

# Monte Carlo Simulation for Underwater Laser Communication

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**ABSTRACT:** For the military, scientific community and industries, sending information through underwater is of great interest. Underwater wireless communication plays an important role in weather prediction, oil exploration, mining, pollution monitoring and research in oceanography. To improve these activities, underwater vehicles and devices have been used. For all these facilities, the communication channel requires high capacity and high bandwidth. Underwater communication is carried out using acoustic, RF and optical transmission techniques. In this paper we describe a long distance underwater laser communication system based on Monte Carlo simulation.

**KEYWORDS:** Underwater Wireless Communication (UWC), Monte Carlo simulation, Underwater Optical Wireless Communication (UOWC)

## I. INTRODUCTION

Two third of earth is filled with water. Humans have exploring the ocean from thousand years. With the increasing change in climate and depletion in resources the research on ocean exploration system is gaining a lot of interest. The underwater wireless communication is gaining much attention now a days as it allows the realization of ocean exploration system.

Data transmission in an unguided water environment using wireless carriers refers to Under Water Communication (UWC) [1]. There are mainly 3 types of communication carriers, namely acoustic waves, radio frequency waves and optical waves. Underwater optical wireless communication (UWOC) offers higher data rate and bandwidth as compared with acoustic and Radio Frequency (RF) waves.

In fresh water, communication using RF signal requires antenna with large height and transmit power. Also, signals get attenuated when they travel through water. To overcome this problem, optical signals are used which provide higher data rate [2]. For a short distance the data rate will be of the order of Gbps because of high frequency of the optical signal [3]. Underwater optical communication using laser is used in different fields like underwater laboratories, which collect and send oceanographic data to the outside world for processing. In the current network centric warfare scenario, one of the most backbreaking and essential technology is submarine to ship, ship to submarine, submarine to submarine satellite to submarine and submarine to satellite communication.

Properties of water bodies and concentration of dissolved substances alter depending on the geographical location. As a result of this optical signals may undergo scattering and absorption in underwater [4].

Before designing under water laser communication, it is necessary to stimulate such a system to analyse the functionality. Monte Carlo mechanism is used as a tool to simulate such an underwater communication scenario. Monte Carlo simulations are used to trace millions of photons based on statistical probabilities. The source for these photons being simulated can be artificial light or sun. As determined by the probabilities of scattering, absorption, transmission reflection or solid-liquid and air-liquid interface, the path of each simulated photon vary randomly from one another.

## II. RELATED WORK

R. S. Sangeetha et.al [5] illustrated an optical communication link using 635nm laser diode and silicon photo detector. Performance of communication between an underwater body and space platform was studied in a laboratory setup. This set up mimic to a satellite to submarine communication and vice versa. Transmitter and receiver were in the

optical communication link. The transmitter had a 635nm laser diode and the receiver had a photo detector. The baud rate achieved in this experiment was 9.2 kbps to 110 kbps.

A. Kumar et.al [6] presented an experimental setup for underwater optical communication. Two UWOC setups were realized, first setup was designed by using opaque PVC pipes and the second setup was designed using aquarium tank. This experimental setups contained transmitter, water tank (channel) and receiver. The input binary signal is converted into an optical signal by optical transmitter. The optical signal is detected by an optical receiver. To retrieve the transmitted signal back, the received optical signal is decoded. With the bit error rate of  $10^{-3}$  for an experimental setup of 1.5m long PVC pipe, the transmit power detected was 0.61 dBm for fresh water and for sea water it was 0.82 dBm. The transmit power differed between 5.134-1.08dBm for the tank setup.

After performing an experiment in a harbor basin in 2016, a sea experiment was conducted on October 2017 under harsh environmental conditions in the western Baltic sea by T. Scholz [7]. There was an experimental setup which consisted of a transmitter and a receiver. The source used here was laser. When the transmitter and receiver was apart by a distance of 2m distance, the maximum data rate achieved was 21Mbps for the transfer of 80 Megabyte video file.

W. Liu et.al [8] studied the characteristics of the non-line-of-sight (NLOS) channel for UWOC, for various optical frequency range ranging from 400nm-600nm. The channel was modelled using the Monte-Carlo ray tracing technique. The impulse response and path loss at different wavelengths in various water conditions were analysed.

Y. Li et.al [9] designed and developed a high speed underwater wireless optical communication system and experimental platform of 100Mbps full-duplex UWOCs. They achieved 100Mbps Ethernet service successfully. The influence of different types of water like pure sea water, deep sea water, coastal sea water, turbid seawater on the performance of communication was examined. The Bit Error Rate (BER) for deep sea water, coastal sea water and turbid sea water were lower than  $10^{-10}$ .

N. E. Farr, et.al [10] explained about the lab and field experiments conducted using short wavelength by optical communication group of Woods Hole Oceanographic Institution for the purpose of nonvisible underwater communication, Wavelength Division Multiplexing (WDM) and enhanced day light performance. For WDM in shallow water and deep water, 405 nm Light Emitting Diodes (LED) were used.

T. Zhou et.al [11] designed and conducted a long distance underwater optical communication in which they used photon counting receiver. To evaluate the system performance and to determine the system parameters Monte-Carlo simulation was performed. The experimental implementation was performed in a long tank filled with clean water. The experimental result showed that the optical communication could be achieved over a distance of 85m. The data rate achieved was 80kbps and BER was less than  $10^{-4}$ .

C.D. Mobley [12] discussed about quantifying the optical properties of light within the water in different ways and also provided an overview of the terminology and definitions used in oceanography and also provided examples of scattering and absorption properties by considering an ocean with clean water and another with high turbidity.

K.J. Waters [13] illustrated that for an ideal collimated light like laser beam, we can simply initiate photons in a common location and point it in same direction with the weight of each photon to be unity. The process of scattering and absorption by sea water was quantified by the scattering coefficient  $b$  absorption coefficient  $a$ . The attenuation coefficient  $c$  is given by  $c=a+b$  and single scattering albedo  $\omega_0$  is defined as  $b/c$ .

### III. METHODOLOGY

Monte Carlo method is a computational algorithm and is based on repeated random sampling. The main idea is using randomness to solve problems which may be deterministic in nature. The advantage of Monte Carlo simulation is that it is quite simple and can be used for both stochastic and deterministic samples.

The values are sampled at random in Monte Carlo simulations. Each set of samples is called an iteration, and the resulting outcome is documented. Monte Carlo simulation does this hundreds or thousands of times, and the result is probability distribution of possible outcomes. This technique tells us not only what could happen but how likely it is to happen.

A numerical way to simulate photon transport is Monte Carlo modelling of light transportation. It is a widely used simulation method for multiscattering channel. The simulation process can easily understood. Monte Carlo simulation is based on the brute tracing of packets of photon. The collisions between the packets of photon and particle is treated as interaction of laser pulse with water.

The important parameters of the water used in simulations are absorption coefficient  $a$ , scattering coefficient  $b$  Attenuation coefficient  $c$  and single scattering albedo  $\omega_0$

$$c=a+b$$

$$\omega_0=b/c$$



In this method the attenuation coefficient of water  $c$  is assumed to be 0.29/m, absorption coefficient  $a$  as 0.073/m, scattering coefficient  $b$  as 0.217/m, initial weight of photon as 1 and minimum weight of the photon to discard it is 0.0001.

Algorithm of Monte Carlo simulation:

- Step. I. Initialize the absorption coefficient  $a$ , scattering coefficient  $b$ , maximum weight of the photon, minimum weight of photon.
- Step.II. Calculate attenuation coefficient  $c$  and single scattering albedo  $\omega_0$ .
- Step.III. Initialize the number of photons to be transmitted.
- Step.IV. Initialize, how many times a photon undergoes scattering.
- Step.V. Initialize the direction cosines of photon.
- Step.VI. Scatter the photons one at a time.
- Step.VII. Compare the weight of the scattered photon with the minimum weight. If the weight of scattered photon is below minimum weight then discard the photon and go to Step III and scatter next photon, else update the direction cosines and go to Step.VI.
- Step.VIII. Find the number of photons survived after it undergoes scattering.

#### IV. EXPERIMENTAL RESULTS

Monte Carlo simulation is widely used to trace the photons. We performed Monte Carlo simulation using MATLAB. We assumed the attenuation coefficient of water  $c=0.29/m$ , absorption coefficient  $a=0.073/m$ , scattering coefficient  $b=0.217/m$ , the maximum weight of the photon is unity and minimum weight is 0.0001. During simulation, 102 photons were transmitted and all the photons have been detected by the receiver with no errors. Further if we transmit 103 photons, in which only 992 photons were received, i.e. there was a BER of 0.008. The BER increased as the number of photons transmitted increased.

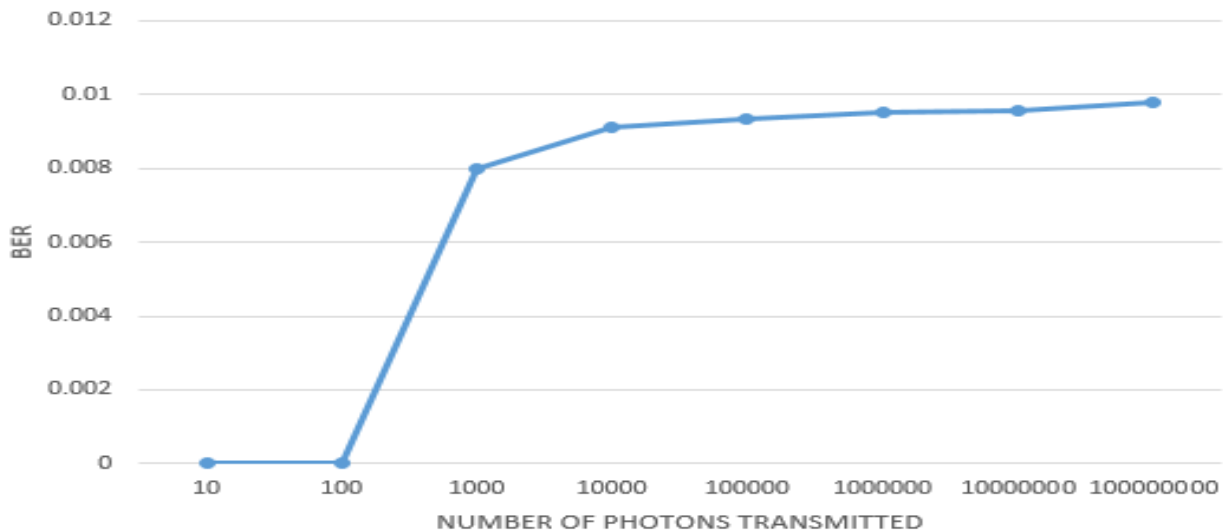


Figure 1. Number of photons transmitted versus BER graph

A graph for number of photons transmitted versus BER was plotted as shown in Figure1. The BER increases as the number of photons transmitted increases.



Table.1 Probability of photon survival for different types of water.

Type of water	Absorption Coefficient $a(m^{-1})$	Scattering Coefficient $b(m^{-1})$	Number of photons transmitted	Probability of photon survival
Clear water	0.114	0.037	$10^6$	0.9880
Coastal ocean	0.179	0.220	$10^6$	0.9779
Turbid harbour	0.366	1.829	$10^6$	0.9436
Pure water	0.073	0.217	$10^6$	0.9904

For the transmission of 106 photons the probability of photon survival is given in Table.1 for different types of water with different attenuation and scattering coefficients.

V. CONCLUSION

Monte Carlo simulations can be used for simulating all kinds of particle transport. The results showed that the Monte Carlo simulation used for underwater laser communication was nearer to the results obtained by [8]. But one major drawback of Monte Carlo technique is that it requires large computer capacity and large computational time. To overcome this problem modified Monte Carlo models can be used.

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