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Research Article

A Simulation Study on Use of Noise Signals for Underwater Communication

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Abstract: Underwater communication in sea environment is very challenging due to extended multipath propagation, dispersion and fading effects. Communication system, in which noise-like signals are used as an information carrier are investigated in this study. The process of cross correlation at the receiver is used for detection of transmitted information. This feature achieves Low Probability of Detection and Low Probability of Intercept (LPD/LPI) communications. The communication signals used are also environmentally safer because of their low levels. A method has been devised based on selected set of available noise like sequences to be used with BPSK modulation, although work on this scheme to be used without any carrier is also being carried out. The probability of error in the reception of signals by such system is given as a function of signal-to-noise ratio at the input of the receiver and the size of signal constellations. Bit error rate is also evaluated for different kinds of noise sequences under the influence of both simulated and actual measured ambient noise at different SNR.

Keywords: Multi-path, noise-like signals, underwater Acoustic communication, underwater communication

INTRODUCTION

The noise-like signals have been used in underwater acoustics mainly because of their simultaneous range and Doppler resolution (Packnold, 2002). These also have been used in acoustic tomography and very long range communications (Kodanev and Zakharov, 1994; Lee and Milica, 2001). Pseudo Noise sequences (PN) are also used for measurement purposes. For example, they have found application in ultrasonic nondestructive testing (Lee and Furgason, 1983; Niederdrank, 1997). The PN sequences have been used for improvement of data acquisition rate in ultrasonic measurement systems (Mayer *et al*., 1990). Usually the main purpose is to improve signal to noise ratio still keeping a good spatial resolution. These sequences are also used in code division multiple access telecommunication systems (Karkkainen, 1991; Stojonivic and Fritag, 2001; Karkkainen, 1995) Some examples of noise like signals are m-sequences (Peterson *et al*., 1995), gold sequences and kasami sequences used in CDMA communications where these are used for multi Access and mitigation of multipath effects. The main problem, met in employment of this type of signals underwater is the difference of channel and transducer parameters for signals used in air telecommunications and underwater systems. Another usage of these noise-like signals is in the DSSS communication which provides jamming resistance, interference suppression and covert communications. In all of these DSSS systems code synchronization of the transmitter and receiver is necessary to achieve low bit error probability. The code synchronization becomes the major obstacle in the reliable communication when the SNR is poor and multipath effects and Doppler shifts are present in the channel. Different mitigations have been proposed in the literature for the code synchronization (El-Tarhuni and Sheikh, 1998; Madhow, 1998; Smith and Miller, 1999) and channel equalization (Capellano, 1997; Kwon and BirdSall, 1991; Stojanovic and Fritag, 2000; Stojanovic *et al*., 1999).

In this study, our objective is to develop a simple receiver algorithm using noise like coded signals for reliable LPI communications in multipath underwater channels without utilizing a DFE or PLL. Coded signals having very low SNR and good cross correlation properties are used to achieve the above-mentioned objective. The code sequences minimize interference between symbols in multipath channels. The cross correlation properties require every code sequence to be almost uncorrelated to any of the remaining code sequences in that set. With this condition, the matched-filter output yields a low side lobe level and thus ensures minimum interference in an environment dominated by multi path propagation. The magnitude of the matched filter output can then be used to determine the symbol sequence. The scheme is tested on different multipath channels through simulation and inferences are drawn from the results. The data rate from such communications is usually not very high as compared to the schemes that operate in positive SNR regime. Thus, the scheme could

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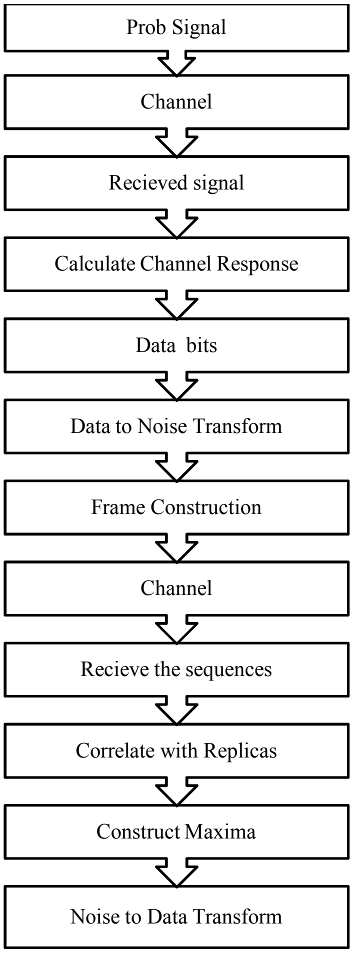

Fig. 1: Signal scheme block diagram

be used for control of non-critical underwater instrumentation.

SIGNALING SCHEME

The scheme starts by sending a probe signal to the environment and then determines the total channel length (T_{ch}) and effective channel length (T_{eff}). Many modeling software available can also be used to determine the channel multipath for the location and environment of the communication scenario. After that the data to noise sequence transformation takes place. In this transformation each data symbol (comprising of adjacent bits) is associated with a noise sequence. This sequence is then appended with AWGN of appropriate length to make the data frame. The length of the appendix is determined by the probe signal in such a way that the total multipath is finished in one frame and frame to frame interference is eliminated .In an another approach the noise sequences are appended from the code set to increase the data rates. As the code sequences are much uncorrelated with each other so the inter-symbol and inter-frame interference is minimized. This frame is sent through the channel and the receiver receives the corrupted signal frame. Correlation with the possible sequences is done at the receiver and a criterion is applied to make the decision about the transmitted noise sequence based on the correlation output. Finally a noise to data transformation is applied to recover the original data. In this scheme the LPI is ensured by randomly changing the code to data transformation using some fixed rules on data length. Simulation of both the frame modulated on some carrier and un-modulated versions have been demonstrated. The results of only modulated frame have been shown in the study. The flow chart of the scheme for the unmodulated transmission is given in the Fig. 1. For the modulation part the modulator and demodulator blocks add up just before and after the channel.

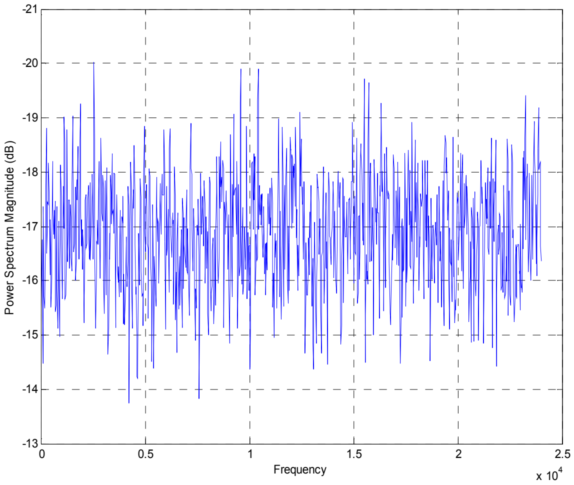

Fig. 2: Typical noise like signal

The signal from the transmitter with very low SNR looks like the Fig. 2.

CODE PARTITIONING

The noise like signals set partitioning can be constructed in many ways .The rule of partitioning is to construct a signal constellation such that the symbols carry as much bits as they can for a given partition. Thus from a chosen set of preferred sequences, which have good minimum mean-square cross-correlation cross-optimal (MSQCC/CO) criteria (Karkkainen, 1991; Karkkainen, 1995) the set is divided into subsets or partitioned. There are two families of the sequences that are used in this demonstration. One is a family of 16 maximal length sequences each sequence having length 255. The other is a family of gold sequences comprising 60 sequences each has a length 2047. Signal constellations can be made for different payload of bits per noise sequence. These are explained in the next subsection.

Case 1: Code partitioning for the M-sequences: The family of m-sequences that has been chosen has 16 members. This means that if we do not make subsets then the signal constellation size remains 16 or 4 bits can be transferred per one noise sequence. If we make 2 subsets of these 16 noise sequences in such a way that there are 8 noise sequences in the first set and 8 in the second set then we can get signal constellation of size 64 using two noises- like sequences at a time. If we partition the sequences in three subsets such that the first contains 8 sequences and the other 2 subsets contain 4 sequences each then also we get the same signal constellation of size 64 using three noises- like sequences at a time. In both the cases the 6 bits are carried by one frame. If further subsets are made by the sequences such that there are four subsets and each subset has four noises like sequences then there are 256 signals in the constellation and hence 8 bits can be transferred by any of the noise like signal in the constellation using the same 16 original MSQCC/CO sequences. If we denote the *ith* m-sequence by *mi* then mathematically some of the subsets can be written as:

Original set = {m1, m2, m3, m4,….. m15, m16}
Bits per frame = 4 Signals/frame = 1
constellation size = 16
subset 1 = {m1, m2, m3, m4, m5, m6, m7, m8}
subset 2 = {m9, m10, m11, m12, m13, m14, m15, m16}
Bits per frame = 6 Signals/frame = 2
constellation size = 64
subset 1 = {m1, m2, m3, m4, m5, m6, m7, m8}
subset 2 = {m9, m10, m11, m12}
subset 3 = {m13, m14, m15, m16}
Bits per frame = 6 Signals/frame = 3
constellation size = 64
subset 1 = {m1, m2, m3, m4}
subset 2 = {m5, m6, m7, m8}
subset 3 = {m9, m10, m11, m12}
subset 4 = {m13, m14, m15, m16}
Bits per frame = 8 Signals/frame = 4
constellation size = 256

One of the possible codes partitioning for the 256 case is illustrated in the Fig. 3.

Each partition of the original sequence generates as set of unique combinations and hence each member in the combination can be associated with a unique number from 0 to 2^k-*1* and hence the corresponding bit sequence where *k* is the bits per frame. The partitioning of the sequences in the subsets increases the bits per frame capacity at the expense of increased length of the frame. The distance metric for such a scheme is not very badly affected by increasing the constellation size as is common in the higher order conventional schemes where the increase in the constellation size reduces the distance metric and hence SNR performance of the communication scheme is decreased. This is because the each member in the constellation is uncorrelated with each other in the subset. And the cross correlation between any two is roughly the same for any other two members. As the frame length increases for the higher bit capacity transmissions the time of the transmission should decrease for a given channel and thus more of the bandwidth will be used in that case. This is in line with the usual DSSS systems where the chip rate essentially determines the bandwidth required for the signal to be spread. It is proposed that the length of the signal in frame in time should not increase by T_{eff} for the signaling schemes in the subset 1 and the total frame length should be not more than T_{ch}. This will insure that inter-frame interference will not occur. For the higher order constellations the code orthogonality will insure that the inter-frame interference does not occur and hence the need for AWGN noise is eliminated for the 256 constellation at somewhat less chip rate as compared to the rate required by 64 constellation case. This is under the assumption that the channel spread is not too much. For an example the frame from the first set (constellation size 16) can be written as:

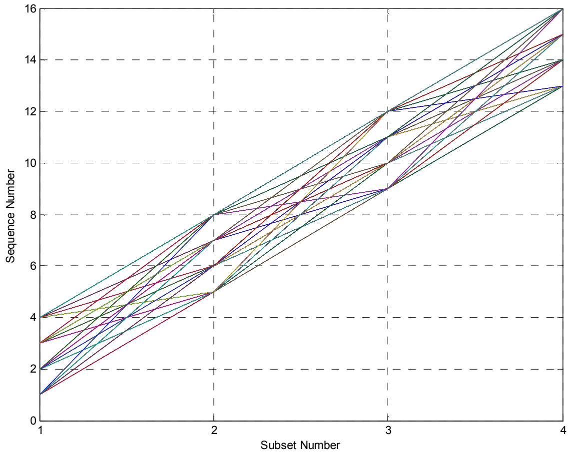

Fig. 3: Example code partitioning for 256 constellation

(m_i, Awgn, Awgn, Awgn)

Here the chip rate will be adjusted so as the time taken by mi is approximately equal to Teff and the time taken by the frame is equal to Tch. Here i = 1to16. In the case of 256 constellation the frame can be written as:

(mi1, mj2, mk3, ml4)

The time taken by the frame is equal to T_{ch}. Here *i* =1to 4. *j* =1 to 4, *k* =1 to 4 and *l* =1 to 4 and the second index represents the set they are taken from.

Case 2: Code partitioning for the gold-sequences: The family of gold-sequences that has been chosen has 130 members. Here again we chose the base set as 16 sequences. As the base sequence set can be used to make subsets then it is possible in this case to form approximately 8 such families. The advantage here would be to use these eight families to transmit simultaneously and achieve approximately eight times the rate of the single family similar to CDMA multiuser approach. For each family the signal constellation size remains 16 i.e., 4 bits can be transferred per one noise sequence if we do not

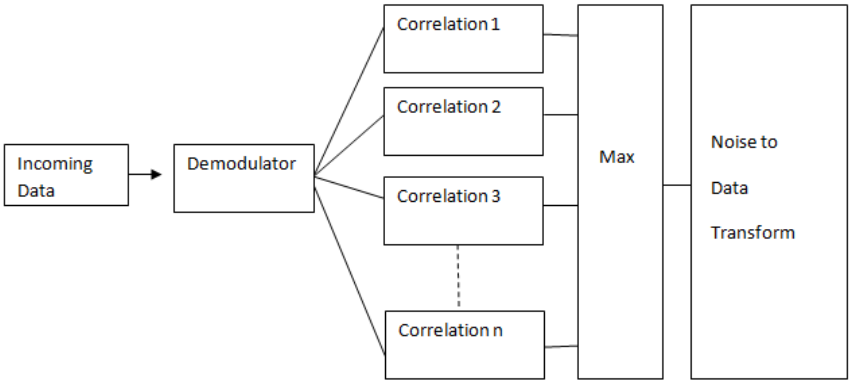

Fig. 4: Receiver block diagram (16 constellation case)

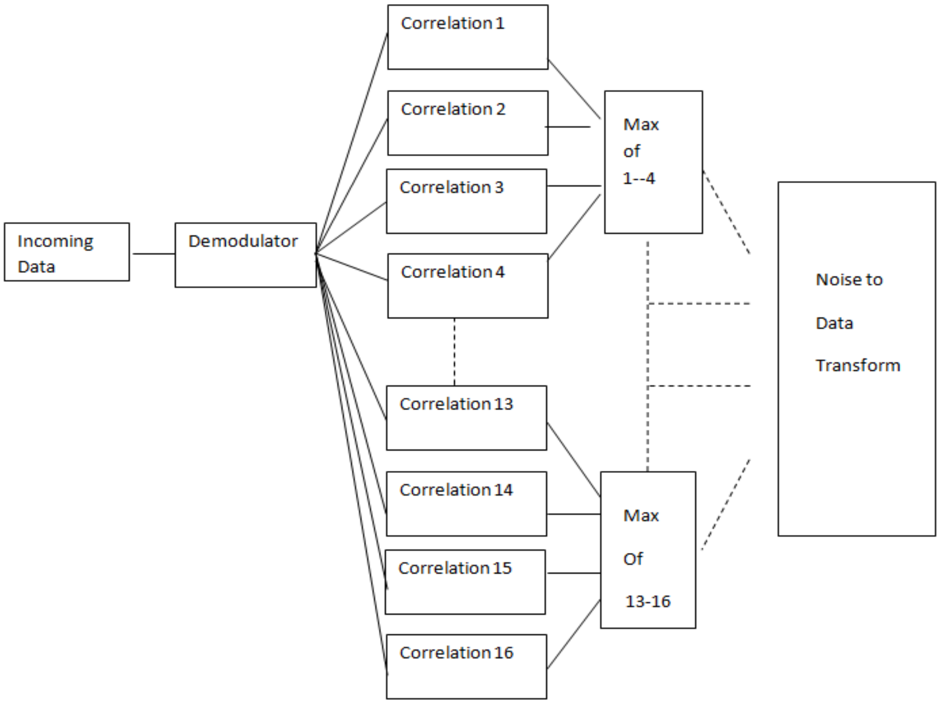

Fig. 5: Receiver block diagram (256 constellation case)

use subsets. The similar arguments can be applicable to the other subsets of this family as described in the previous case of m-sequences. The length of each member of the family has increased in the case of gold sequences thus the correlation length and hence the SNR performance of this family will be better than that of m-sequences.

RECEIVER STRUCTURE

The receiver structures for the above mentioned cases are very simple. The structure is slightly modified for first set (without any partitioning) and the remaining classes based on of partitioning being used. The receiver collects the data which has induced multipath and noise from the channel .The sixteen base correlations are done on the data and the resultant correlation amplitude determines the noise sequence that is detected which in turn determines the data being sent.

The case in which signal constellation exceeds 16, i.e., the case of 64 or 256, the correlations are done the same way but the correlation peaks are separately dealt with for each subset and then the combination of the noise sequences is determined from them. For example the 256 case the correlations from m1, m2, m3, m4 determine the first sequence, the correlations from m5, m6, m7, m8 determine the second sequence, the correlations from m9, m10, m11, m12 determine the third and sequence and the correlations from m13, m14, m15, m16 determine the fourth sequence of the transmission. When the four sequences have been identified then the noise to data transformation takes place and the data bits being sent are recovered. In this way the receiver recovers the original data being sent. It is pertinent to mention that the numbers of correlations required are equal to the number of sequences in the base family no matter what the constellation size is.

The receiver structure for the above mentioned cases is described as under. The first figure (Fig. 4) represents the receiver structure for the un partitioned case while the second figure (Fig. 5) represents the case where the 4 subsets have been made from the original set for signal constellation of 256.

TEST LOCATIONS AND RESULTS

There are four test locations where the multi path channel responses have been obtained .The first two are measured multipath channel responses and the last two are simulated (Qiao *et al*., 2012). These include:

- Indoor pool 1
- Indoor Pool 2
- The rising continental shelf near Ormara
- Shallow water near Karachi port

The absolute soft and plane boundary conditions were chosen for the sea surface and seabed was assumed as acoustic elastic half space for the last two cases. The multipath profiles are given in the Fig. 6 to 9, respectively.

The results have been obtained for different cases which are given in the paragraphs to come:

- **Effect of set partitioning:** The set partitioning determines the signal frame and the receiver structure. For the first case (Fig. 10), the signal constellation is 16 and the subsets are not formed. The second case (Fig. 11 and 12) is when the sets are formed by dividing the family in 2 subsets of 8 sequences each. Thus, the constellation size is 64.The third case (Fig. 13 and 14) is when the sets are formed by dividing the family in 4 subsets. There are four sequences in each subset. In this case, the constellation size is 256.
- **Effect of AWGN, colored and actual measured noises on performance:** In this simulation three kinds of Noises are introduced with varying SNR for performance evaluation. 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. The Fig. 15 below shows the spectrum of the colored noise. The third is noise (Fig. 16) actually measured at a lake by using a towed array of 32 hydrophones. This array was drifting in the lake so some amount of flow noise along with manmade and marine noise is also present. The results presented in the Fig. 17 below

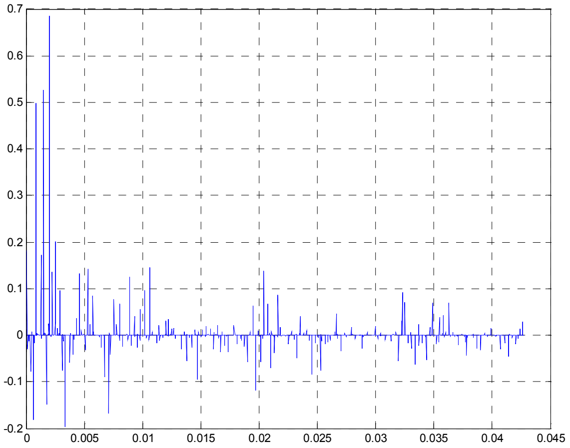

Fig. 6: Channel multipath response (Indoor Pool 1)

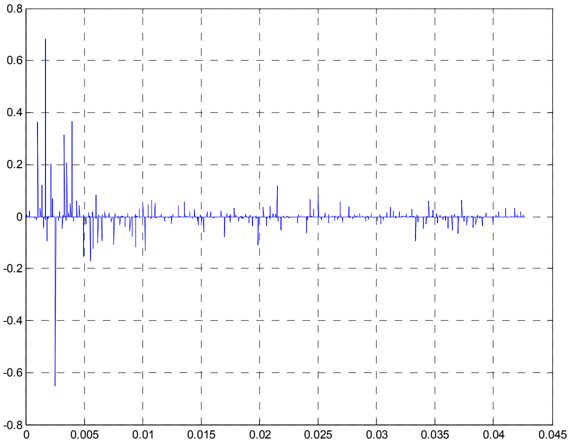

Fig. 7: Channel multipath response (Indoor Pool 2)

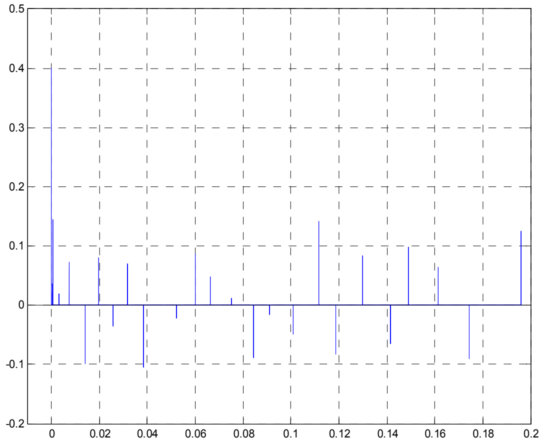

Fig. 1: Channel multipath response (Karachi Flat Sea)

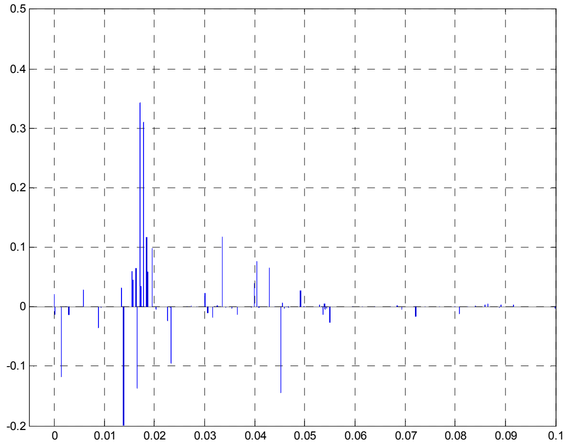

Fig. 9: Channel multipath response (O'Mara Sloping Sea)

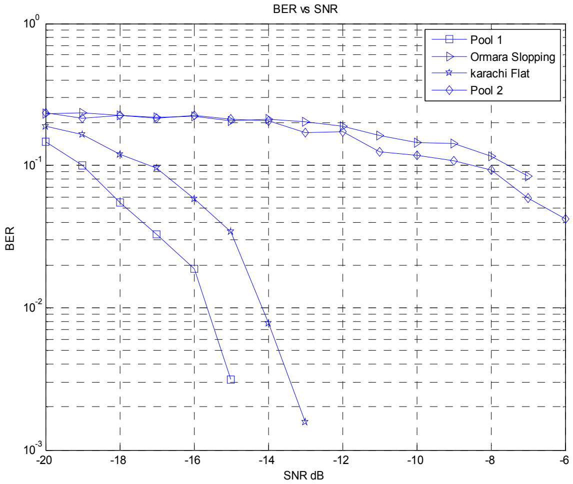

Fig. 10: m-255 BER vs. SNR for 16 constellations case

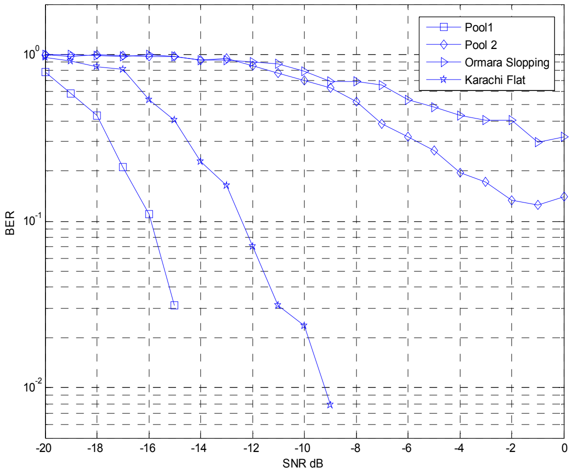

Fig. 11: m-255 sequence BER vs. SNR for 64-constellation case

show that the noise type affects the performance of scheme and the performance margin from the AWGN to the actual can be approximately 6dB.

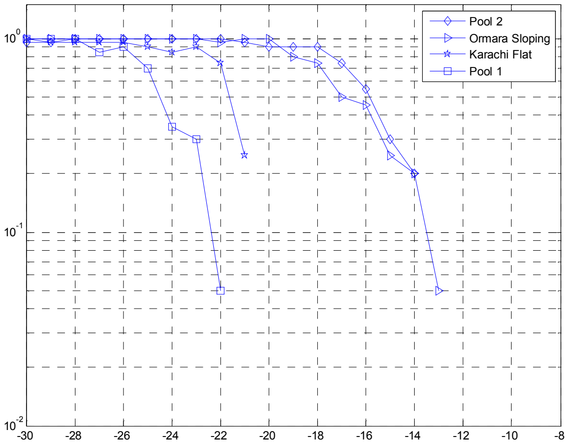

Fig. 12: Gold 2047 sequence BER vs. SNR 64 constellation case

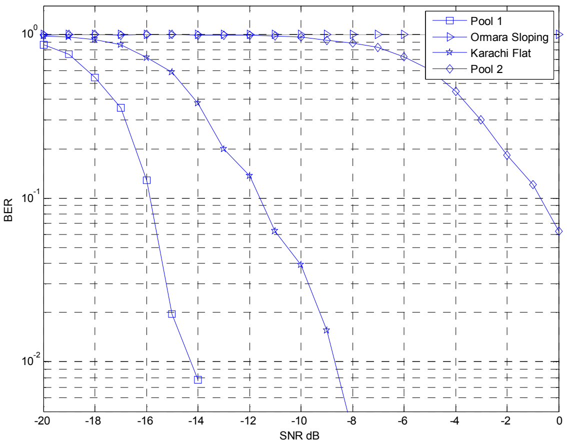

Fig. 13: m-255 BER vs. SNR for 256-constellation case

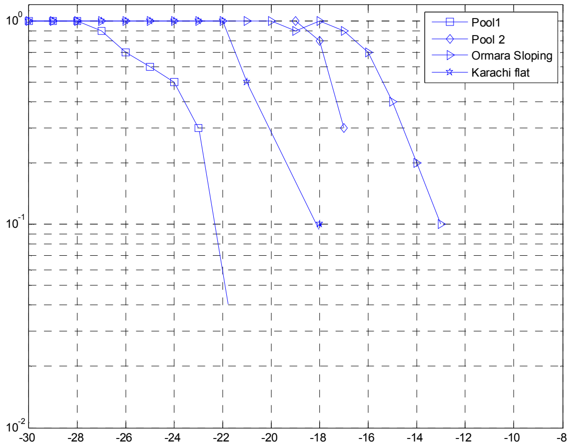

Fig. 14: Gold 2047 sequence BER vs. SNR 256 constellation case

- **Effect of chipping rate:** The chip rates are increased to cater for the longer pulses in the same amount of time. This increases the bandwidth used by the

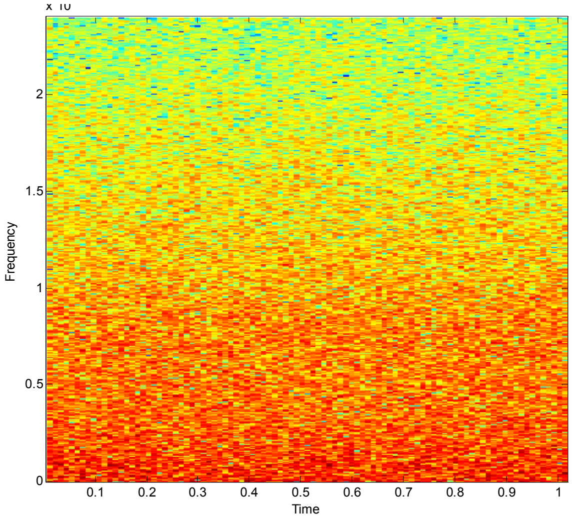

Fig. 15: Spectrum of simulated colored noise

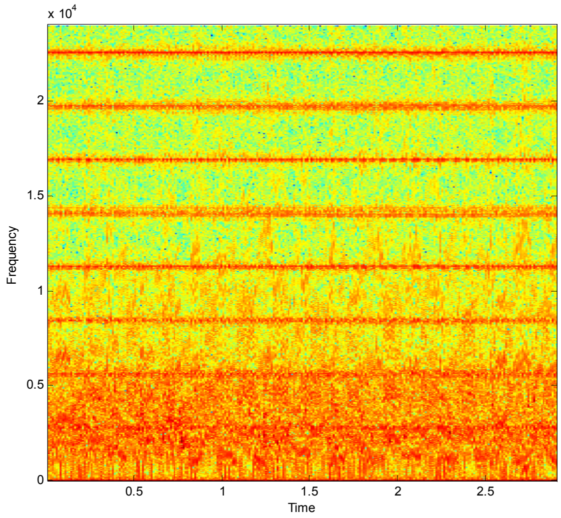

Fig. 16: Spectrum of measured noise

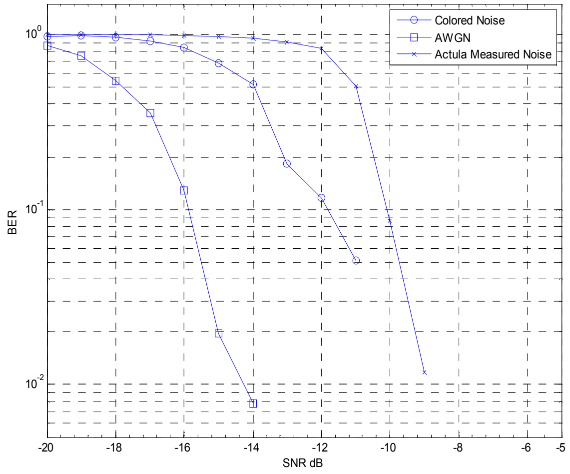

Fig. 17: BER for different noise types

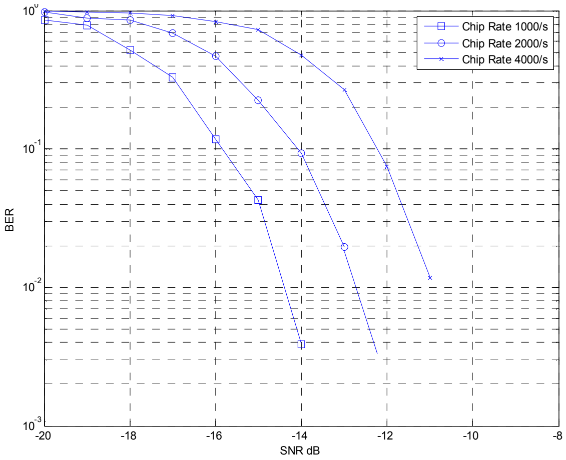

Fig. 18: Effect of chip rates at BER

system. The results of the simulation show the effects of increase of chip rate on the BER. The Fig. 18 depicts the results of the simulation.

CONCLUSION

In this study a very simple underwater communication algorithm has been proposed based on set partitioning of the noise sequences. The algorithm has been tested by simulation on actual as well as simulated underwater channels. The results for these channels indicate that it is capable of achieving low data rate communication in reverberant environments with different error rates at different locations. The results also indicate that this scheme may be employed for low rate telemetry solutions in different noise environments. Future work should focus on both experimental and analytical results. Experimental demonstration of the algorithm proposed should be conducted in different underwater communication scenarios. Analytical work should address theoretical performance assessment of different correlation techniques and implementations of optimal receiver parameters, as well as extension of acquisition principles to multiuser case and to multichannel receivers.

REFERENCES

Capellano, V., 1997. Performance improvements of a 50 km acoustic transmission through adaptive equvilization and spatial diversity. Proceeding of OCEANS '97, MTS/IEEE Conference. Halifax NS, 1: 596-573.

El-Tarhuni, M.G. and A.U.H. Sheikh, 1998. Code acquisition of DS/SS signals in fading channels using LMS adaptive filter. IEEE T. Commun., 02(4): 85-88.

Karkkainen, K., 1991. Comparison of the performance of some linear spreading code families for asynchronous DS/SSA systems. IEEE T. Com., MilCom 2: 784-790.

Karkkainen, K., 1995. Influence of various PN sequence phase optimization criteria on the SNR performance of an asynchronous DS-CDMA system. Proceeding of IEEE Military Communications Conference (MILCOM '95). San Diego, CA, 2: 641-646.

Kodanev, V.P. and Y.V. Zakharov, 1994. Experimental research of underwater acoustic long-range transmission of high-rate data. J. Phys. 4 France, 4(C5): C5-1105-C5-1108.

Kwon, H.M. and T.G. BirdSall, 1991. Digital waveform coding for ocean acoustic telemetry. IEEE J. Oceanic Eng., 16(1): 56-65.

Lee, B.B. and E.S. Furgason, 1983. High speed digital Golay code flaw detection system. IEEE Ultrason., 21(4): 153-161.

Lee, F. and S. Milica, 2001. Basin Scale Acoustic Communication; A feasibility study using acoustic tomography using m-sequences. Proceedings of OCEANS 2001 MTS/IEEE, 4: 2256-2251.

Madhow, U., 1998. MMSE interference suppression for timing acquisition and demodulation in direct-sequence CDMA systems. IEEE T. Commun., pp: l065-1075.

Mayer, K., R. Marklein, K.J. Langenberg and T. Kreutter, 1990. Three dimensional imaging system based on Fourier transform synthetic aperture focusing technique. Ultrasonics, 28: 241-255.

Niederdrank, T., 1997. Maximum length sequences in non-destructive material testing: Application of piezoelectric transducers and effects of time variances. Ultrasonics, 35: 195-203.

Packnold, S.P., 2002. Ambiguity and cross-ambiguity properties of some reverberation suppressing waveforms. Technical Memorandum, Defense R and D Canada, Atlantic. DRDC-Atlantic-TM-2002-129.

Peterson, R.L., R.E. Ziemer and D.E. Borth, 1995. Introduction to Spread Spectrum Communications. 1st Edn., Prentice Hall, New Jersey.

Qiao, G., *et al*., 2012. A Study on Static Structures of Multi-Path Impulse Response of Acoustic Propagation in Northwestern Arabian Sea. In Press.

Smith, R. and S.L. Miller, 1999. Acquisition performance of an adaptive receiver for DS-CDMA. IEEE T. Commun., 47(9): 1416-1424.

Stojanovic, M. and L. Freitag, 2000. Hypothesis-feedback equalization for direct-sequence spread-spectrum underwater communications. Proceeding of IEEE Oceans'2000 MTS/IEEE Conference and Exhibition. Providence, RI, 1: 123-129.

Stojanovic, M., L. Freitag and M. Johnson, 1999. Channel-estimation-based on adaptive equalization of underwater acoustic signal. Proceeding of Occans'99, MTS/IEEE. Riding the Crest into the 21st Century Conference. Seattle, WA.

Stojonivic, M. and L. Freitag, 2001. Multi-user undersea acoustic communications in the presence of multipath propagation. Proceeding of OCEANS, 2001, MTS/IEEE Conference and Exhibition. Honolulu, 4: 2165-2169.