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Channel Estimation and Modelling for Underwater Acoustic Sensor Network

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***Abstract*: -- Underwater wireless communication is a rapidly growing area of research and engineering. Various scientists are exploring fundamental aspects of Underwater Acoustic Communication for various underwater applications like Oceanographic data collection, Pollution monitoring, offshore exploration, Disaster prevention, Assisted Navigation, Tactical Surveillance, and Mine Reconnaissance. To achieve this objective, sensors and vehicles self-organize in an autonomous network, which can adapt to the characteristics of the ocean environment. The above-described features enable a broad range of applications for underwater acoustic sensor networks. Acoustic communication transmission technology is used for this UWASN (Underwater Acoustic Sensor Network), but still, due to the physical properties of the propagation medium, underwater acoustic signals suffer from severe transmission loss, time-varying multipath propagation, Doppler spread, limited and distance-dependent bandwidth, and high propagation delay. Also, waves under the water are scattered and propagate very slow which produces the propagation delay in it. The scattering nature of underwater communication channel raised the problem of multipath fading, Doppler delay, Doppler shift and Doppler spread. The proposed system gives the maximum possible solution to all these issues using maximum entropy modeling method where the channel is modeled based on the Gaussian distribution for the rapidly time-varying delay factor. In this method, the Doppler spread is identified between the transmitted signal and the received signal. Also, as the communication under the water gives scattering nature of transmission, the bit transmission rate and bit error rate are calculated based on channel transmission scheme using OFDM.**

***Index Terms* – Underwater Sensor Network, Acoustic Signal, Acoustic Channel, OFDM, Channel Estimation, Channel Modelling.**

I. INTRODUCTION

Underwater Acoustic Sensor Networking is the emerging technology for various applications like oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation, tactical surveillance, and mine reconnaissance. etc. Underwater Acoustic Sensor Networks (UWASN) is designed to monitor the underwater data continuously with the help of sensors. The objective of this research is to explore fundamental key aspects of underwater acoustic communications, propose communication architectures for UASNs, and develop efficient sensor communication protocols used for the underwater environment. In this proposed system, the underwater Acoustic Communication channel is model using maximum entropy modeling technique with its root mean square. Doppler spread is 0.5 - 2 Hz only. Here, the acoustic channel satisfy the smart antenna approach by using IEEE standard 802.15.4, which gives the data transmission rate up to 250 Kbps at 2.4 GHz carrier frequency for at least 2m vertical link and approximately 100 m horizontal link, by keeping the depth of water up to 1.5m. The system is tested in a 25m x 13m (i.e. 325 m2) swimming pool with 1m to 1.5m depth. Therefore, the acoustic channel is also estimated based on shallow water conditions. Since shallow water acoustic communication is consider. For this the bandwidth was kept up to 2.4GHz. This can generate the maximum signal-to-noise ratio (SNR) is up to 1.477 dB and its Bit Error-Rate (BER) is calculated as -14.9513 dB. As the signal gets scattered in to the water, therefore orthogonal frequency division multiplexing technique is implemented, which divide the carriers into equivalent sub-carriers. Here 16 to 64 sub-carriers at the frequency of 3.6 MHz are used and each sub-carrier are made to process 256 bits per sub-channel, therefore, maximum 4096 bps to 16384 bps can be actually transmitted with the help of sub-carriers. Based on this concept, the system is simulated for 20 numbers of nodes then, for simulating this network the maximum energy required is 0.4094 Joules. Based on above tested and simulated results, here we designed the smart underwater acoustic communication system with fast communication and less power consumption.

II. UNDERWATER ACOUSTIC CHANNEL ESTIMATION

Taking into account the physical models of acoustic propagation loss and ambient noise, the optimal frequency allocation for communication signals can be calculated. Considering optimal signal energy allocation, such frequency band is defined so that the channel capacity is maximized [5]. The results that are assessed suggest that, despite the fact that frequency spectrum [6][8] for underwater acoustic communications, the possibilities in terms of usable frequency bands are not numerous, due to acoustic path propagation and noise characteristics.

2.1 SNR and SER

The narrow-band signal to noise ratio (SNR) observed at a receiver over a distance L m when the transmitted signal is a tone of frequency f and power P is given by:

$$SNR(l,f) = \frac{\frac{P(F)}{A(L,F)}}{Nf\Delta f}$$

$$p(l) = SNR_0 B_{3dB}(l) \frac{\int_{B3dB}(l)N(f)df}{\int_{B3dB}(l)A-1(l,f)df}$$

where Δf is a narrow band around the frequency f, and S(f) is the power spectral density of the transmitted communication signal. Directivity indices and losses other than the path loss are not counted. The AN product, A(l,f)N(f), determines the frequency-dependent part of the SNR. The inverse of the AN product is illustrated in Figure 2.1.

Figure 2.1 Simulation results of SNR with BER

2.2 OPTIMAL FREQUENCY

Observing the inverse of the AN product, 1/A(l, f)N(f) in Figure 2.2 , it can be concluded that for each

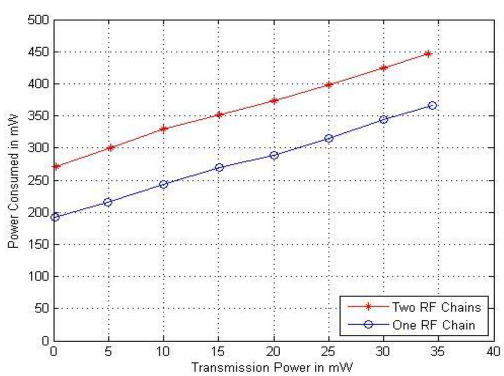
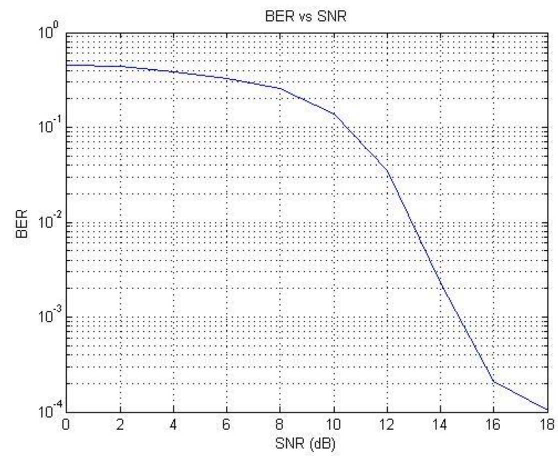


Figure 2.2 Simulation results BER with AN Product.

distance, there exists an optimal frequency f0(l) for which the maximal narrow-band SNR is obtained at the receiver. The optimal frequency is plotted as a function of transmitter receiver distance. When implementing a communication system, some transmission bandwidth around f0(l) is chosen. The transmission power is adjusted so as to achieve the desired SNR level throughout the selected frequency band. Practically, the response of the transducers and hydrophones must be taken into account and the optimal transmission frequency may vary.

2.3 TRANSMISSION LOSS

Once the transmission bandwidth is set, the transmission power P(l) can be adjusted to achieve a desired narrow-band SNR level corresponding to the bandwidth B(l). If we denote by Sl(f) the p.s.d. of the transmitted signal chosen for the distance l, then the total transmitted power is where the transmitted signal p.s.d. is considered constant in the signal bandwidth as shown in figure 2.3.



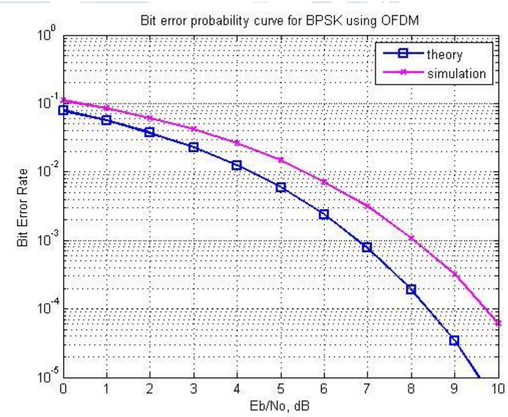


Figure 2.3 Simulation results of Transmission Power with Power Consumption

2.4 CHANNEL ESTIMATION

Xbee systems are based on the IEEE 802.15.4 standard. The physical interface is based on OFDMA, which is a multiuser multicarrier modulation technique, in which the different sub-carriers of each symbol may be shared between several users. The bandwidth can be scaled from 1.1 MHz (corresponding to 64 sub-carriers) to 3.6 GHz (corresponding to 64 subcarriers), leading to significant flexibility in system design. The bandwidth of each sub-carrier is 25.6 MHz in all configurations leading to a constant OFDM symbol duration

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of 3.2 µs, not including the cyclic prefix. Several coding and modulation schemes are contained in the standard.
There are seven mandatory schemes including modulations from QPSK to 64 QAM and convolution coding with rates 1/2, 2/3 and 3/4. The spectral efficiency can then be varied from one information bit per symbol to 4.5 information bits per symbol and hence enabling systems to adapt to varying received SNRs. Multiple antenna techniques further enhance the performance of the technology. There are mainly two MIMO techniques included in the standard. In order to estimate the underwater acoustic channel using OFDM approach. The channel is sub-divided into 64 sub-carriers through which the data can be transmitted with 25.6MHz bandwidth of each sub-carrier. Each sub-carrier is having is used to transmit 256 bits at a time. The OFDM symbol duration is 3.2µs and it generate the Doppler spread up to 0.5-2Hz with delay spread is 1ms. The proper guard intervals are inserted to avoid the Interference in between the sub-carriers as shown in figure 2.5. The underwater system performance can be tested based on the three different algorithms, like Rayleigh fading channel, MSE of the channel estimator and BER performance.

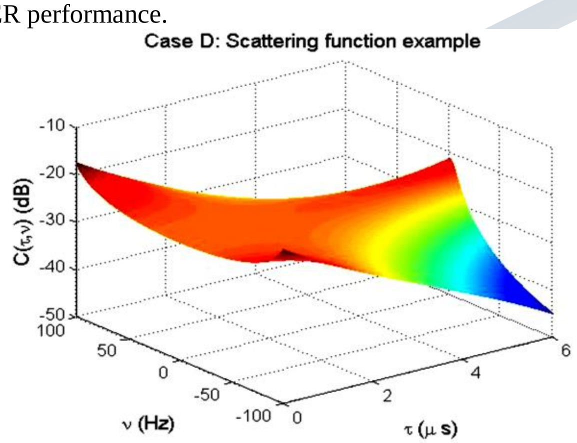

Figure 2.4 Channel Estimation using Scattering Function

All the three has used and been tested using their simulation environment. The channel model used in this work is a basic Rayleigh fading channel with additive white Gaussian noise, which is commonly used in analysis of radio communication systems as shown in figure 2.4 (b). The simulated MSE of the channel estimator as function of the Doppler spread is shown for 16 and 64 sub-carriers, respectively. The curves corresponding to a normalized Doppler spread of 0.01 shows little degradation compared to the case of no Doppler spread, while the curves corresponding to a normalized Doppler spread of 0.1 exhibits an errorous that starts to appear at Eb / N0 below 10 dB, which is lower than the operating point for most of the system configurations.

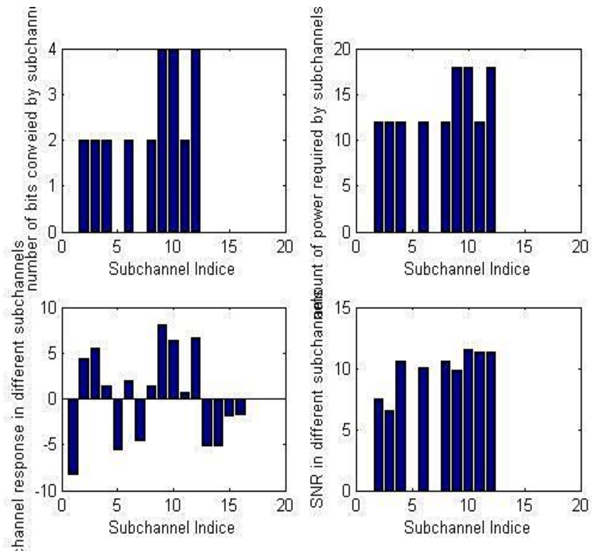

Figure 2.5 Sub-carrier channel estimation using OFDM

Simulated BER with 1/2-rate convolution coding, QPSK modulation and single transmit and receive antennas is shown in Figure 2.6. The scheme corresponds to mode 1 coding in the IEEE 802.15.4 standard. The curves indicate that the estimation error starts to become critical for Doppler spread around 0.5 - 2 Hz (corresponding to normalized Doppler spread around 0.05 and 0.1) and delay spread around 1 ms (corresponding to normalized delay spread in the order of 0.01). To obtain BERs in the order of 10-5 and delay spread should be lower than shown in the figures 2.6.

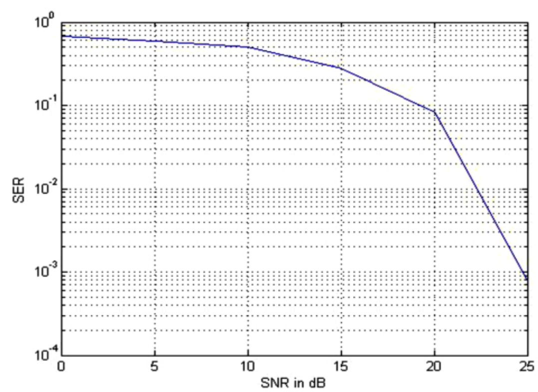

Figure 2.6 Simulated BER with 1/2-rate convolution coding

III. A SMART ANTENNA APPROACH

In this proposed system, we used micro-strip antenna for fast and efficient transmission at the data transmission rate 250 Kbps using 2.4 GHz frequency band. To support this antenna, IEEE standard 802.15.4 Xbee is also used which actually providing the transmission rate up to 250 Kbps. The used of smart antenna help us to reduced the power consumption at every stage of transmission. The maximum power require to transmit any data from transmitter to receiver is not more than 0.3459Joules. The same power consumption can also be simulated for 25 numbers of nodes using 64 sub-carriers, each used 256 bits at 25.6 MHz frequency to transmit using MC-ESE algorithm which calculate the energy consumption as per the given mathematical formulas:

$$E_b = E_a na + E_d ig$$

$$E_b = E_t rans + E_c ircu$$

$$E_{trans} = (a+1)P_t.T_o n/L$$

$$E_t rans = ((P_{cana} + P_{detector} + P_{cdig})T_{on} + 2P_{syn}T_{tr})/L$$

where are the power Pcana , Pdetector , Pcdig and Psyn are dissipations on the analog circuitry, the detector, the digital circuitry and the frequency synthesizer respectively.

3.1 SIMULATION RESULTS

We have presented algorithms for estimating the standard deviation of some AWGN when observations derive from signals less present than absent in this background. According to experimental results, this algorithm is very promising. An application of two sensor nodes have been designed and tested on free air environment and under acoustic /aquatic environment for transmitting the data from transmitter to receiver. Using this MC-ESE algorithm, the efficient energy consumption is calculated and its simulating results are shown using MATLAB coding results as per the table given in Table 3.1.

Table 3.1 Energy Efficient Results for Proposed Algorithm

Relay Algorithm		Proposed Algorithm	
Distance Travels by Nodes (m)	Energy Consumption (J)	Distance Travels by Nodes (m)	Energy Consumption (J)
20	0.15	10-20	0.2962
40	0.35	21-30	0.3471
78	0.39	31-45	0.275
100	0.72	**46-100**	**0.3459**

The energy efficiency can also be calculated using Greedy algorithm; these algorithms rely on the connectivity matrix. In short, a logical matrix where true represents a connection and the connections are determined by the distance between nodes and the range of the active modem. When a node receives a radio message it will use the connectivity matrix to determine its furthest connected neighbor, the performance of the model implementing this algorithm is summarized in Table 3.2.

Therefore it is very much clear from the table shown above that, as the number of nodes increases, the power consumption to that much number of nodes reduces up to certain extended depends upon the distance between the transmitting and receiving nodes. Here we have simulated this results using Greedy algorithm, where the nodes distance is kept within the range of 10m to 100m and its power consumption is ranging from 0.2962J to 0.3459J. as shown in the table 3.1. These results are achieved using Greedy Furthest Acoustic.

Table 3.2 Simulating Results for Greedy Algorithm

Parameters	Number of Nodes			
	25	50	75	100
Avg. Distance (m)	90.0642	89.235	68.9515	57.6881
Avg Depth (m)	25	25	25	25
Avg Energy(J)	0.4050	0.2007	0.2232	0.2052
Avg Time (ms)	0.22	0.31	0.28	0.38

IV. CONCLUSION

Research on underwater communications and the use of Underwater Sensor Networks is becoming a very hot topic because of the appearance of new marine/oceanographic applications. As a consequence, other available underwater acoustic technology can support mostly point-to-point, low-data-rate, delay-tolerant applications. Some of the shown experimental results for point-to-point acoustic modems use signaling schemes that can achieve data rates lower than 20 kbit/s with a link distance of 1 km over horizontal links. Whereas in the proposed system, where Communications is based on RF signal transmission offers great benefits such as, increase of the data rate of the link to transmit more information. The underwater acoustic communication channel is model using Maximum Entropy modeling technique for Acoustic channel simulation with its root mean square. Doppler spread is 0.5 to 2 Hz. The Acoustic communication channel satisfy smart antenna approach by using IEEE standard 802.15.4 which gives the data transmission rate up to 250 Kbps at 2.4 GHZ carrier frequency for at least 2m vertical communication link and approximately 2m horizontal link by keeping the depth of water up to 1m, Since shallow water acoustic communication is consider. For this, the bandwidth was kept up to 2.4 GHz. The system can generate the maximum signal-to-noise ratio (SNR) is up to 1.477 dB and its Signal-Error-Rate (SER) is calculated as -14.9513 dB. As the signal gets scattered in to the water, therefore orthogonal frequency division multiplexing technique is implemented, which divide the carriers into equivalent sub-carriers. Here 16 to 64 sub-carriers at the frequency of 3.6 MHz and each sub-carrier are made to process 256 bits per sub-channel; therefore, maximum 4096 bps to 16384 bps can be actually transmitted with the help of each sub-carrier. Based on this concept, the system is simulated for 25 numbers of nodes. For simulating this network the maximum energy required is 0.4094 Joules. Thus, the smart underwater acoustic communication system is designed with fast communication and less power consumption.

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