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Underwater Acoustic Communication Modem Using QPSK Modulation for Improved Performance of BER

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ABSTRACT :*Transmission reliability in acoustic communication is a challenge due to various effects such as multipath propagation, quick channel variations and Doppler shift. As one of the means to achieve transmission reliability, in this paper, QPSK modulation with convolution coding is incorporated at the transmitter end and at the receiver, a Viterbi decoder is developed to decode the message coded by the convolution encoder at the transmitter. An in-depth analysis of the Viterbi decoder is discussed by comparing various results obtained by varying the design parameters. An optimized Viterbi decoder is chosen from the simulation results, which is used in the establishment of underwater wireless acoustic communication system. A better performance in bit error rate (BER) is achieved for a minimum Signal to Noise Ratio (SNR) required at the detector input.*
KEYWORDS *-Acoustic channel, QPSK modulation, Convolution encoder, Viterbi decoder, Bit error rate, Signal to Noise Ratio, Multipath propagation*

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I. INTRODUCTION

In the years of seventies and eighties of previous century, the underwater communication link for a single carrier transmission used various digital modulation techniques such as amplitude shift keying (ASK) [1], frequency shift keying (FSK) [2], phase shift keying (PSK) [3] and quadrature amplitude modulation (QAM) [4]. The above techniques suffered issues of poor data rate and reliability.

II. CONVOLUTION CODING

Due the uncertainties, the underwater environment is rapidly prone to high probability of error, hence in order to reduce it, convolution coding technique is discussed.

The convolutional codes can be generated with shift registers and XOR gates. The performance of the convolutional codes in error correction is equal or superior to block codes. The convolutional encoder may be characterized in a number of ways using the connection vector, impulse response, polynomial representation, state diagram, tree diagram and trellis diagram. Tree diagram is an extension of state diagram with an additional dimension of time. The tree diagram is not convenient representation of the encoder when the message word is large.

Coding a message sequence with the help of Trellis diagram is easier comparatively. Trellis codes are bandwidth efficient and used to combat interference. This coding technique improves the reliability of digital transmission over partial-response channels [5].

Let the message sequence be $\{m\} = \{m_o m_1 m_2 m_3 \ldots\ldots\ldots..\}$

$$x_1 = x_i^{(1)} = \sum_{l=0}^{M} g_l^{(1)} m_{i-l}$$

$$x_2 = x_i^{(2)} = \sum_{l=0}^{M} g_l^{(2)} m_{i-l} \qquad (1)$$

After convoluting the message sequence we obtain x_1 and x_2 as in (1), i. e $x_i^{(1)}$ and $x_i^{(2)}$

Then our coded sequence will be $\{x\} = \left\{x_0^{(1)} x_0^{(2)} x_1^{(1)} x_1^{(2)} \ldots\ldots..\right\}$

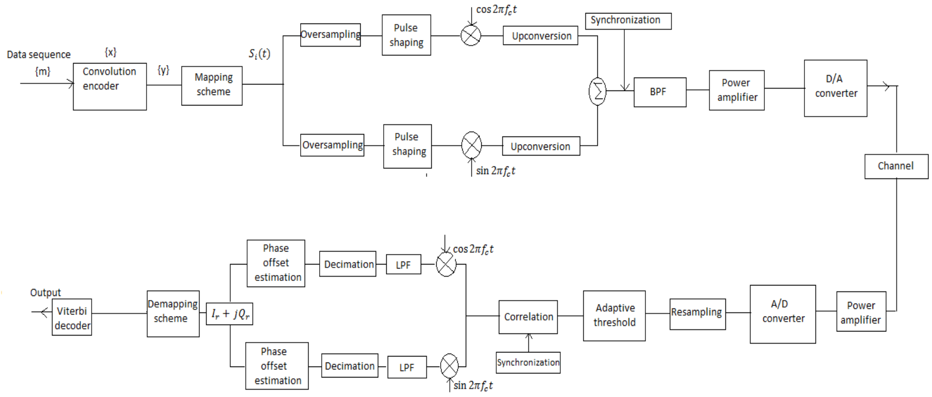

Fig. 1: Block diagram of a Communication system with Convolution coding and Viterbi decoding

The proposed method of QPSK modulation with convolution coding at the transmitter end and Viterbi decoding at the receiver end is shown in Figure 1.

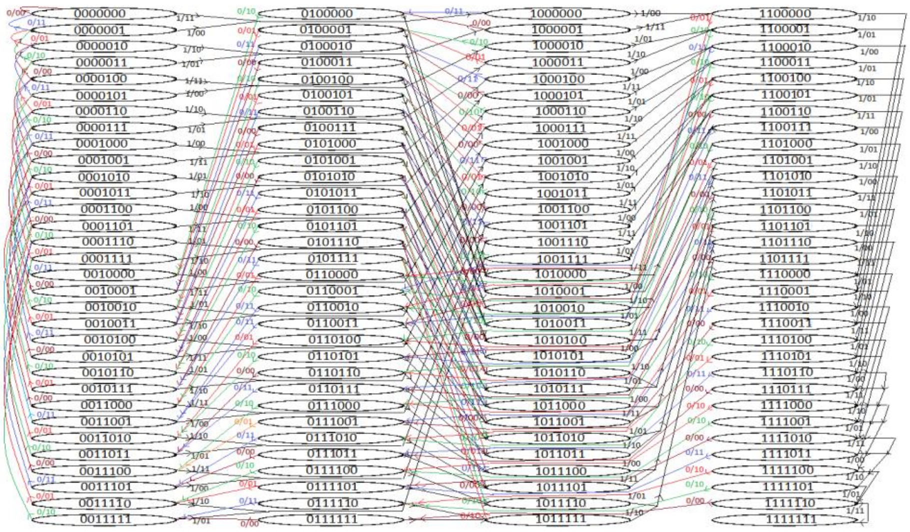

Fig. 2: State diagram representation for an 8-bit data

Representing convolutional codes as a state machine is an exquisite way to briefly describe what the convolution encoder does at the transmitter. It also gives an idea about, how to decode the received stream of bits at the receiver. The state diagram representation for an 8-bit data with the color coding given to distinguish path '0' as brown for '00', red for '01', green for '10' and blue for '11' outputs is as shown in Figure 2.

III. MAPPING SCHEME

In this paper QPSK modulation scheme is employed for bandwidth efficiency, as the usable bandwidth of an underwater sound channel is characteristically a few kHz for huge distances.

QPSK produces fixed amplitude signal ensuring better performance in fading channel and help to achieve higher data rate as two bits are sent over each sub-carrier. QPSK described by (2), is the most common technique, because it increases the bandwidth efficiency without suffering from Bit Error Rate (BER) degradation.

$$S_i(t) = A\cos(2\pi f_c t + \theta_i) \quad 0 \le t \le T$$
$$\theta_i = \left(\frac{2i+1}{4}\right)\pi \qquad i = 0,1,2 \ldots \qquad (2)$$

The frequency of carrier is chosen such that it is an integral multiple of the symbol rate and in any symbol interval the initial phase is one of the four phases as shown in Table 1.

Input successive bits	Phase shift in carrier
00	45^o
01	90^o
10	135^o
11	180^o

Table 1: Phase shifts for different input bits

4.1 Over-sampling and Pulse shaping
The real and imaginary part of the coded symbol is separately taken and padded with zeroes. The zero padded symbols are convolved with a pulse shaping function. The pulse shaping will reduces the inter symbol interferences. In this paper, raised cosine filter is uses pulse shaping technique as in (3) .

$$M_p(t) = S_i(t) \times h(t) \quad (3)$$

Where the raised cosine filter has the transfer function as shown in (4)

$$H(f) = \begin{cases} 1 & for \quad |f| < \omega - 2\omega_0 \\ (cos(\frac{\pi}{4}\frac{|f|+\omega-2\omega_0}{\omega-\omega_0}))^2 & for \quad \omega - 2\omega_0 < |f| < \omega \\ 0 & for \quad |f| > \omega \end{cases} \quad (4)$$

4.2 Up-conversion
The basebandsignals need to be up-converted to 12 KHz to 18 KHz. The widely used I-Q conversion technique is adopted here.

4.3Synchronization
Synchronization is very much essential in wireless communication systems. For this purpose usually a pilot is sent before the actual data transmission. In this design, a Linear Frequency Modulation (LFM) signal of 1ms is used as the pilot. In the receiver side, the received signal is correlated with a replica of the pilot, and when it crosses the threshold we can estimate the point from which convoluted symbol is available. The synchronization is to be repeated after certain time interval.

4.4Viterbi Decoder
It is highly difficult in checking the list of all possibly transmitted message sequences and comparing the hamming distances because of the 2^N probable code words for a transmitted sequence of N bits. An efficient and frequently applicable method for solving this problem is a unique structure called the “trellis”.
In terms of the trellis diagram, the method of designing a decoder algorithm can be known. One of the frequently used algorithm which tries to decode the convolutional codes is the “Viterbi decoder”.
The ideal path for the message transmitted for the convolution encoder [171,133]8 is represented in Figure 3.

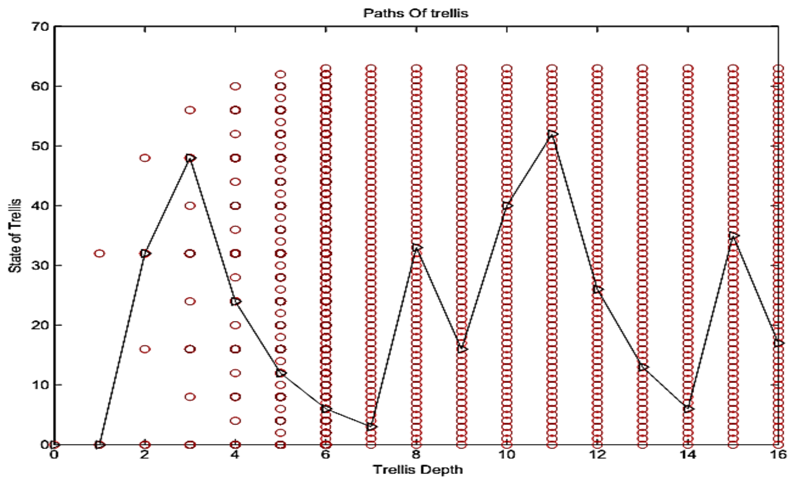

Fig. 3: Ideal path of Trellis for [0 1 1 0 0 0 0 1 0 1 1 0 0 0 1 0] message

The parameters chosen for the experiment are shown in Table 2.

S.No	Parameter's	Design Values
1	Baseband signal frequency	6.3 KHz
2	Symbol duration	40.65msec
3	Up conversion frequency	12-18.3 KHz
4	Sampling frequency	44.1KHz

Table 2: Parameters of the experiment

IV. RESULTS

The basic step is to calculate the SNR value for the Quadrature Phase Shift Keying modulation technique that has a better BER value and then compare the system modeled with these basic results over WGN channel. This is illustrated in Figure 4 which reflects that at nearly 10 dB of SNR, the least BER is achieved.

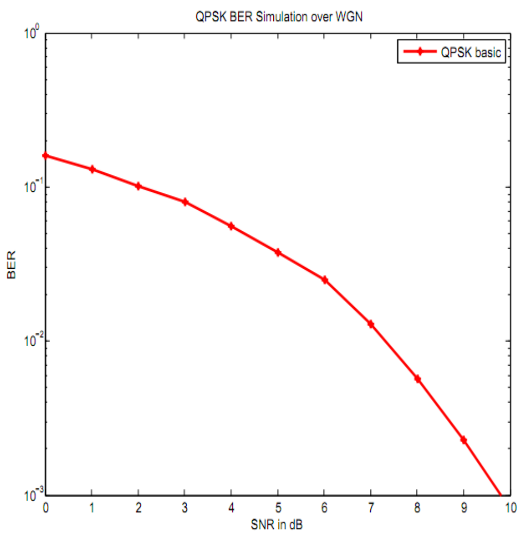

Fig. 4: QPSK BER simulation in WGN Enviroinment

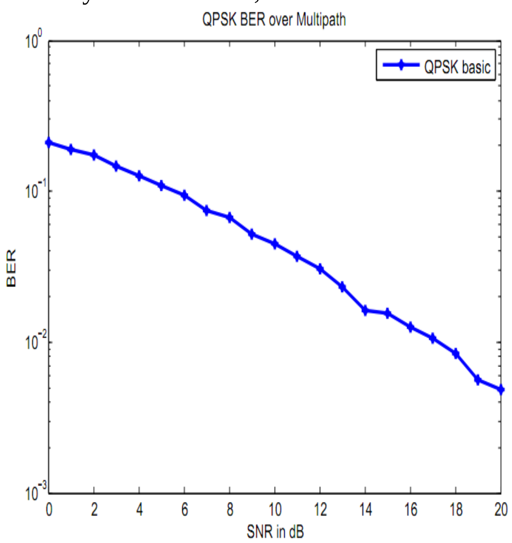

Fig. 5: QPSK BER simulation in multipath

The next step is the calculation of the SNR value for the Quadrature Phase Shift Keying modulation technique that has a better BER value and then compares the system modeled with this basic result over multipath channel defined. This is illustrated in Figure 5 which reflects that at 20 dB the least BER is achieved.

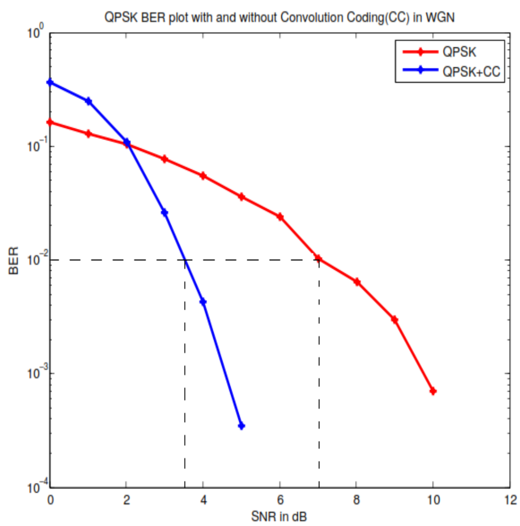

Fig. 6: QPSK BER Simulation by introducing Convolution Coding in WGN

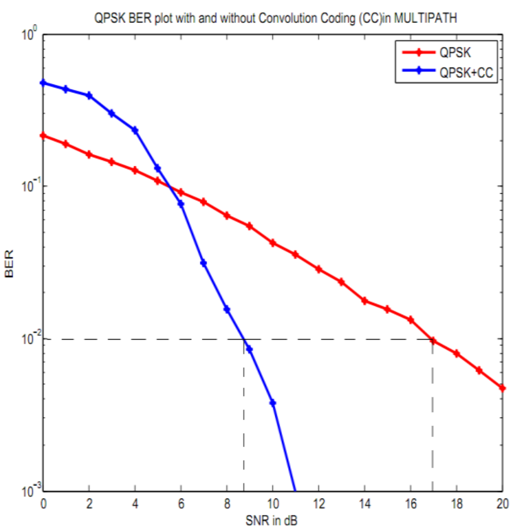

Fig. 7:QPSK BER Simulation by introducing Shaping in WGN

One of the best known techniques to improve the BER performance of a system is to introduce error correcting technique to the system, so the convolution coding technique is added to the basic QPSK communication module and the resulting BER plot is shown in Figure 5 from which the improvement in BER in terms of SNR can be interpretted. The coding gain at 10^{-2} BER value is 3.52 dB as illustrated in Figure 6.

The convolution coding technique is added to the basic QPSK communication module over the multipath channel and the resulting BER plot is shown in Figure 7 from which one can interpret the improvement in BER in terms of SNR. The coding gain at 10^{-2} BER value is 8.23 dB as illustrated in Figure 7.

As convolution coding introduces channel bandwidth redundancy, some method has to be employed to limit the effective band width of the transmitted pulses, hence a pulse shaping filter is used to compensate the bandwidth redundancy. First the system is examined with only appending the pulse shaping filter to the basic QPSK model, the BER performance improves by doing so for WGN channel as shown in Figure 8, the filter gain at 10^{-2} BER is 3.09dB. The major contribution of pulse shaping is viewed when there is a time varying channel, i.e. the channel where the coherence bandwidth is less when compared to the signal bandwidth, which leads to inter symbol interference. Hence, the pulse shaping for communication model in multipath is helpful in reducing the number of bit errors.

From the Figure 9with BER Simulation by introducing Pulse Shaping in multipath, it is observed that though here is no improvement of BER in terms of SNR, the filter gain at 10^{-2} BER is 3.00dB.

By verifying how the two techniques of convolution coding and pulse shaping help in improving the BER performance of the basic QPSK model, this is illustrated in Figure 10, the overall gain obtained by introducing both convolution coding and pulse shaping at 10^{-2} BER is 6.43dB.

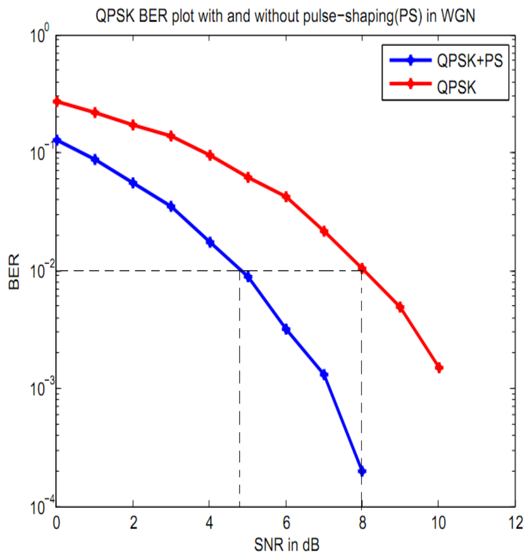

Fig. 8: QPSK BER Simulation by introducing Pulse Convolution Coding in multipath

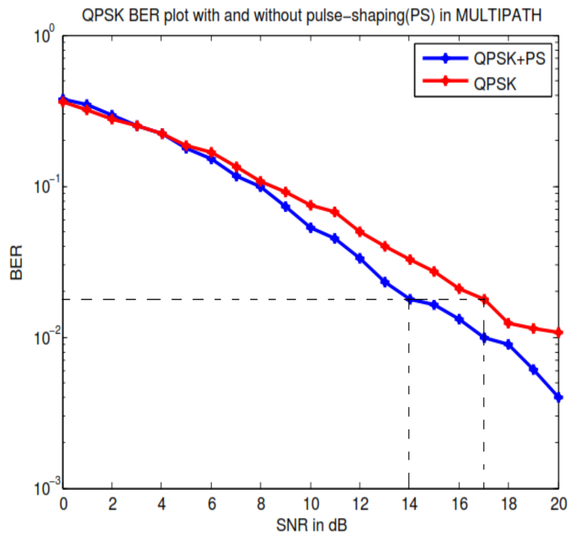

Fig. 9: QPSK BER Simulation by introducing Pulse Shaping in multipath

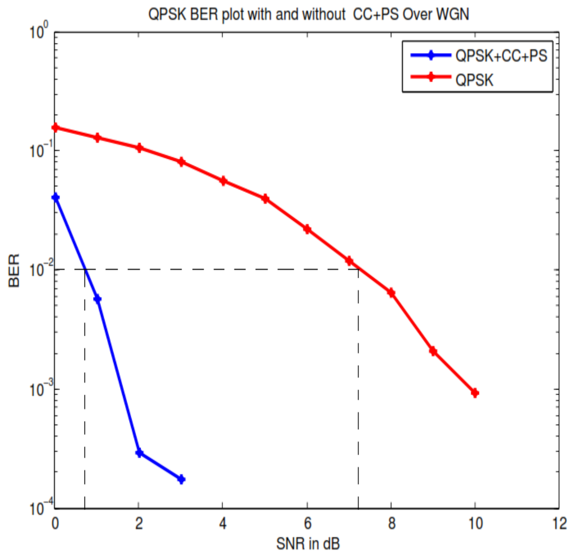

Fig. 10: QPSK BER Simulation by introducing convolution coding and pulse shaping to the QPSK modem in WGN

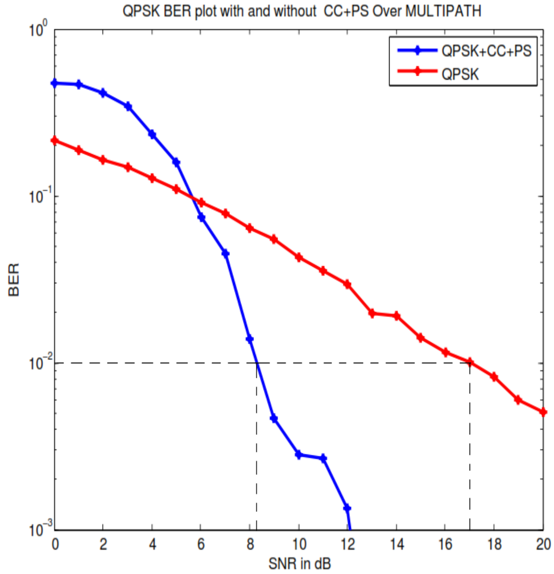

Fig. 11: QPSK BER Simulation by introducing convolution coding and pulse shaping to the QPSK modem in Multipath

The collective collaboration of convolution coding and pulse shapingto the QPSK modem in multipath helps in the improvement of BER performance in multipath transmission of data. It is observed from Figure 11 that at 10^{-2} BER value, the SNR is beyond 8 dB.

It is derived that the BER performance improves as the constraint length of the convolution code increases but practically this is restricted as the complexity of Viterbi decoder increases with the increase in constraint length. Hence, from Figure 12, and 13it is derived that as the BER performance of constraint length 7, 8 are nearly comparable choose codes of constraint length 7 to obtain the optimum results in terms of BER as well as practical complexity.

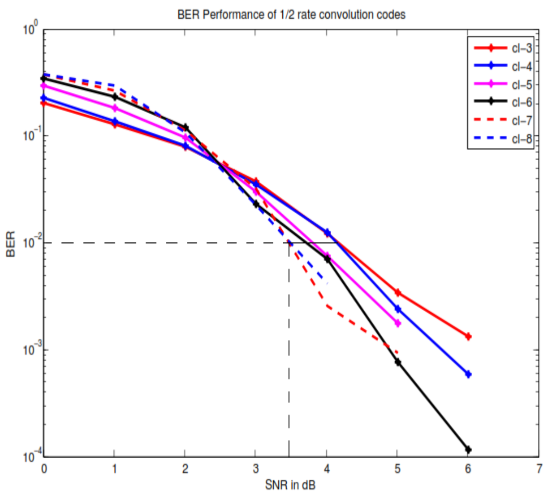

Fig. 12: Comparision of ½ convolution codes by varying constraint length over WGN.

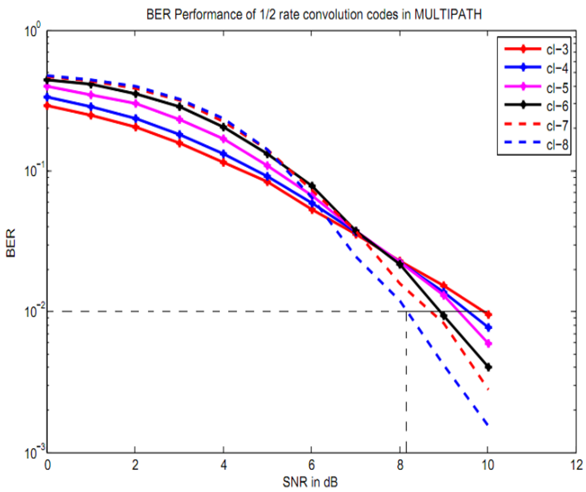

Fig. 13: Comparision of ½ convolution codes by varying constraint length over multipath

It is clearly observed from Figure 14 and 15that for 1/n rate codes the coding gain is higher as the value of 'n' increases.

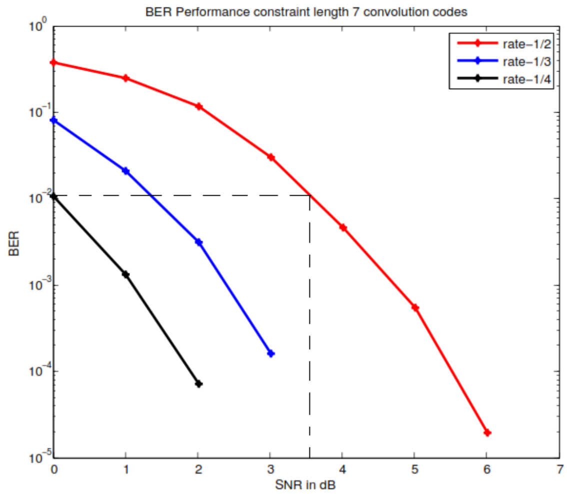

Fig.14 :Comparision of constraint length 7 Convolution codes by varyingcode rates over WGN

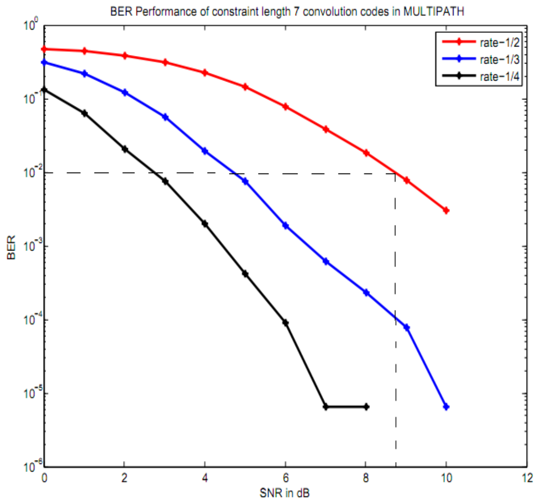

Fig.15 : Comparision of constraint length 7 convolution codes by varying code rates over multipath

V. CONCLUSION

Applications like simple status reports or transfer time position co-ordinates in under water may require a bit rate of 100 *bps*. In image transmission based applications like seafloor mapping and in some military applications bit rates of several kbps are required due to the transfer of images with high resolution. As an initial step to explore systems for communication that have the potential of transferring data at rates of multiple *kbps* over distances of several kilometres in underwater, this communication model is developed.

This communication model is designed for communicating with the help of QPSK modulation technique along with a channel coding technique in an UAC. It provides a thorough insight into various problems that are encountered by underwater sound channel and also explains the degradation of bit error rate (BER) due to channel variations in the presence of multipath propagation and how to compensate them.

It is also shows how to select a particular convolution codes based on their properties such as constraint length, code rate. Overall system gain obtained using a half rate convolution code of constrain length seven $[171,133]_8$ and pulse shaping is 8.78 dB.

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