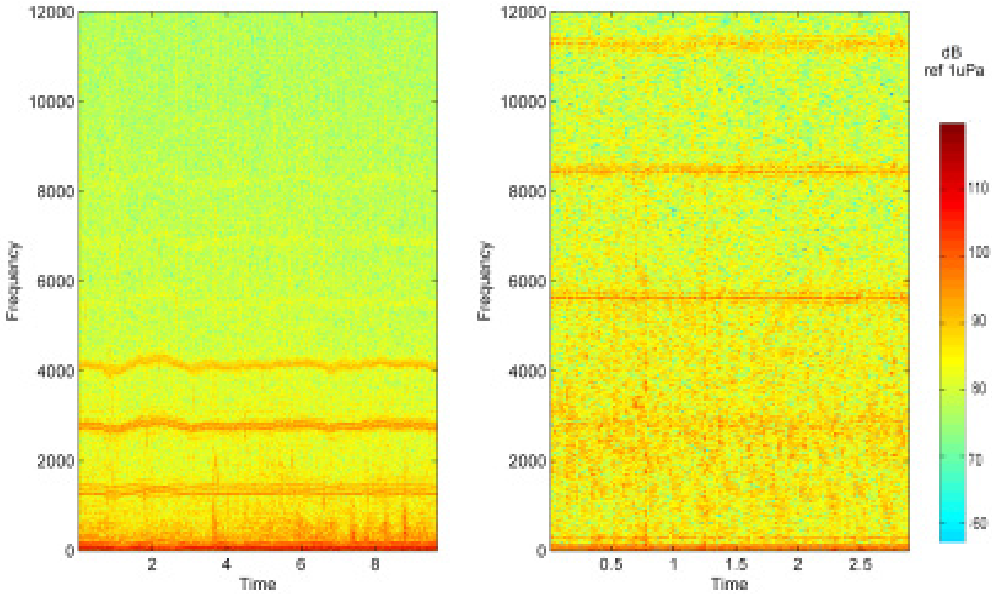


Figure 13: Spectrum of Measured Ambient Noise

The noise also contains some strong narrow band noises, which act as narrow band jammers. The method adopted for introducing this type of noise into the simulation is similar to that described in (Yang & Yang, 2008).The results presented in Figure (14) show that the noise type affects the performance of the scheme and the performance margin from the AWGN can be estimated.

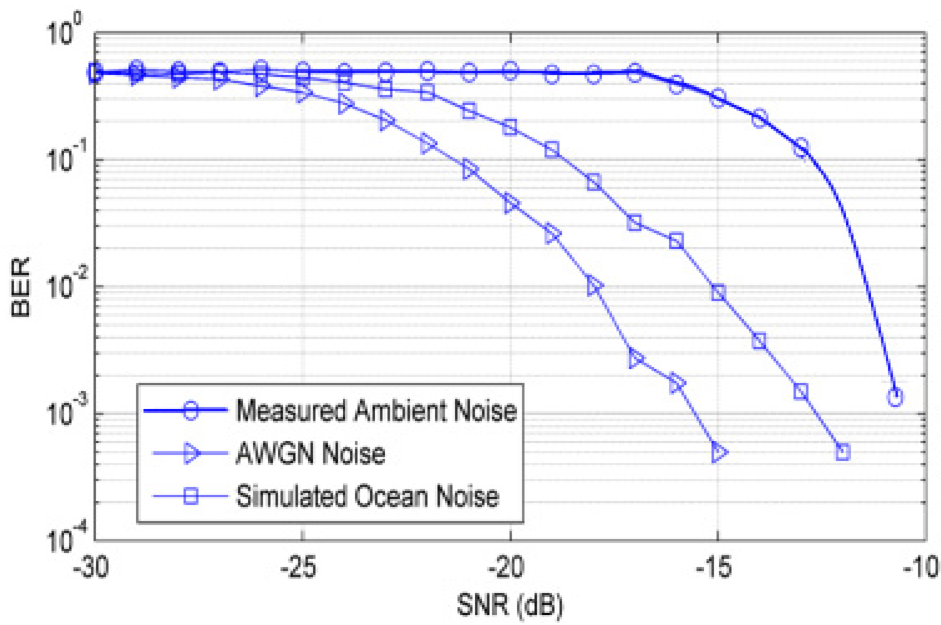


Figure 14: BER for Different Ambient Noise Type

Conclusions

In this paper, performance evaluation of a DSSS communication scheme has been done for multipath underwater acoustic channels of some important locations of the northwestern Arabian Sea using simulation. The simulation uses actual/measured sea environmental parameters (such as salinity, temperature, pressure, ambient noise, etc.) as input hence the results of the simulation should be very close to that of the actual environment. The results indicate the feasibility of the proposed communication scheme for that particular area.

This scheme is primarily intended for channel tolerant low data rates underwater communications. The results indicate that the error rate for a deep flat channel at Ormara is lower than that of the flat and sloping shallow water channels at Ormara and Karachi. This is mainly because of its relatively sparse and less complicated channel response function. The sensitivity of error rates with the noise distribution is also examined. The effect of increasing bit rate for a given bandwidth has been investigated. One of the findings of the work is the identification of the loss of synchronization at very low SNR. This work can be used as an input to a more detailed design phase for developing a practical acoustic communication system for that area of the sea. This DSSS scheme can also be used for multiple modems operating together in a CDMA network for enhanced coverage. In the case of point-to-point communication, more data can be transmitted simultaneously by use of more codes and data rate can be improved.

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