Efficient Encoding and Decoding Schemes for Underwater Acoustic Communication

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Abstract- **This paper focus on developing a novel efficient encoding and decoding scheme for Under Water Acoustic Communication (UWAC).Under water communication finds application in communication between UAV's, submarines, deep sea divers, etc and also for sensor applications. Among the various alternatives like optical, electrical and radio frequency communication, under water acoustic communication is efficient in terms of less power loss, less antenna size and higher effective range. But still water poses serious threats to efficient UWAC due to absorption, scattering, spreading, noises, etc. These factors are considered and an underwater acoustic channel has been characterized. Using this channel model, various coding schemes and their concatenated structures are analysed and evaluation in terms of their probability of error, Bit Error Rate (BER) and Signal to Noise Ratio(SNR).**

Keywords-Under Water Acoustic Communication (UWAC), Bit Error Rate (BER) and Signal to Noise Ratio (SNR).

I. INTRODUCTION

Underwater acoustics are used for communication in a broad range of applications, mostly sensor-based, including ocean sampling networks, environmental monitoring, undersea explorations, disaster prevention, assisted navigation, speech transmission between divers, distributed tactical surveillance, and mine reconnaissance. Wireless information transmission is also useful for surveillance and other military applications, as well as Autonomous Underwater Vehicles (AUVs) which could serve as mobile nodes in future Underwater Wireless Sensor Networks (UWSNs). Although radio and optical techniques can be used for very short range applications, acoustic signals are generally used for communicating underwater (UW). Radio waves that propagate underwater are the extra low frequency ones (30 Hz – 300 Hz), but these require very large antennas and extremely high transmission power [2].

Optical techniques do not suffer from the problem of attenuation as much; however, they are affected by scattering. Moreover, optical communication requires very high precision in pointing a narrow laser beam in the right direction, which is still being perfected for practical use. Hence acoustic transmission looks like the best possible option for UW transmission for now.

Since both tethered and standalone devices have numerous disadvantages, most underwater sensor networks employ a wireless physical layer with acoustic links. Two other wireless methods, radio frequency (RF) and optical transmission, have several limitations that prevent them from being widely utilized in underwater channels, the most significant being short propagation distance. While pure water is an insulator, most bodies of water contain dissolved salts and other matter, making them partial conductors. The level of attenuation of radio signals is directly proportional to the conductivity of the water. The attenuation of radio waves in water also rises with an increase in frequency and is proportional to where *f* is the frequency in Hz, and *s* is the conductivity of the water in mhos/meter1. Because of the salinity levels, attenuation in sea water is very high, and to communicate at any depth, it is necessary to use very low frequencies (long wave radio, 10 – 30 kHz) where attenuation is on the order of 3.5 to 5 dB per meter[4].

II. LITERATURE SURVEY

In [5] several fundamental key aspects of underwater acoustic channel are investigated. According to [6] Acoustic propagation is characterized by three major factors: attenuation, multipath propagation and noise. In [7] Thorp experience formula is adopted in order to simulate seawater absorption properties. According to [8] there is no single channel model that captures the relevant acoustic propagation characteristics in all underwater environments. In [9], impulse response of a time-varying acoustic channel will be modeled as a superposition of multiple propagation paths. In [10], presents a statistical method for developing a computationally efficient and simulation friendly approximation of a physics model of path loss. [11] focuses on presenting a novel high efficiency channel encoding. For the systems and methods for implementing a control channel, e.g., in underwater communication system, are presented in [12]. According to [13] concatenated Reed Solomon and convolutional codes have been used by several wireless communication standards.

III. CHARACTERISTICS OF UNDERWATER ACOUSTIC CHANNEL

A. Underwater Acoustic Channel: The underwater acoustic channel combines the worst properties of a radio channel, i.e., poor physical link quality of a mobile terrestrial radio channel and the high latency of a satellite channel. These channels are considered to be the most difficult to communicate on due to the limited bandwidth and the wideband nature of the signals used. Delay spreads of over tens and up to hundreds of milliseconds result in frequency selective distortion, and the almost unavoidable relative motion between the transmitter and the receiver creates Doppler effects as well. The background noise is neither

Gaussian nor white, and in many cases has a power spectral density decaying with frequency [13]. Moreover, surface waves, internal turbulence, the variation of the speed of sound due to variation in density, and several other small scale phenomena create random signal variations. As a result of these factors, there is no standard channel model which fully describes the effect of the UWA channel. Salinity, temperature, depth, environmental noise, transmission loss, spreading loss, frequency used, etc., are some of the factors that have been considered, in varying levels of detail, for modeling the channel. Some of the properties of the UWA channel are discussed.

B. Propagation Delay: The speed of sound in water increases with the salinity, temperature, and pressure of the water. Near the surface of the water the temperature and pressure are almost constant, thus leading to a constant speed of sound.

Let T be the temperature in degrees Celsius, S the salinity in parts per thousand, and D the depth in meters. Then the speed of sound in water can be estimated using any of the following empirically derived formulae [14]:

$$C_1 = 1492.9+3(T-10)-6\times10^{-3}(T-10)^2 - 4\times10^{-2}(T-18)^2+1.2(S-35)-10^{-2}(T-18)(S-5)+D/61 \quad (1)$$

$$C_2 = 1449.2+4.6T-.055T^2 + .00029T^3+(1.34-10^{-2}T)(S-35)+1.6\times10^{-2}D \quad (2)$$

$$C_3 = 1448.96+4.591T- .05304T^2 +.0002374T^3+ 1.34(S-35)+.0163D+1.675\times10^{-7}D^2 - .0102T (S-35) -7.139\times10^{-13}TD^3 \quad (3)$$

$$C_4 = 1449+4.6T+.055T^2+.003T^3+(1.39-.012T) (S-35) +.017D \quad (4)$$

$$C_5 = 1449.2+4.6T+.055T^2+.00209T^3+(1.34-.01T) (S-35)+.06D \quad (5)$$

The propagation delay can be calculated as:

$$\tau = d/c \quad (6)$$

where, τ is time in seconds, d is distance in meters.

C. Transmission Loss: The distinguishing property of acoustic channels is that path loss depends on the signal frequency. This is a direct consequence of absorption, i.e. the transfer of acoustic energy to heat. Path loss in the ocean can be categorized into attenuation loss and spreading loss. Attenuation loss includes losses incurred due to absorption, leakage out of ducts, scattering, and diffraction. In the low frequency range (100 Hz - 3 kHz) the absorption coefficient can be calculated as [15]:

$$\alpha(f) = \frac{0.11f^2}{1+x^2} + \frac{44f^2}{4100+f^2} + 2.75\times10^{-44}f^2 + .003 \quad (7)$$

where f is frequency in kHz, α is absorption coefficient. The absorption coefficient increases rapidly with frequency. The spherical spreading factor (SS) is given by:

$$SS = 20\log_{10} r \quad (8)$$

where r is the distance in meters between the transmitter and the receiver. The spreading loss increases with distance. Transmission loss describes the weakening intensity of sound over a distance and is comprised of losses from both spreading and attenuation. Spreading loss is a geometrical effect that represents the weakening of sound as the wave moves outward from the source. It can be further classified as spherical spreading, cylindrical spreading, or a variant with properties somewhere between the two. Spherical spreading is omnidirectional, where the sound intensity decreases with the square of the range. Cylindrical spreading, on the other hand, takes place in horizontal channels, where the pressure of the sound varies inversely with the range [1].

Finally, transmission loss (TL) is given by [16]

$$TL = SS + \alpha(f)r \times 10^{-3} \quad (9)$$

The overall path loss is

$$A(l,f) = \left(\frac{l}{l_r}\right)^k \alpha(f)^{l-l_r} \quad (10)$$

where l is the transmission distance taken in reference to some l_r.The path loss exponent k models the spreading loss and its values are usually 1 or 2 for cylindrical and spherical spreading respectively.

D. Noise: Noise in an acoustic channel consists of ambient noise and site specific noise. Ambient noise is always present in the background, while the site specific noise is unique to the location. These types of noises are non-Gaussian and generally modeled using a Gaussian mixture, generalized Gaussian, Gaussian double exponential or stable distributions. The ambient noise in an underwater environment can be divided into four categories [13], namely turbulence ($t\ N$), shipping ($s\ N$), wind ($w\ N$), and thermal ($th\ N$):

$$10 \log N_t (f) = 17 - 30 \log_{10} f \quad (11)$$

$$10 \log N_s(f) = 40+20(s- .5)+26 \log_{10} f-60 \log_{10}(f + 0.03) \quad (12)$$

$$10 \log N_w(f) = 50+7.5\sqrt{w}+20\log_{10}f-40 \log_{10}(f+0.4) \quad (13)$$

$$10 \log N_{th}(f) = -15 + 20 \log_{10} f \quad (14)$$

where w and s refer to the speed of wind and ship in m/s, f refers to the frequency of operation.

While this noise is often modeled as Gaussian, it is not white. The power spectral density of the ambient noise decays at a rate of approximately 18 dB/decade Hence the attenuation which increases with frequency and noise whose spectrum decays with frequency result in a signal to noise ratio (SNR) that varies over the signal bandwidth. Let Δf refer to a narrow band of frequencies around some frequency f. Then the SNR in this band can be expressed as [13]

$$SNR(l,f) = \frac{S_l(f)}{A(l,f)N(f)} \quad (15)$$

Where $S_l(f)$ is the power spectral density of the transmitted signal.

For any given distance the SNR is a function of frequency. Hence it is apparent that the acoustic bandwidth depends on the transmission distance. The bandwidth is severely limited for very large distances.

E. Multipath: This is caused by the presence of multiple paths that sound waves can take to travel from the transmitter to the receiver. Unless complex adaptive filters are utilized, the duration of a communication systems symbol time must be greater than the delay spread of the channel in order to avoid intersymbol interference, or ISI.

Multipath is created underwater by two different effects: sound reflection at the surface, bottom, and any objects, and refraction of sound. The latter is caused by the spatial variation of the speed of sound. The impulse response of the acoustic channel depends on the nature of the channel and its reflection and refraction properties, which in turn determines the number of propagation paths that contribute significant energy components at the receiver. Each path of an acoustic channel can be assumed to act like a low pass filter, and hence the overall impulse response can be written as [13]:

$$h(t) = \sum_p h\, p(t - \tau_p) \quad (16)$$

where $h_p(t)$ refers to the time varying path gain, τ_p refers to the path delay of the p^{th} path.

The delay spread of the channel depends on the longest path delay, which is typically on the order of tens or even hundreds of milliseconds. Another property of the UWA channel is that it varies with time. This is caused by two factors: inherent changes in the transmission medium which would range from changes which occur over a long period of time to changes which occur relatively quickly and changes caused by the relative motion between the transmitter and receiver.

F. Doppler Effect: Non-negligible Doppler shift/spread is another factor that distinguishes an acoustic channel from the radio channel. The magnitude of the Doppler effect (a shift) is measured by the ratio a=v/c,where *v* is the relative velocity between transmitter and receiver, *c* is the speed of sound, and *a* is called the relative Doppler shift.For a single frequency component, at say ω_n, the Doppler effect can be modeled as a scaling of frequency:

$$\widetilde{\omega_n} = \omega_n(1+a) \quad (17)$$

This assumption often works for narrow band signals in which the whole spectrum is assumed to be shifted by the same frequency as the carrier. In such cases the Doppler shift can be negated by carrier synchronization, which is equivalent to adjusting the local carrier frequency. In wideband signals, the Doppler effect is more accurately modeled as a time scaling of the signal waveform. Hence each frequency component is shifted by an amount which is significantly different from that at other frequencies.

$$r(t) = s((1+a)t) \quad (18)$$

where $s(t)$ and $r(t)$ refer to the transmitted and Doppler shifted received signals respectively. This wideband model of the Doppler effect is used for UWA communication. We now discretize by sampling the signals with period T_s :

$$r(n\, T_s) = s((1+a)\, n\, T_s) \quad (19)$$

If the relative Doppler shift is known, the Doppler effect can be negated by inverse time scaling the received signal. In a multirate DSP system this is equivalent to resampling the received signal by the factor $1+a$.

$$s(nT_s) = r\left(\left(\frac{n}{1+a}\right)T_s\right) \quad (20)$$

Hence, correcting the received signal for Doppler involves scaling the sampling frequency.

$$\widetilde{f_s} = (1+a)f_s \quad (21)$$

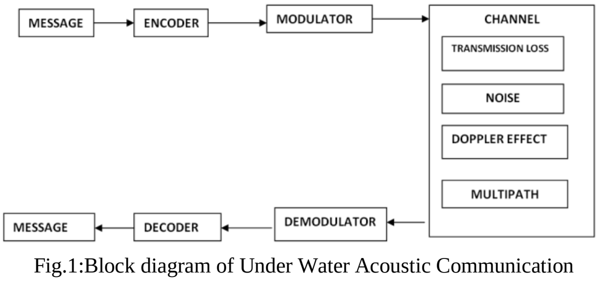

Fig.1:Block diagram of Under Water Acoustic Communication

IV. DIFFERENT ENCODING AND DECODING SCHEMES

Water puts a damper on communication capacity, slowing down the signal propagation and creating background noise and echoes. The efficiency can be increased through using CRC encoding. A circular trellis check and Viterbi decoding can also be used to increase efficiency and maintain error detection capabilities. Symbol Error Rate(SER) can be reduced in embodiments described herein over that of tail-biting convolutional coding with a CRC. However, acoustic systems though capable of long-range communication transmit data at limited speeds and delay delivery rates due to the relatively slow speed of sound in water. So, an underwater acoustic channel presents a communication system designer with many difficulties. The three distinguishing characteristics are frequency-dependent propagation loss, multipath, and low speed of sound propagation. For underwater instruments to communicate underwater, they must mimic the communication networks on land. Thus, coding channel techniques have been developed to improve the underwater coding data taking into account the constraint underwater channel in term of latency and multipath problems. The modulation and coding provides fundamental link between the user and the wireless channel, and determine the performance of the system and its use of the resources of bandwidth and signal power. The BER is an important parameter in wireless communication for quality measurement of recovered data.

A. Convolutional Codes: This is described by three integers n, k and K, where the ratio k/n has same code rate significance that it has for block codes where the integer K is constraint length; it represents the number of k-tuple stages in the encoding shift register. The constraint length represents the number of k-bit shifts over which a single information bit can influence the encoder output. At each unit of time, k bits are shifted into the first k stages of the register; all bits in the register are shifted k stages to the right, and the outputs of the n adders are sequentially sampled to yield the binary code symbols or code bits. These code symbols are then used by the modulator to specify the waveforms to be transmtted over the channel. Since there are n code bits for each input group of k message bits, the code rate is k/n message bit per code bit, where k<n.

B. Viterbi Convolutional Decoding Algorithm: This essentially performs maximum likelihood decoding; however, it reduces the computational load by taking advantage of the special structure in the code trellis. This involves calculating a measure of similarity, or distance, between the received signal, at time t_i, and all the trellis paths entering each state at time t_i.

C. Error Correcting Capabilities: The code can, with maximum likelihood decoding, correct t errors within a few constraint lengths, where “few” here means 3 to 5. The exact length depends on how the errors are distributed. For a particular code and error pattern, the length can be bounded using transfer function methods.

D. Reed Solomon Coding: These codes are nonbinary cyclic codes with symbols made up of m-bit sequences, where m is any positive integer having value greater than 2.

E. Finite Fields: To understand the encoding and decoding principles of non binary codes, such as a Reed Solomon(RS)codes, it is necessary to venture into the area of finite fields known as Galois Fields(GF). For any prime number p there exists a finite field denoted GF(p), containing p elements. It is possible to extend GF(p) to a field of p^m elements, called an extension field of GF(p), and denoted by GF(p^m), where m is a nonzero positive integer. Note that GF(p^m) contains as a subset the elements of GF(p). Symbols from the extension field GF(2^m) are used in the construction of Reed Solomon (RS) codes.

F. Primitive polynomial: An irreducible polynomial, f(X), of degree m is said to be primitive, if the smallest positive integer n for which f(X) divides $X^n + 1$ is $n = 2^m - 1$. This cannot be factored to yield lower order polynomials, and A divides B means that A divided into B yields nonzero quotient and a zero reminder.

G. Concatenated Codes: This is one that uses two levels of coding, an inner code and an outer code, to achieve the desired error performance. The inner code interferes with channel errors. The outer code, usually configured to correct most of the channel errors which is at the higher-rate code, and then reduces the probability of error to the specified level. The reason for using a concatenated code is to achieve a low error rate with an overall implantation complexity which is less than that which would be required by a single coding operation. An inter leaver is shown between the two coding steps. This is usually required to spread any error bursts that may appear at the output of the inner coding operation.

One of the popular concatenated coding systems uses a Viterbi-decoded convolutional inner code and a Reed-Solomon(R-S) outer code, with interleaving between the two coding steps [2]. Operation of such systems with E_b/N_0 in the range 2.0 to 2.5 dB to achieve $P_B = 10^{-5}$ is feasible with practical hardware [9]. The demodulator outputs soft quantized code symbols to the inner convolutional decoder, which in turn outputs hard quantized code symbols with bursty errors to the RS decoder.

H. Turbo code: This can be thought of as a refinement of the concatenated encoding structure plus an iterative algorithm for decoding the associated code sequence. Because of its unique iterative form, we choose to list turbo as a separate category under structured sequences.

I. The Map Algorithm: The process of turbo-code decoding starts with the formation of a posteriori probabilities(APPs) for each data bit, which is followed by choosing the data-bit value that corresponds to the maximum a posteriori(MAP) probability for that data bit. Upon reception of a corrupted code-bit sequence, the process of decision making with APPs, allows the MAP algorithm to determine the most likely information bit to have been transmitted at each bit time.

J. Justesen Codes: This form a class of error-correcting codes that have a constant rate, constant relative distance, and a constant alphabet size.

I. Modulation: The chosen modulation scheme should allow large data throughput and also offer some degree of immunity to the deleterious effects that limit the performance of underwater communication links. These effects include scattering from the channel boundaries (the water surface and the sea-bottom), reverberation, signal fading and noise contamination.

V. IMPLEMENTATION RESULTS

Digital communication systems, particularly for underwater use, need to perform accurately and reliably in the presence of noise and interference. Among many ways, Forward Error Correction coding is the most effective and economical. The power of this codes increases with the length constraint k and approaching the Shannon limit with a large number of k. The implementation results are given below.

A. Transmission Loss: This is a function of frequency which is in most cases in the range of 18 kHz to 34 kHz. Attenuation and thereby the transmission loss are plotted using equation (9) in Figure 1, 2.

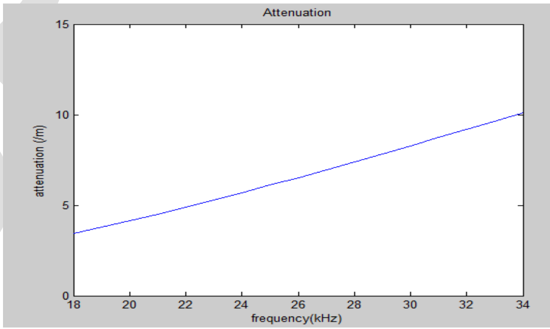

Fig.2: Frequency (kHz) Vs. Attenuation(/m)

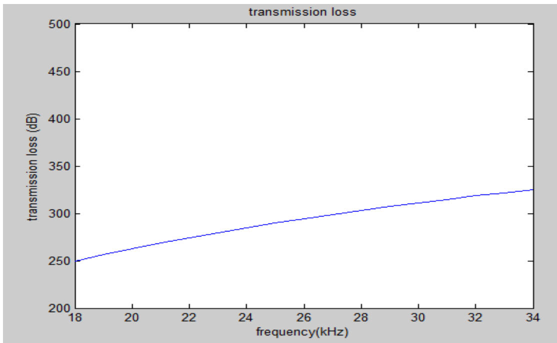

Fig.3: Frequency (kHz) Vs. Transmission loss(dB)

B. Ambient Noise: This is more dominant than site specific noise from. The four different ambient noises say, thermal, wind, turbulence and shipping noise.

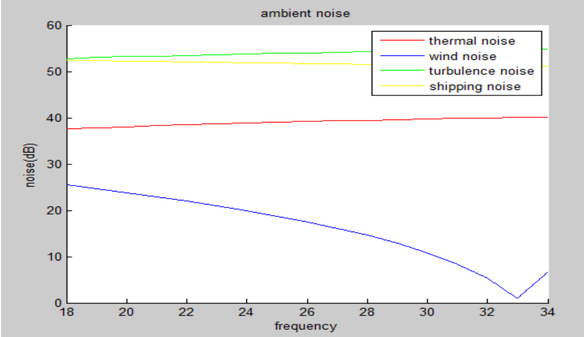

Fig.4: Frequency Vs. Noise(dB)

The signal to noise ratio is plotted against frequency using equation(15) in Fig.5.

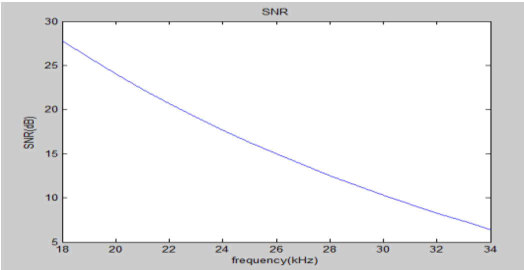

Fig.5: Frequency (kHz) Vs. SNR(dB)

The input signal is chosen to be a random sequence as shown in Fig.6

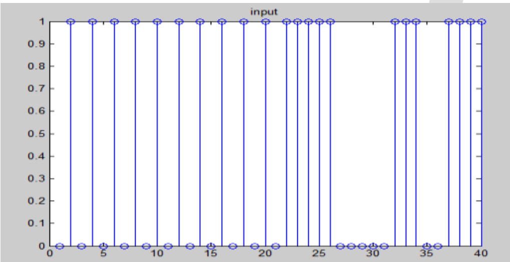

Fig.6: Input message signal

The encoded signal for different encoding schemes are :

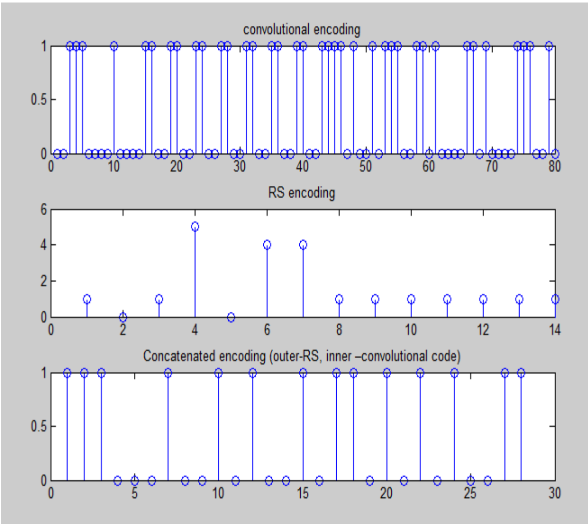

Fig.7: Convolutional encoding, RS encoding and concatenated codes

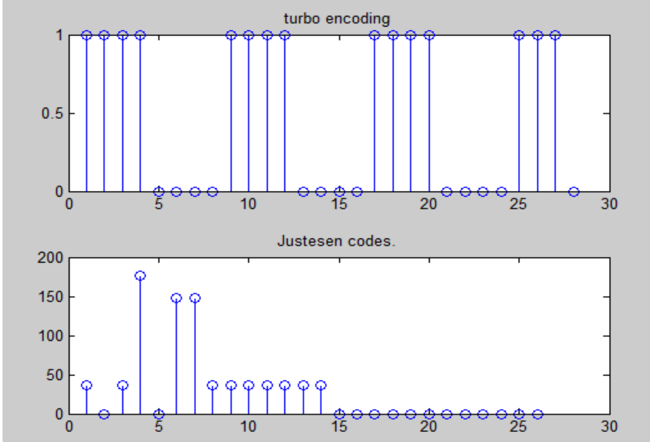

Fig.8: Turbo encoding, Justensen codes

The encoded signal is DPSK modulated and transmitted through a channel characterized by noise, transmission loss, Doppler shift and multipath fading. The resulting signal is DPSK demodulated and decoded.

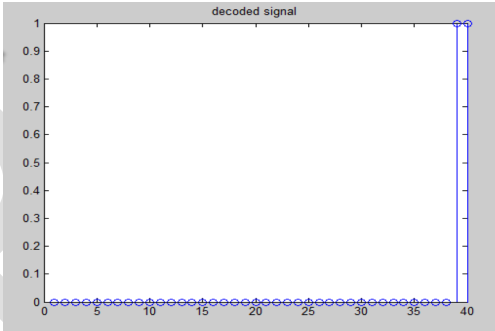

Fig.8: Convolutional decoding

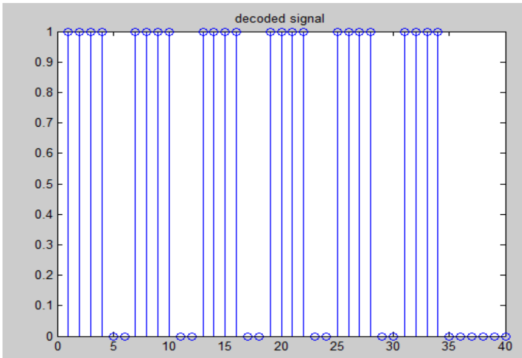

Fig.9: RS decoding

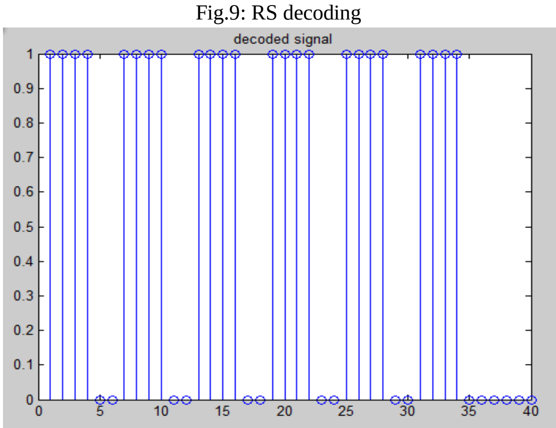

Fig.10: Concatenated decoding(outer-RS, inner – convolutional code)

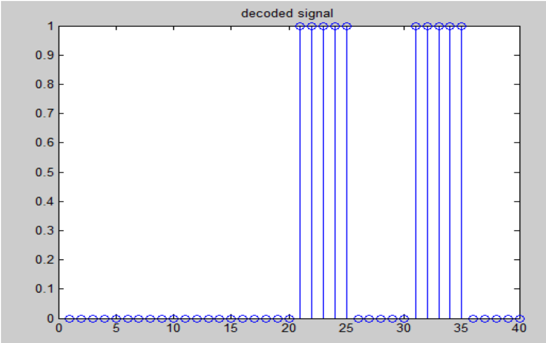

Fig.11: Turbo decoding

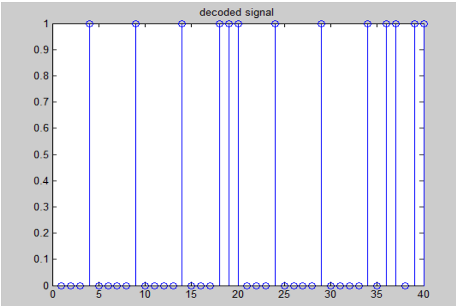

Fig.12: Justesen decoding

The BER for various coding schemes are compared in the Tables 1-6 and Fig.13&14.

TABLE I
BER FOR CONVOLUTIONAL CODING

Frequency (kHz)	SNR (dB)	BER($x10^{-3}$) (considering)		
		Doppler Effect	Multipath propagation	Doppler Effect+ Multipath propagation
18	84.29	0.17	0.0619	0.51
19	84.75	0.165	0.157	0.495
20	85.23	0.16	0.1524	0.48
21	85.72	0.155	0.1476	0.465
22	86.23	0.15	0.1429	0.45
23	86.77	0.145	0.1381	0.435
24	87.32	0.14	0.1333	0.42
25	87.91	0.135	0.1286	0.405
26	88.52	0.13	0.1238	0.39
27	89.16	0.125	0.119	0.375
28	89.83	0.12	0.1143	0.36
29	90.53	0.115	0.1095	0.345
30	91.26	0.11	0.1048	0.315
31	92.04	0.105	0.10	0.33
32	92.86	0.1	0.0952	0.3
33	93.72	0.095	0.0905	0.285
34	94.63	0.09	0.0857	0.27

TABLE II
BER FOR REED SOLOMON CODING

Frequency (kHz)	SNR (dB)	BER($x10^{-3}$) (considering)		
		Doppler Effect	Multipath propagation	Doppler Effect+ Multipath propagation
18	84.29	0.1889	0.17	2.6
19	84.75	0.1833	0.165	2.5
20	85.23	0.1778	0.16	2.4
21	85.72	0.1722	0.155	2.3
22	86.23	0.1667	0.15	2.3
23	86.77	0.1611	0.1450	2.2
24	87.32	0.1556	0.14	2.1
25	87.91	0.15	0.135	2.0
26	88.52	0.1444	0.13	2.0
27	89.16	0.1389	0.125	1.9
28	89.83	0.1333	0.12	1.8
29	90.53	0.1278	0.115	1.7
30	91.26	0.1222	0.11	1.7
31	92.04	0.1167	0.105	1.6
32	92.86	0.1111	0.1	1.5
33	93.72	0.1056	0.095	1.4
34	94.63	0.1	0.09	1.4

TABLE III
BER FOR CONCATENATED RS-CONVOLUTIONAL CODING

Frequency (kHz)	SNR (dB)	BER($x10^{-3}$) (considering)		
		Doppler Effect	Multipath propagation	Doppler Effect + Multipath propagation
18	84.29	0.9444	0.1545	0.255
19	84.75	0.9167	0.15	0.2475
20	85.23	0.8889	0.1455	0.24
21	85.72	0.8611	0.1404	0.2325
22	86.23	0.8333	0.1364	0.225
23	86.77	0.8056	0.1318	0.2175
24	87.32	0.7778	0.1273	0.21
25	87.91	0.75	0.1227	0.2025
26	88.52	0.7222	0.1182	0.195
27	89.16	0.6944	0.1136	0.1875
28	89.83	0.6667	0.1091	0.18
29	90.53	0.6389	0.1045	0.1725
30	91.26	0.6111	0.1	0.165
31	92.04	0.5833	0.0955	0.1575
32	92.86	0.5556	0.0909	0.15
33	93.72	0.5278	0.0864	0.1425
34	94.63	0.5	0.0818	0.135

TABLE IV
BER FOR TURBO CODES

Frequency (kHz)	SNR (dB)	BER($x10^{-3}$) (considering)		
		Doppler Effect	Multipath propagation	Doppler Effect+ Multipath propagation
18	84.29	0.1889	0.1789	0.5667
19	84.75	0.1833	0.1737	0.55
20	85.23	0.1778	0.1684	0.5333
21	85.72	0.1722	0.1632	0.5127
22	86.23	0.1667	0.1579	0.5
23	86.77	0.1611	0.1526	0.4833
24	87.32	0.1556	0.1474	0.4667
25	87.91	0.15	0.1421	0.45
26	88.52	0.1444	0.1368	0.4333
27	89.16	0.1389	0.1316	0.4167
28	89.83	0.1333	0.1263	0.4
29	90.53	0.1278	0.1211	0.3833
30	91.26	0.1222	0.1158	0.3667
31	92.04	0.1167	0.1105	0.35
32	92.86	0.1111	0.1053	0.3333
33	93.72	0.1056	0.1	0.3167
34	94.63	0.1	0.947	0.3

TABLE V
BER FOR JUSTESEN CODES

Frequency (kHz)	SNR (dB)	BER($x10^{-3}$) (considering)		
		Doppler Effect	Multipath propagation	Doppler Effect + Multipathpropagation
18	84.29	0.17	0.1889	0.3
19	84.75	0.165	0.1833	0.2912
20	85.23	0.16	0.1778	0.2824
21	85.72	0.155	0.1722	0.2735
22	86.23	0.15	0.1667	0.2647
23	86.77	0.145	0.1611	0.2559
24	87.32	0.14	0.1556	0.2477
25	87.91	0.135	0.15	0.2382
26	88.52	0.13	0.1444	.2294
27	89.16	0.125	0.1389	0.2206
28	89.83	0.12	0.1333	0.2118
29	90.53	0.115	0.1278	0.2029
30	91.26	0.11	0.1222	0.1941
31	92.04	0.105	0.1167	0.1853
32	92.86	0.1	0.1111	0.1765
33	93.72	0.095	0.1056	0.1676
34	94.63	0.09	0.1	0.1588

TABLE VI
BER DUE TO DOPPLER EFFECT AND MULTIPATH FADING FOR VARIOUS ENCODING SCHEMES.

Frequency (kHz)	BER (10^{-3})				
	Convolutional Codes	RS codes	Concatenated codes	Turbo codes	Justesen codes
18	0.51	2.6	0.255	0.5667	0.3
19	0.495	2.5	0.2475	0.55	0.2912
20	0.48	2.4	0.24	0.5333	0.2824
21	0.465	2.3	0.2325	0.5127	0.2735
22	0.45	2.3	0.225	0.5	0.2647
23	0.435	2.2	0.2175	0.4833	0.2559
24	0.42	2.1	0.21	0.4667	0.2477
25	0.405	2.0	0.2025	0.45	0.2382
26	0.39	2.0	0.195	0.4333	.2294
27	0.375	1.9	0.1875	0.4167	0.2206
28	0.36	1.8	0.18	0.4	0.2118
29	0.345	1.7	0.1725	0.3833	0.2029
30	0.315	1.7	0.165	0.3667	0.1941
31	0.33	1.6	0.1575	0.35	0.1853
32	0.3	1.5	0.15	0.3333	0.1765
33	0.285	1.4	0.1425	0.3167	0.1676
34	0.27	1.4	0.135	0.3	0.1588

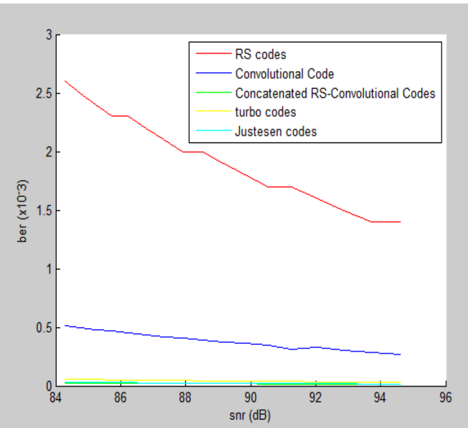

Fig.13: Comparison among various encoding schemes

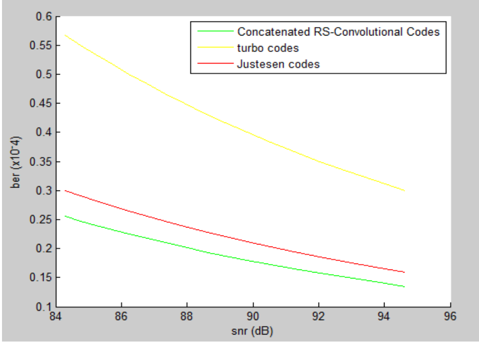

Fig.14: Comparison among the concatenated codes

VI. CONCLUSIONS

For a given value of SNR, better Bit Error Rates are obtained when a multi-level coding is done, than a single layer coding as shown in Fig.13. The former, typically indicates the process of combining an inner code and an outer code. This significantly becomes a solution to the problem of finding a code that has both exponentially decreasing BER with increasing block length and polynomial time decoding complexity, while normal codes by Shanon's theorem have exponential time decoding complexity.

Further,it can be seen that RS-Convolutional code concatenation scheme provides better performance than others in terms of BER. Further Justesen codes with RS coding in the outer layer and any linear code (here, Hamming codes) in the inner layer has lesser value of BER than turbo codes.

Further, both BER and SNR (function of frequency) decrease with increase in frequency. This infers that, at higher frequency, BER is less which is desired but lesser value of SNR is not desirable. Hence, determining an optimal operating frequency with values of BER and SNR acceptable by the receiver characteristics is mandatory.

This work can be extended by using various different linear codes in the outer layer for Justesen codes. Hence, a coding scheme which provides better performance than the existing schemes can be formulated.

Besides, the channel characterization which includes the common and inevitable conditions in underwater acoustic communication viz, Doppler effect, multipath propagation, transmission loss and ambient noise can be expanded in each of the above discipline. In case of noise, site specific noise also plays an important role in deteriorating the acoustic signal.

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