

# *Recent Trends in Adaptive OFDM and Future Direction on Underwater Acoustic Communication*

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## **Abstract**

*Underwater wireless communication (UWC) has played a vital role in the exploration of aquatic environments such as oceans, rivers, ponds, etc. The acoustics transmission in underwater faces a lot of hurdles such as temperature, pressure, water characteristics environment, and noises variety which makes underwater acoustics (UWA) communication more challenging and unique. UWA channel model is the most challenging task due to its time-varying and multipath spread properties. The main initiatives and contributions of this study provide the current UWA communication survey on channel estimation. The current and previous work is also summarized of orthogonal frequency division multiplexing (OFDM) UWA communication techniques concerning applied theoretically. The summary of current research activities and future trends has been presented.*

**Keywords**— *Underwater communication, Orthogonal frequency division multiplexing (OFDM), Channel estimation, Channel modeling, Recent trends*

## **INTRODUCTION**

The earth's surface is covered more than 75% by the ocean. The ocean's continent-wrapping currents, each holding an enormous amount of water as all the world's rivers combined, will justifiably be thought-about the planet's vascular system. It appears that this circulation has begun to thump faster. For nearly last twenty-five years the currents are speedily rushing up, part due to global warming, and it has become a prior issue for several decades, due to climate change involvement and the continuous rise of global warming [1]. The polar ice sheets are melting gradually, so, that sea level is continuously rising. Hence it is required to monitor the activities of the ocean environment, water sampling, water pollution, and ocean graphic data. In recent decades, researchers are taking an interest in the exploration of the underwater environment such as the ocean, sea, river, and pond. The underwater communication (UWC) investigation technique is attracted by the researcher in recent decades. The UWC is used to earthquakes early detection seismic, warning of tsunami information underwater telephones, and exploration of underwater things. At present underwater communication is used in three manners such as

optical communication, radio frequency (RF) communication, and acoustics communication.

Optical communication provides high bandwidth and high data rates with low latency [2]. Because of the underwater channel, the dispersion is a high and minimum spreading delay. In 800 BC, optical wireless communication was used in the battles field to deliver a message by the ancient Greeks and Romans [3]. In the 1880s, the wireless telephone was invented by Alexander Graham Bell, to send and receive sound up to 200m based on optical waves. In the late 19th century under military application heliographs are used which works on optical signaling [4], [5]. The fiber optics and photonic crystal fiber (PCF) were introduced after the 1970s because of the large divergence of laser beams.

In the 19th century, Electromagnetic (EM) communication is used through the Morse code over long distances for military applications. EM wave which is used in radio frequency wave (RF). The range between transceiver is up to high data rate acquisition and transformation in shallow water over short distance [6]. The EM wave propagates underwater with very high speed and frequency for a short distance. Because of water medium-high speed and limited parameter of RF

communication in underwater have become major challenges [7], [8]. Even today, UWC is attained by engaging acoustics waves [9]–[17]. It is most popular for employing the acoustics signals for UWC over the long-distance transmission. UWC is capable of long-distance transmission with high spreading delays and low latency. It supports the low data rates for medium distances with quite an increase in information signal delay. In the 15th century, Leonardo da Vinci was introduced in their experimental work. In 1826s, J.D.Colladon experimented in the lake and proposed the speed of sound. By using optical flash, the velocity of sound in underwater was measured 1435 m/s. Further, Rayleigh gave a theorem on the velocity of sound over their entire related work. In the late 19th century, underwater acoustics (UWA) communication was proposed over 20 m depth and 13 km water surface, the data rate is 8 kbps [10], [15], [17]. In 2005, by using a 32 quadrature amplitude modulation (QAM) technique, UWA communication systems were proposed with a 125 kbps data rate.

In a UWA communication environment, Channel estimation is a challenging aspect nowadays [11]–[20]. The water channel is defined according to water properties, so different researchers using different channel models with different system models have estimated. Water properties are defined with their salinity, temperature, pressure, etc. As the water channel is moving to depth the pressure of water is increases, so, we can say that refractive indexes of water increases [2], [3]. The underwater channel is estimated using adaptive signal processing based on the least square ray theory and sparse recovery [11] methods base on researchers.

The rest of the paper is organized as follows: In section II, we introduce the channel characteristics for underwater acoustic transmission. Section III briefly explained the channel estimation algorithm which is used in UWC. Section IV reviewed the OFDM based channel estimation for UWC. Section V explained future trends in 5G UWC communication. Finally, the concluding remarks for this review paper in section VI.

**UNDERWATER CHANNEL CHARACTERISTICS FOR UAC**

The UWA channel complexity includes multipath delays, time-varying property, and large Doppler spread due to a large number of arrivals, environmental characteristics, and sea surface motion respectively. The underwater channel characteristics depend upon water salinity, currents, seabed relief, tides, and temperature. So

the UWA characteristics also include their water characteristics.

**A. Acoustics wave**

UWC is attained by employing acoustics waves despite it ensures the low data rate for medium distances. Acoustics waves revel very low speed over long distances with lower attenuation. For better communication, the velocity of sound is 1500m/s. which is four times bigger than air (at 340 m/s, sound travels decently through the air). As we have optical and RF technologies that have limited propagation ranges other than Acoustics communication technology propagates a large range in the underwater channel [17]. It propagates lower bandwidth and frequencies as well as a lower speed of sound 1500 m/s. Researchers are also proposed that as moving in the depth of underwater the acoustics wave speed increases nearly 17 m/s per kilometer. Similarly in salinity acoustics wave increases 1 practical salinity unit (PSU). Table. I explain the Bandwidth and data rates over ranges in the UWA link and Table. II explains the comparison of different UWC technologies. The bandwidth is defined very low for UWA communication because the Speed of sound in UWC environments has discussed an acoustics model with water depth up to 1 km [12]. From the Table. I, the data rate is 10 kbps and 5kbps for medium and long ranges respectively.

$$c = 1448.96 + 4.591T - 0.591T - 0.05304T^2 + 2.374 * 10^{-4} T^3 + 1.340(S - 35) + 0.0163d + 1.67 * 10^{-7} d^2 - 0.01025T(S - 35) - 7.139 * 10^{-13} T(d^3) \tag{1}$$

where T denotes the underwater channel temperature, d denotes the depth of water and salinity of water represents by S. As acoustics wave moving to a depth of water the temperature increases by 1°C to nearly 4 m/s increment in speed of sound in underwater

**Table I. Bandwidth and Data Rates Over Ranges in Uwa Link [5, 18]**

Propagation distance	ranges (meter)	Bandwidth (kHz)	Data rates (kbps)
Very sort	< 0.1	>100	500
Short	0.1-1	20 to 50	30
Medium	1-10	Up to 10	10
Long	10-100	2-5	5
Very long	>1000	<1	600

**B. Path loss**

Francois and Garrison, as well as Fisher and Simmons, were proposed empirical formula for Absorption loss which varies with pressure

according to with depth, temperature and frequency expressed as [19]

$$\alpha(f) = \frac{A_1 P_1 f_1 f^2}{(f_1^2 + f^2)} + \frac{A_2 P_2 f_{21} f^2}{(f_2^2 + f^2)} + A_3 P_3 f^2 \quad (2)$$

where the absorption coefficient is represented by  $A_1$ ,  $A_2$ , and  $A_3$  are coefficients which depends on effects of temperature on signal absorption.  $P_1$ ,  $P_2$ , and  $P_3$  are pressure intensities.  $f_1$  and  $f_2$  defines the relaxation frequencies. The absorption coefficient is the overall sum of the chemical relaxation and absorptivity by water. The path loss/ attenuation loss in underwater is frequency-dependent and expressed as )

$$A(l, f) = l^k \alpha(f)^l \quad (3)$$

where  $f$  is the signal frequency and  $l$  is the distance between transmitter and receiver. The propagation constant is represented by  $k$ . The spreading loss and the energy absorption of the pressure waves are major caused by the distance and this cause is frequency-dependent.

**C. Multipath channel**

The multipath propagation is the major and common issues in UWA communication. The acoustics signal is transmitting transmitter to receiver links. In general, the acoustics signal is affected by the surface of the water, bottom surface in water, or from the other objects, affected by interference. So, acoustics signal to reach the receiver with different multiple paths. The channel impulse response is expressed as,

$$h(\tau, t) = \sum_p A_p(t) \delta(\tau - \tau_p(t)) \quad (4)$$

**D. Doppler spread**

The relative motion between the transceiver causes the Doppler spread frequency. Due to the acoustics signals relatively low frequency in underwater, the Doppler factor is about  $a=10^{-4}$ .

**CHANNEL ESTIMATION ALGORITHMS FOR UWC**

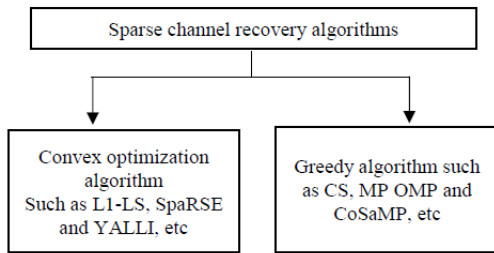
The UWA channel is sparse which means channel impulse responses have more values are zero or very near to zero, so, in the sense that few propagation paths are carrying channel energy. Fig. 1 depicted the condition for underwater sparse channel recovery algorithms which is divided into two manners: first one convex optimization algorithm, second, greedy algorithm. L1-LS [20], SpaRSE [21], and YALLI [22] is proposed as a convex optimization algorithm for the UWA channel model. A greedy algorithm such as compressed sampling (CS), matching pursuit (MP) orthogonal matching pursuit (OMP), and CoSaMP (compressed sampling matching pursuit) [23], etc. According to the information being used, channel estimation is divided into three manners: first, training symbols using a part of bandwidth which is also called pilot-assisted. Second, a blind approach and third semi-blind approach. Blind approaches are also known as the estimation of the channel without using the knowledge of transmitted data. Semi blind approaches in estimation are just inversely to blind approaches where the exploit partial knowledge of the transmitted data. The channel estimation simulation for orthogonal frequency division multiplexing (OFDM) has been a challenging issue [24]. Researchers are always focusing on reducing the channel matrix complexity because the channel estimation involves the inversion of a massive matrix. Due to the low SNR of UWA communication, mainly focusing on the reduction in space complexity are categorized. The basic channel estimates  $\hat{h}$ , the channel frequency responses on each data subcarriers  $k$  are given by

$$\hat{H}(k) = \sum_{l=0}^L \hat{h}(l) e^{-j2\pi k l / K} \quad (5)$$

**Table II Comparison of Different UWC Technologies [18]**

UWC technologies	Ranges	Transmission power	Affecting factors by underwater channel quality	Latency	References
Underwater optical wireless communication (UWOC)	Up to 100 m	mW - W	Scattering, absorption, dispersion, turbidity and organic matter of channel link	Low	2,3,4,5
Underwater wireless radio frequency communication (UWRF)	Up to 10 m	mW - W	Permittivity and conductivity	Moderate	7,11,16
Underwater acoustic communication (UAC)	Up to 20 km	Greater than 10 W	Scattering, absorption, dispersion, pressure, temperature and salinity	High	11,12,13,17,18,

Where  $K$  is the number of subcarriers and  $L$  denotes the channel order.



**Fig. 1: Adaptive recovery algorithm for UWC**

## CHANNEL ESTIMATION IN UWC SYSTEMS

This section represents the brief research on symbol detection, error measurements, and channel estimation. In [25], the author proposed the CS channel estimation across Doppler frequency by using non-uniform sampling across the different frequency ranges. Estimated Results are represented in the 2D frequency domain of shallow water acoustics channel. Normalized MSE (NMSE) for performance evolution SNR is represented to sampling ratios. Data on the 2008 surface processes and acoustics communication experiment (SPACE08) channel in Martha's Vineyard is used. Logarithmic minimization 1st order cost function methods such as logarithmic cost least mean squares (LCLMS), logarithmic cost least mean absolute (LCLMA) and 2nd order cost function method logarithmic cost recursive least absolute (LCRLA), logarithmic cost recursive least square (LCRLS) are focused by the authors in [26]. The authors focused on the results of adaptive filtering in the trade-off between convergence rate and steady-state performance. Further also proposed frequency and phase offsets. Using 1st and 2nd order BER and MSE versus SNR are also obtained.

In [27]–[33], the authors have been proposed the OFDM technique. The MP with maximum posterior probability (MAP) is used to improve the channel estimation technique in [27]. The MAP based on space-alternating generalized expectation-maximization technique (SAGE) used to improve the channel estimation technique. Fast adaptive channel estimation is proposed based on the least square (LS) and the RLS algorithm in [28]. The authors proposed a pilot routing algorithm in [29] which increases the accuracy of transmission and channel estimation efficiency through BER. The BER vs. SNR and MSE vs. SNR are produced for different values of mutual coherence. Clustering and sparsity can improve channel estimation in UWA communication. The authors proposed the Markov chain Monte Carlo

(MCMC) MMSE channel estimation algorithm in [30]. The output is obtained at NMSE vs. SNR for 128 pilot subcarriers and SNR 5dB with BER vs. SNR. A frame-based CS algorithm in terms of the frequency domain is proposed in [31]. The fast Bayesian MP (FBMP) estimation of sparsity is proposed in [32]. The output of channel estimation in [33] is obtained BER performance against OMP. The result FBMP saves SNR of 4dB which is compared to OMP. In [34], filtered multitone (FMT) OMP for the underwater channel which is defined similarly to sparse channel estimation is proposed and the estimation technique reduces the complexity through splitting sub-bands.

In [35], the authors proposed a motion-induced Doppler frequency offset. The proposed method in a multicarrier communication system based on pilot assisted OFDM. To target Doppler frequency offset through two methods such as hypothesis testing (HT) and Stochastic Gradient (SG) algorithms. The experimented channel model MACE'10 is used for transitions of high data rate, where, HT algorithm is defined as a simple linear search over the hypothesized interval. Through the SG estimation method average, MSE is achieved below -12 dB for 90% of OFDM blocks. This method also enables a very high rate of low-density parity-check (LDPC) code. The excellent BER of  $10^{-5}$  is achieved by the LDPC code. In [36], the authors proposed the coherent detection problem of OFDM signals transitions through a multipath propagation channel. OMP Algorithm With modified Gram–Schmidt (MGS) and least squared (LS) algorithm is compared with the path identifier (PI) algorithm. The sparse channel estimation with a PI algorithm is used to achieve average MSE below -14 dB for 93% of OFDM blocks. The OMP and LS algorithm delivered 83% and 68% of OFDM blocks respectively. In [37], the authors proposed OFDM based FFT channel estimation using Fast Walsh- Hadamard transform (FWHT) which avoids the time offsets.

In [38], the authors experimentally proposed an in-band full-duplex UAC system. The pool experiment is done and the dimension of the pool is taken as  $45\text{m} \times 6\text{m} \times 5\text{m}$  (length  $\times$  width  $\times$  depth) respectively. The equispaced pilot assisted OFDM signal is used as a system model where each pilot is spaced by 3. ML channel estimation is used to estimate the sparse self-interference (SI) channel. The ML channel estimation is done in the time offset domain. The MSE comparison between the non-parametric maximum likelihood (NPML) and LS estimation is proposed.

In [39], the author proposed the experimental results in Wdzydze Lake (53°58'31'' N 17°54'19'' E) on 5th May 2017. Four configurations of the OFDM modulation UWA communication system is proposed. The enormous BER of less than 10<sup>-4</sup> is achieved. The UWA MIMO OFDM system is presented joint low complexity regularized zero forcings (JLRZF) equalizer in [40], [41]. The JLRZF equalizer performs in both equalization and carrier frequency offset (CFO). MMSE equalization technique is proposed and compared with traditional Zero forcings (ZF), the SNR is given in the range of 0.53 and 4.19 respectively. The BER is achieved at 10<sup>-2</sup>. In [41], the author proposed a pH value to boric acid (B(OH)<sub>3</sub>) and magnesium sulfate (MgSO<sub>4</sub>), which is used to calculate the attenuation in seawater.

### 5G INTEGRATION IN UWC

The emerging 5G cellular technology with an exponential rise in wireless communication. The huge demand for 5G will be the future's forthcoming wireless networks. According to the survey [18], [42] 5G would be the greatest prominent sway among the new applications, suggested by researchers such as the Device to device (D2D) communication, Internet of things (IoT), Internet of underwater things (IoUT) and UWC. The existing 4G cellular communication technology supports to increase in connectivity and huge data usage and this technology are based on the OFDM technique which supports a maximum of 20MHz bandwidth [43].

Generalized frequency division multiplexing (GFDM) is a frequency and time based multicarrier transmission scheme that is derived from filter bank multi-carrier (FBMC) [43]. In [44], 5G wireless network experimental work experiments in the underwater domain. The authors proposed GFDM based experimental model on the 5G network in the underwater domain. A high-speed UWC based OFDM provides in the same direction has been discussed.

### CONCLUSION

This paper gives the recent development in OFDM based underwater acoustic communication survey. The channel estimation of OFDM based system model in the field of UWC is reviewed. Proper explanation of the water channel for communication which is affecting the underwater signal, such as water salinity, currents, seabed relief, tides, and temperature. The transfer function in the underwater channel model is explained theoretically and mathematically. UWC technologies are compared among RF signal,

optical wave, and acoustic signal. As demand for high-speed communication in UWC is increased day by day, so based on demand MIMO OFDM in UWC is a new research interest. The emerging 5G technology in UWC is also reviewed. The prime objective of this paper is to encourage research efforts in UWC and encourage interest in 5G technology in UWC.

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