Acoustic Underwater Communication: Literature

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Abstract

Underwater communication is one of the unique and challenging fields in communication engineering in the case of both designing and communication. But it is very necessary to study on UWC as major portion of earth contains sea water. UWC has many scopes in various areas like Radar, Sonar, oceanography, UWIoT, etc. UWC mainly of three types through optical fiber, RF waves, and acoustic waves. Communication with acoustic waves use low decibel sound waves and have long transmission range than others. This paper explains about some acoustic wave's communication within underwater. Mainly different areas and applications in UWC with acoustic waves are explained as a literature work.

Keywords: UWAC, Acoustic waves, FDE, Estimation, OFDM, multihop networks, delay diversity

I. INTRODUCTION

THE wide underwater environment is extremely rich with natural resources such as minerals and oil fields waiting to be explored. Underwater exploration [7] activities are mainly hampered by the lack of efficient means of real time based communication below water. Although wire line systems through deployment of fiber optical links have been used to provide real time communication in some underwater applications, their high cost and operational disadvantages due to the lack of flexibility become restrictive for most practical cases. This triggers the growing demand for underwater wireless links. The transmission ranges of radio and optical underwater systems are limited to short distances. Due to the high attenuation of radio frequency signals in water, long range RF communication is problematic and requires the use of extra low frequencies, which necessitate large antennas and high transmit powers. With relatively favorable propagation characteristics of acoustic waves, acoustic systems achieve longer transmission ranges. With the emerging bandwidth hungry underwater applications and the concept of underwater internet of things, demanding requirements are further imposed on underwater acoustic [7] (UWA) systems. The underwater channel through which acoustic wave propagates has a high transmission loss, non-uniform sound velocity, multi-path propagation, varying Doppler Effect, higher bit error rates and the omnipresent ambient noise contaminate the signal. Thus, the underwater channel is the most challenging medium for communication. This first underwater acoustic telephone operated at 8.3 kHz and used single sideband suppressed carrier amplitude modulation. Until the 1980s, research efforts on UWAC were mainly dominated by military applications. Coupled with the limited bandwidth availability of the underwater channel, FSK became a bottleneck, limiting the operation of underwater acoustic communication systems to very low rates unacceptable for many modern applications. Emerging data heavy underwater applications impose further requirements on UWAC system design [7]. A wide variety under water communication system is available, but designers and engineers always search for a reliable and fast system when compare with all the previous systems. There are some familiar communications systems which is similar or which led to the development of a new system is given here as the literature papers. This paper follows with some literature paper works and limitations leading to a new system design. Also this paper covers and concluded with a summarized version of underwater communication with acoustic waves.

II. OVERVIEW OF UWAC

Acoustic waves are longitudinal waves type that propagate by means of adiabatic compression and decompression. The waves with same direction of vibration as their direction of travel are longitudinal waves. The main factors or quantities for describing an acoustic wave include the sound pressure, particle displacement and sound intensity. These waves can travel with the speed of sound, which depends on the medium they are passing through or they propagate. Underwater acoustic communication can be classified in terms of depth of water as shallow water and deep water which indicates the depth of ocean.

In frequency domain equalizer[3] for UWAC system, amplify and forward relay technique to simultaneously increase the range and data rate of underwater acoustic communication by dividing the channel between transmitter and receiver into two hops was applied. Due to the application of the relay node, the delay spread of the effective transmitter-relay receiver multipath channel is longer than that of the direct transmitter-receiver channel, which increases the complexity of channel equalization at the receiver[3]. By relaying signals at intermediate terminals between source and destination, cooperative communication technique improves total network channel capacities as well as reduces required transmission power. Cooperative communication scheme also exploits diversity characteristics of channels by combining signals propagated through different hops. Due to the application of the relay node, the delay spread of the effective transmitter-relay receiver multipath channel is

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longer than that of the direct transmitter-receiver channel, which increases the complexity of channel equalization at the receiver. To reduce the computational complexity of channel equalization, a fractionally spaced frequency domain equalizer[3] is designed. BER performance of a single relay two hop cooperative UWAC system with a fractionally spaced linear minimum mean squared error frequency domain equalizer[3]. Numerical simulations are carried out with real at sea channel measurement data, and different over sampling factors are used for performance comparison. Significant BER performance improvement can be achieved through using relay technique in UWA communication [3]. The transmitter and receiver structures are illustrated in Fig. 1. At the transmitter, modulated symbols are divided into blocks with length of N/m, where m is the up sampling factor. Each block is sampled at the rate of m/T, where T is the symbol period, before being appended with a cyclic prefix of length L. The cyclic prefix for each block is the repetition of last L symbols of the block to form a transmitted data block. The transmitted signal is distorted by the equivalent channel $h(i)$ and corrupted by additive noise $v(n)$. The received signal is then passed through receiver filter g before removing the cyclic prefix. The equalized symbols are then transferred back to time domain through inverse DFT before being decimated with the factor of m. With the aid of the relay and the fractionally spaced FDE, the performance of the UWAC system is improved when compared with the conventional equalizer in non-cooperative communication scheme.

Delay diversity [1] in UWAC system is another paper which explains an OFDM based scheme to combat the asynchronies problem in cooperative UWA systems without adding a long CP at the transmitter. By adding a much more manageable CP at the source, and obtain a delay diversity structure at the destination for effective processing and exploitation of spatial diversity by utilizing a low complexity viterbi decoder at the destination [1]. It provides pair wise error probability analysis of the system for both time invariant and block fading channels showing that the system achieves full spatial diversity. It focuses on asynchronous cooperative UWAC where only the destination node is aware of the relative delays among the nodes. Existing signaling solutions for asynchronous radio terrestrial cooperative communications rely on quasi static fading channels with limited delays among signals received from different relays at the destination in which every transmitted block is preceded by a time guard not less than the maximum possible delay among the relays. Therefore, it cannot directly apply them for cooperative UWAC[1].

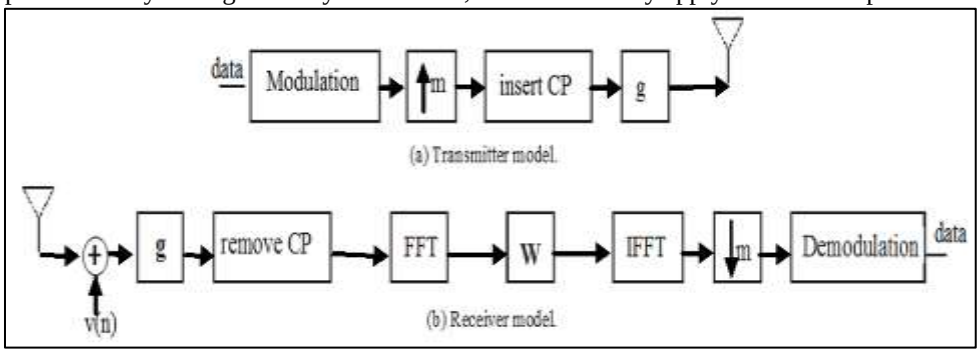

Fig. 1: Transceiver structure.

In a space frequency coding approach is proposed which is proved to achieve both full spatial and full multipath diversities. In OFDM transmission is implemented at the source node and relays only perform time reversal and complex conjugation. A trivial generalization[1] of existing OFDM based results to compensate for large relative delays may be to increase the OFDM block lengths. The main drawback in this case is that inter carrier interference is increased due to the time variations of the UWA channels. Another trivial solution is to increase the length of the CP. This is not an efficient solution either, since it dramatically decreases the spectral efficiency of the system. The main focus was on OFDM based cooperative UWAC systems with full duplex AF relays where all the nodes employ the same frequency band to communicate with the destination. It assumes an asynchronous operation[1] and potentially very large delays among different nodes and a new scheme which can compensate for the effects of the long delays among the signals received from different nodes without adding an excessively long CP.

Design of the space time codes is out of the scope of this work[1] however, the PEP performance analysis of the system under quasi static and block fading frequency selective channel conditions which can be useful in a diversity order analysis of the scheme and possible space time code designs[1]. The PEP analysis for the quasi static and block fading frequency selective channels is as follows. Assume that the channels from the source to the relays have significantly higher SNRs than the channels from the relays to the destination. Then first give the considered block fading channel model and provide a discussion on the discrete noise samples at the destination under the block fading channels. At the end provide the PEP analysis for which similar to the quasi static channel conditions, and assume that no coding is employed over the subcarriers and focus on the spatial diversity analysis of the system. The main drawback is it focused only error rate[1] in time varying channels.

Linear multihop UWAN[5], is a multihop underwater acoustic line network, which consists of a series of equal distance hops connected by relay transceivers in a tandem[5], is considered. Messages are originated as coded packets from a source node at one end, relayed sequentially hop by hop, and finally received by a destination node at the other end of the network. Several key characteristics of underwater acoustic channels, namely, frequency dependent signal attenuation and noise, interhop interference, half duplex modem constraint, and large propagation delay, are taken into account in the analysis. Simple transmission protocols with spatial reuse and periodic transmit or receive schedule are considered[5]. Performance bounds and scheduling design are

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developed to satisfy the half duplex constraint on relay transceivers in the presence of long propagation delay. To efficiently cope with frequency dependent channel characteristic and interhop interference, the power spectral density of the signaling is analytically optimized in a way analogous to water filling[5]. However, the situation dramatically changes for multihop networks with half duplex relay transceivers and with interference among hops. Such a situation arises in wireless radio links, or underwater acoustic links.

The interference among hops is due to the broadcasting nature of wireless communications, and it fundamentally changes the network model from a simple multihop tandem to a general relay network, for which the capacity problem is extremely difficult and still open. It is not the aim to solve the general information theoretic problem which is its main drawback, but instead, [5] it consider several suboptimal transmission protocols which explicitly consider features of underwater acoustic channels, and analyze their performance. Then consider the problem of determining the minimum number of hops between two fixed end nodes, for supporting a prespecified rate and reliability, which is measured in terms of packet error probability. Then find conditions for determining the minimum number of hops, under either the ideal situation of capacity achieving coding with sufficiently long packets, or the more realistic situation of reliability rate tradeoff with finite packet lengths.To improve the spectral efficiency, the idea of spatial reuse is critical, in which for each time slot, a certain subset of nodes transmit while another subset of the nodes that receive. For practical systems, it is noted that, this may be more relevant to evaluate the channel reliability function in an ad hoc fashion for the specific coding scheme used.

In some applications such as underwater acoustic communications, the low speed of the acoustic wave results in a very long delay between the channel state information[2] measurement time and the relay assignment time, which leads to a severely outdated CSI. To remedy this, a distributed coding schemes that aim at achieving good diversity[2] multiplexing trade off for multiuser scenarios where CSI is not available for resource allocation. Then consider a network with multiple source nodes, multiple relay nodes, and a single destination, first introduced a distributed linear block coding scheme, including Reed-Solomon codes,[2] where each relay implements a column of the generator matrix of the code, and soft decision decoding is employed to retrieve the information at the destination side. Then end to end error performance of this scheme and show that the achievable diversity equals the minimum Hamming distance of the underlying code, while its DMT outperforms that of existing schemes. The contributions of this paper can be summarized as, a distributed coding schemes that aim at achieving good diversity multiplexing tradeoff without the need to have the CSI available for relay assignment. Both block codes and convolutional codes are considered.

The DMT of the scheme outperforms that of existing schemes. This property is related to employing soft decision decoding at the destination which can achieve diversity equal to the Hamming distance of the underlying code. Since the scheme is not adaptive, the relays do not need to send an extra bit map field to inform the destination about the corresponding messages included in the packet. In this way, fixed relays are assigned to each source node and thus, the management of the network will be much easier. This scheme offers the best diversity among competitive schemes except for distributed space time schemes. Those space time schemes require very careful inter user synchronization at the bit/baud level, but the scheme is free of this limitation. To obtain diversity using channel codes, different coded symbols should undergo different channel fades. This model for[2] distributed convolutional codes where parallel convolutional codes were employed at each source to provide the required diversity at the relays and achieve the desired E2E performance.

Long acoustic multipath limits the applicability of MIMO-OFDM channel estimation methods[6]. To overcome this problem, sparse nature of the channel is exploited in an algorithm based on a compact signal representation that leads to two forms of adaptive implementation, that requires matrix inversion but of a reduced size, and another that completely eliminates it. Channel estimation is coupled with phase tracking and prediction to enable decision directed operation in the presence of non-uniform Doppler distortion, which in turn provides improved performance and reduced overhead. The Framework of decision directed adaptive block processing is adopted, making use of the Doppler compensation principle and focusing on channel estimation. To fully exploit the frequency correlation, it focuses on LS channel estimation in the impulse response domain, seeking reduction in complexity through channel sparsing and a block adaptive method that eliminates the need for matrix inversion. Multiple channels are estimated simultaneously and the process is coupled with non-uniform frequency shift compensation. The knowledge of data symbols rests on the ability to accurately estimate the channel, and the assumption that the channel does not change much from one OFDM block to another. Channel estimates from the previous block can then be used to make tentative symbol decisions that will in turn be used to update the channel estimate. An adaptive channel estimator can be obtained by filtering the instantaneous estimate. This estimator still requires matrix inversion, and although its size has been reduced, further simplification may be desired[6]. Slow convergence of the LMS algorithm is not considered as an issue. OFDM, which offers low complexity post FFT processing of multipath distorted signals, was considered in a MIMO setting as a means of increasing the bit rate via spatial multiplexing over bandwidth limited acoustic channels.

To counteract the inevitable motion induced Doppler distortion, non-uniform phase tracking was employed together with adaptive, decision directed channel estimation. Discarding the insignificant channel coefficients provides improved performance on naturally sparse underwater channels, as well as the additional benefit of reducing the size of the channel estimation problem in a MIMO framework[6]. An adaptive estimator of the LMS type was employed to further reduce the computational complexity by eliminating the need for matrix inversion. The algorithm was tested on experimental data, showing excellent performance at no pilot overhead.

A fully angle domain frequency[4] selective sparse channel estimation algorithm for MIMO-OFDM UAC systems was designed. The algorithm is divided into two stages finding nonzero tap positions and finding nonzero angle domain coefficients

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to reduce the computational complexity. It has been demonstrated that the 2-stage orthogonal matching pursuits algorithm provides an efficient way to estimate the under determined frequency selective sparse channel with reduced complexity for MIMO-OFDM UAC systems [4]. Compressive sensing has been studied for sparse signal recovery for a long time in applied mathematics, and is now being widely applied to various signal processing applications, such as imaging, radar, data acquisition, and channel estimation. The poor performance of the MP algorithm is due to the correlations in the dictionary atoms. The performance difference between the 2-stage OMP and 1-stage OMP[4] algorithms is prominent in the low SNR region. This is because selecting the nonzero tap positions in the first stage effectively reduces the potential estimation error by constraining the dictionary in the second stage to be constructed only from the selected nonzero taps. It has been demonstrated that the 2-stage OMP algorithm provides an efficient way to estimate the underdetermined, frequency selective, sparse channel with reduced complexity for MIMO-OFDM UAC systems[4]. The main contribution in this system is to show the application of the OMP algorithm to the angle domain MIMO UAC channel estimation, which will lead to efficient analysis and design of MIMO communication systems.

III. CONCLUSION

After a detailed survey among various underwater communication fields with acoustic waves it can be concluded that the scope and researches on UWAC is emerging day by day. This paper deals with acoustic wave communication in different areas and applications in underwater communication and search for the limitations in practical implementation of these systems. Thereby understood the advantages to incorporate with a system design and filtered out the limitations that should be avoided for a reliable system design. This literature followed an overview of UWAC by analyzing diversity coding, frequency and angle domain equalization and data detection, MIMO-OFDM based system designs, multihop networks etc. To develop a new underwater communication system, research and review should be a main factor, so this paper can be concluded wisely as it met both aspects. Thus some future scopes are observed to implement in upcoming researches.

IV. FUTURE SCOPES

Future advancements in this system can be implemented in terms of its limitations and including its advantages to design a new system. Data estimation was previously considered but equalization or error removal is not achieved. As underwater communication is susceptible to multipath fading, effective measures have to design.

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