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Underwater Communication by using OFDM System

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Abstract- OFDM has several distinct challenges in the underwater channel environment. The underwater channel is known to be highly frequency selective with large delay and Doppler spreading as well as fast time variance. To overcome the poor communication environment between the underwater acoustic signal transmitter and receiver, previous research applied underwater acoustic OFDM communication system which had efficient bandwidth capacity and could mitigate multi-path delay spread effect via guard interval. Concurrently with this OFDM signal, additional data could be transmitted through spread spreading technique, which was called water-line technique. However, this decreased the performance of the OFDM modulation because the water-line signal degraded OFDM signal. An essential feature of this system is that it offers greater power and schemes with significant error protection for the transmission of sensor data information requiring a higher quality of service (QoS). The proposed underwater acoustic multimedia system employs high power, low speed modulation, and schemes providing significant error protection for the transmission of sensor data messages requiring a stringent bit-error rate (BER). In contrast, low power, high speed modulation, and less capable error protection schemes are provided for messages that can tolerate a high BER.

Index Terms- OFDM, Water-line, Spread Spectrum, Underwater Channel

I. Introduction

In last decades, Orthogonal Frequency Division Multiplexing (OFDM) based communication a system has been identified as one of key transmission techniques for next generation wireless communication systems. The main attractions of OFDM are handling the multi-path interference, and mitigate inter-symbol interference (ISI) causing bit error rates in frequency selective fading environments. Wireless mobile communication systems of the 21st century have to confirm a wide range of multimedia services such as speech, image, and data transmission with different and variable bit rates up to 2 Mbit/s. It is all recognized that there is a great impact of channel coding on the performances of OFDM based wireless communication system to provide high data rates over severe multipath channels. The transmission scheme of additional data based on underwater OFDM system is described in Figure 1. The input serial bit sequence is modulated by M-ary modulator and it is converted to N 's parallel data sequence through the A/D(Analog to Digital Conversion). The IFFT (Inverse Fast Fourier Transform) pair is used for the high-speed transform implementation. Because this data is affected from the previous symbol, it is transmitted through the underwater channel by inserting the GI (Guard Interval) to maintain the orthogonal between the two sub-carriers. The GI part uses the CP (Cyclic Prefix) that copies the back of OFDM symbol to the front of the original data to avoid the continuous ISI (Inter Symbol Interference).

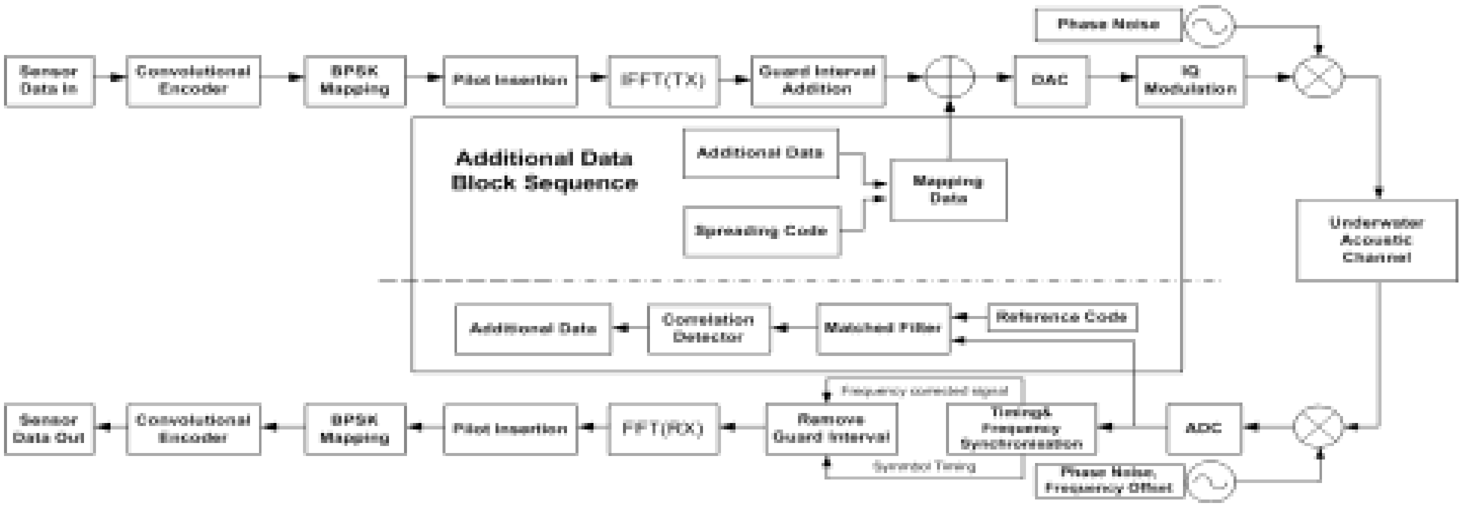

Figure 1: Block Diagram of OFDM Communication System and Water-line in the Underwater Channel

$$X(t)= {}_{l}(K)\ \phi_{l,k}\ (t- lT_{sym}) \qquad (1)$$

The ***N*** is OFDM sub-carriers number, ***X*** **(*k*)** ***l*** means the information signal ***l*** –th symbol and ***k*** -th sub-carriers, T_{sym} =Tg +Td , Tg is the length of Guard Interval, T***d*** is the actually transmitted OFDM symbol duration, and $\phi_{L,K}$ **(K)** is the basic signal element. $\phi_{L,\ K}$ **(K)** is presented by.

$$\phi_{l,k} = \qquad (2)$$

II. Research Elaborations

THE UNDERWATER ACOUSTIC CHANNEL

The underwater acoustic communication channel is extremely complex in nature. The complexity arises from the fact that the channel is not perfectly homogeneous. The numerous imperfections are mainly due to density and temperature gradients and the non-homogeneities of the water due to suspended particles of solid or gaseous matter. The constant water motion and the channel boundaries like the bottom and the surface further increase the complexity. The effect of such complex nature of the channel is the strong multi-path phenomenon and the Doppler spread. These phenomena are themselves not constant and are continuously varying. When viewed from a communication system designer's point of view, the four aspects that are of fundamental concern are namely

a) Multi-path phenomenon causing Inter-Symbol Interference and reverberation. b) Transmission
Loss due to geometrical spreading and absorption.

c) Ambient Noise.

d) Doppler Spreading due to relative motion between the transmitter and receiver.

It is to be noted that all the four aspects listed above are continuously varying in nature and the communication system design needs to constantly track these variations to effectively mitigate their effects. The following paragraphs further elaborate the above stated aspects.

a) Multi-path Phenomenon: This is the most challenging aspect of the underwater acoustic channel. The boundaries of the surface and bottom reflect the energy; so numerous travel paths exist between the transmitter and the receiver.

This is further complicated by imperfect boundaries. The whole phenomenon results in time dispersal of the signal.

This time spreading can be as high as hundreds of milliseconds in shallow water to several seconds in deep waters. At high frequency, the total time spread is less due to absorption at boundaries and attenuation in water.

b) Transmission Loss: The acoustic wave reduces in intensity as it propagates through the medium due to geometrical spreading and absorption mechanism. Though the attenuation of acoustic waves in water is negligible as compared to the RF waves in water, there is considerable loss in energy due to absorption mechanism in water. The loss due to geometrical spreading can be either spherical or cylindrical in nature. The loss per unit range is a strong function of frequency and is given by where TL is the transmission loss in dB, '*f*' is the frequency and 'α'is the absorption function .

c) Ambient Noise: Ambient Noise influences the received Signal to Noise ratio and largely controls the transmitter power. It generally decreases in frequency over the range of interest. Inshore environment and marine worksites are noisier than deep ocean environment and the communication system design needs to cater for the worst case performance conditions. The platform noise from which the system operates also needs to be considered despite the efforts to isolate the transducers. Knudsen curves give a good insight into the ambient noise in the underwater medium.

d) Doppler Spread: This is introduced by relative motion between the transmitter and receiver, or by option of the water. The shift is 0.35 Hz / (knots. KHz) one way, or 0.70 Hz / (knots. KHz) two way of relative motion. Due to the scarcity of channel bandwidth (caused by absorption losses and projector transducer characteristics), Doppler spread may easily result in further reduction in available bandwidth. This is because some allowances for guard band must be made especially for FSK system.

OFDM PARAMETERS SELECTION

The main parameters which need to be fixed in the transmitter are namely,

- Sampling Frequency, Fs
- Number of FFT and IFFT points, N
- The length of the cyclic prefix, as a fraction of the symbol duration
- The modulation scheme of the individual sub-carriers.

The selection of Fs and N automatically fixes a number of other dependent parameters such as i) The symbol duration (T) without the cyclic prefix. This is because, T = N / Fs
ii) The number of frequency bins (N) and the bin spacing or the carrier separation, (Fs / N)
iii) The number of bins falling within the bandwidth of interest i.e., from 6 KHz to 9 KHz, and hence the number of sub-carriers available for modulation. The indices these useful bins into the N-point IFFT can also be ascertained. The selection of the cyclic prefix length and the modulation scheme of individual carriers affect the data rate and the robustness of the system to channel effects. In this project, the limitations in the selection of the parameters are:

- The minimum sampling frequency needs to be about 2.56 times (or at-least 2 times) the value of maximum frequency content (i.e., 9 KHZ) of the signal.
- The length N, of the FFT or IFFT needs to be a power of 2, for ease of processing.
- The symbol duration needs to be more than 30 msec in order to overcome the effects of multi-path and hence the ISI. This will also ensure a better integration at the receiver end when the symbol is being detected.
- The sub-carrier spacing needs to be more than the maximum deviation due to Doppler shift. If this limitation is to be overcome, there has to be a suitable algorithm for Doppler compensation.

Higher sub-carrier spacing results in lesser Inter-Carrier-Interference (ICI) due to minor drifts in sampling rate, but the downside is the reduction in data rate. It can be seen that the selection of the above-mentioned parameters is an iterative one, and any set of parameters is a tradeoff between integration time of the symbol duration, immunity to ISI and Gaussian Noise; and the data rate. The communication system being reported has the following set of parameters:-

Sampling frequency	32768 Hz
FFT and IFFT length	1024
Guard time / Cyclic prefix	3.906 ms
Symbol duration without cyclic prefix	31.25 ms
Symbol duration with cyclic prefix	35.1562 ms
Number of carriers used	96
Carrier spacing	32 Hz
Frequency band of usage	6016 Hz to 9088 Hz

Table: 1.2

To increase the transmission rate we generate twelve such basebands in the frequency range 6016 Hz to 9088 Hz .Each such baseband accommodates 5460 bits. These sub bands are then frequency shifted so that they occupy frequency range 28672 Hz to 65536 Hz .Frequency shifting is done by modulation and filtering techniques. This gives effective bit rate of 65520 bits per second.

III. Simulation and Results

The trials and tests of the Communication System discussed in the previous chapters can be broadly categorized into two types, namely, 1) Simulation of the channel within the same computer and 2) Trials carried out in the acoustic test water tank. These are considered separately in the following paragraphs. Trials on Simulated Channel Channel Model**:** An underwater acoustic communication channel, as discussed in Chapter 3, has the four main characteristics

- Multi-path phenomenon
- Transmission Loss
- Additive Noise
- Doppler Effects

Any channel model of the underwater medium needs to incorporate the above four features. The hypothetical channel considered for the purpose of simulation has the following characteristics:

- Channel length 2000 m
- Depth of channel 300 m
- Transducers depth 50 m
- Loss due to bottom / surface bounce 3 dB

Under the above conditions, there can be multiple paths between the transmitter and the receiver. Not all of the secondary paths have sufficient strength to interfere at the receiver. For the purpose of simulation, we can consider a direct path and a few indirect paths. The signal arriving from the indirect paths are reduced in strength due to the extra distance traversed (hence more path loss – proportional to the extra distance) and one or more bottom / surface bounce loss. It can be safely concluded that the strongest of the indirect path signals are at least 4 dB below the direct path signal. This means that its strength is 0.63 times the strength of the direct path signal. The next issue is the extent of delay of the indirect path signal. Since it traversed the extra distance, the delay is the time taken for the sound wave to travel this extra distance in the water medium. The underwater channel considered above can be modeled as a FIR filter with the tap delays equal to the delay of each indirect path signal arriving at the receiver and the coefficients are the relative strength of these signals with respect to the direct path signal. For the first set of Simulations, one indirect path signal of strength 0.63 and delay of 56 milliseconds is considered. The Additive noise is added in the channel such that the SNR varies from 0 dB to 30 dB. This model of the channel simulates strong multi-path effects, propagation loss, and additive noise. The transmitter itself simulates the Doppler effects sending out a re-sampled waveform. Simulations were carried out over the channel discussed above by considering a random set of 50,000 bits for each simulation. The simulation results are as follows:

No multipath effect for SNR = 8 dB BER = 3 in 1000; SNR= 10 dB
BER = 3 in 10000;
With Multipath effect for SNR = 8 dB BER = 2 in 100
SNR = 10 dB BER = 1 in 100.

IV. CONCLUSION

In this paper, we studied the improve the performance of the water-line signal on top of OFDM underwater communication. An acoustic data communication system has been designed for 'Underwater Channel' with the features as brought out in first part. A modulation scheme namely, OFDM has been used in the design of the system, deviating from the conventional path of using 'Single Carrier-Frequency Systems' for such applications. The simulation yielded results comparable with the conventional systems. The performance of the system in actual trials in Acoustic Test Water-Tank further proves the efficacy of such a modulation scheme. The system could prove the concept of high data rate using OFDM for underwater applications. In the case of implementation on a special purpose DAQ card, the initial Channel Probe / Message Detect algorithm may be suitably modified, and Barker sequences may be used.

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