

# Enhancing IoUT Monitoring with Relay-Based Underwater Optical Wireless Communication

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**Abstract** — Issues like misalignment, limited range, and water turbulence have a detrimental effect on underwater wireless optical communication (UWOC) performance. The viability of widespread deployment may be impacted by these difficulties. When it comes to connecting different Internet of Underwater Things (IoUT) devices, UWOC can be far more important than traditional acoustic and radio frequency (RF) communication. In this study, a relay-based UWOC system called "aqua-sense" is designed and evaluated with the goal of improving communication connection performance and increasing the optical receiver's reception area. The optical relay uses combining strategies including Equal Gain Combining (EGC), Majority Logic Combining (MLC), and Selection Combining (SC) to maximize diversity gain and improve performance. To further enhance communication connection performance, a channel-aware algorithm also powers the optical relay, also known as the "opto-relay." At a communication link distance of up to 7.5 meters, the aqua-sense system transmitted at a rate of 0.2 Mbps and achieved a packet success rate of 68% in moderately murky water circumstances with a turbidity level of 25 NTU. Additionally, in clear water with a turbidity of 0.01 NTU, the sensor node, "opto-sense," consistently achieved a transmission rate of 0.5 Mbps. Within a 2-meter communication link range, these results held steady even in the presence of moderate water waves with a displacement rate of 5 liters per minute and air bubbles with an airflow rate of 5 liters per minute.

**Key Words:** Equal Gain Combining (EGC), Majority Logic Combining (MLC), and Selection Combining (SC), Underwater wireless optical communication (UWOC).

## 1. INTRODUCTION

Since their debut, wireless communication technologies have experienced several advancements and modifications. With the widespread availability of cutting-edge technology like smartphones, connected cars, and the Internet of Things (IoT), all of these new technologies

depend on wireless communication to meet their shared needs for high bandwidth and data rates [1]. The use of visible light (VL) band (400 THz to 800 THz) for optical wireless communications has been proposed as the best alternative to current communication systems that operate in the radio frequency (RF) band (3 kHz to 300 GHz) in order to overcome the over-crowded, low-frequency bands and provide higher data rates. Free space optical (FSO) systems are optical wireless communications used for outdoor applications; underwater wireless optical communication (UWOC) is the name used for underwater data transmission [2]. Data transmission between underwater devices or between an underwater device and the surface is known as underwater communication. Oceanographic research, underwater exploration, environmental monitoring, underwater surveillance, and underwater robotics are just a few of the many applications in which it is essential [3]. The limited range, low data transfer rates, and severe signal attenuation of underwater communication channels are some of the difficulties that underwater communication encounters. Since sound waves can travel great distances in water and pass through obstructions, they are frequently employed in underwater communication. However, data transmission rates are constrained by the limited bandwidth of sound waves. UOWC devices transfer data through water using lasers or light-emitting diodes [4]. UOWC can pass through water with less attenuation than higher-frequency light waves since they function in the visible or near-infrared (NIR) region of the electromagnetic spectrum. Higher big transfer rates, longer communication ranges, lower latency, and more secure data transmission are just a few of the many benefits that UOWC systems have over traditional acoustic-based systems [5]. The number of undersea activities has likewise increased in tandem with societal growth. As a result, the need for long-distance, high-speed underwater communications is increasing. Due to its greater flexibility when compared to wired communication systems, wireless communication systems have found

wider application in underwater operations, including underwater oil exploitation, natural disaster warning, and underwater environment sensing. [6]. Nowadays, acoustic and radio frequency (RF) technologies are the mainstays of underwater communication technology. The former is primarily used to achieve low-speed long-distance communication, while the latter is primarily used to achieve high-speed short-distance communication. However, there is a significant time delay in the acoustic communication system due to the sluggish sound wave propagation. Seawater's electrical conductivity significantly restricts RF transmission. Environmental monitoring, oil and gas development, and border security are just a few of the applications for UOWC systems in underwater surveillance. Real-time surveillance is made possible by the UOWC system's high data transfer rate and low latency, which is crucial for spotting and resolving security concerns [7]. Underwater Robotics: Remotely operated vehicles (ROVs) and unmanned underwater vehicles (UUVs) can be controlled and communicated with using UOWC systems. For these devices, real-time control and feedback are made possible by UOWC systems' low latency and high data transmission rate. Underwater Mining: Data from mining equipment can be transmitted to the surface using UOWC systems in underwater mining applications [8]. Real-time mining operations monitoring is made possible by UOWC systems' high data transmission rate and extended communication range. Aquaculture: UOWC systems are useful for keeping an eye on temperature, water quality, and other factors that are critical to the wellbeing of fish and other aquatic life. The aquatic environment's health depends on real-time monitoring, which is made possible by UOWC systems' high data transfer rate and low latency [9].

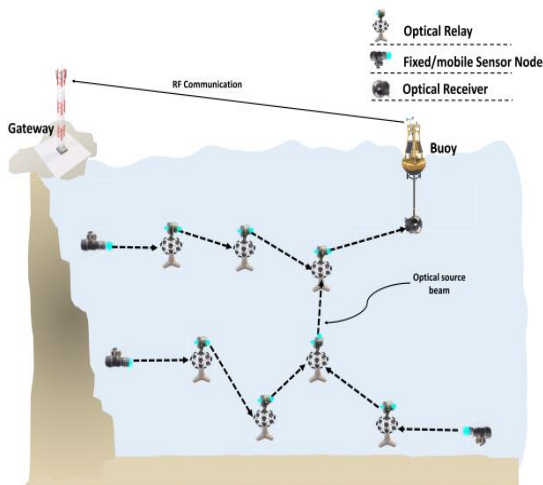


Fig 1: Architecture diagram

## 2.METHODOLOGIES

These BER values BEREGC, BERMLC, and BERSC are used by the OCS algorithm to choose the combining strategy that performs the best in terms of BER. The identifying key and related average voltage gain value (AVG) derived from the best-performing combining approach are returned to the main endless machine via the OCS algorithm. The best-performing combining approach is chosen using this identifying key, MinBERID, and AVG, whereas  $V_t$  is used for the payload packets' present reception. Following the estimation procedure, the token (T) is enabled as "LOW," or binary 0, to initiate the RPS algorithm's reception mode. Utilizing the chosen combining technique, the RPS receives the payload packets, which include the following: sensor data (temperature, pressure, and altitude data from the Bar02 sensor), sensor node identification key, synchronization byte ( $0 \times 180$  in hexadecimal), end byte ( $0 \times 00$  in hexadecimal) to identify the end of the payload packet, and header byte ( $0 \times 255$  in hexadecimal) to start the payload identification process. The payload packet is seven bytes in size. During the receiving mode, the functions return a null value for both the MV and the BER. These payload packets were finally routed by the opto-relay to the stationary optical receiver, which had a dependable communication channel to the outside world for in-the-moment observation and physical analysis.

### 2.1 Channel Modeling Module

An essential part of simulating the underwater optical wireless communication (UWOC) channel is the Channel Modeling Module. By taking into account the effects of the aquatic environment, it offers a realistic depiction of how optical signals behave underwater. explains how light travels through water and loses optical signal strength. The twin effects of signal absorption by water molecules and scattering by suspended particles are modeled by the absorption and scattering model. Turbidity levels and the type of water (coastal, turbid, or clear) affect these impacts. gives information about the possible communication range by taking into account the exponential decay of signal intensity with distance. Beam Spreading and Divergence: This model replicates how an LED or laser light beam spreads out over space, losing strength at the receiver. takes into consideration photons' tendency to scatter before arriving at the receiver, which is important in murky seas. comprises the effects of changing environmental factors that change the signal route, such as water waves, currents, and bubbles. In underwater habitats, ambient noise mimics the interference of natural light sources such as sunlight and bioluminescent animals. Shot Noise: This type of noise is caused by the distinct light

particles that the receiver detects. Thermal Noise: Simulates the noise produced by the optical receiver's electronic parts. adds complexity to the communication channel by simulating signal distortion brought on by reflections from underwater surfaces. These components work together to make the Channel Modeling Module a vital tool for developing and evaluating underwater optical communication systems. It ensures that the technology is robust, efficient, and capable of withstanding real-world challenges in diverse aquatic conditions.

## 2.2 Relay Network Module

To increase the communication range and dependability, put in place a relay-based network. Relay Node Placement and Selection: Based on signal strength, distance, or energy, this algorithm establishes the best relay node placement and selection criteria. Relay Handover Mechanism: Maintains the strongest communication link by controlling relay switching. An essential part of improving underwater wireless optical communication (UWOC) systems' communication range and dependability is the relay network module. This module ensures strong and long-lasting underwater communication lines by reducing signal attenuation and scattering effects by adding relay nodes to the communication network. use algorithms to find the best location for relay nodes, guaranteeing maximum coverage and little signal loss. To guarantee effective network topology, variables including water turbidity, node distance, and environmental factors are taken into account. uses variables such as distance measurements, energy efficiency, and signal intensity to dynamically choose the best relay node. Link quality monitoring in real time aids in network adaptation to shifting circumstances.

optimizes the number and placement of relay nodes to reduce energy consumption. This is particularly important for underwater gadgets that run on batteries. Continuous data transmission is ensured by seamless switching, which controls relay node changeover without interfering with the communication channel. Handover to the path with the best link quality is carried out by utilizing a channel-aware algorithm that assesses the quality of alternative relay paths. Load balancing: To avoid overloading and guarantee steady network performance, data traffic is divided across several relay nodes. By linking several relay nodes, multi-hop communication allows for multi-hop data transmission and greatly increases the communication range. The network is adaptable for bigger underwater deployments thanks to its scalable design, which can accommodate the addition of more relay nodes. Cluster-Based Relay Networks: Enhance network efficiency and

structure by implementing clustering techniques in which nodes in a particular region connect with one another via a specified cluster head relay. Latency Reduction: Minimizes the number of hops needed for data transmission and optimizes relay placement to reduce communication delay.

## 2.3 Communication Protocol Module

Control the flow of information between the central monitoring station, relay nodes, and sensors. Modulation and Demodulation: To maximize bandwidth and minimize error, use particular modulation algorithms for optical communication. Data Encoding and Decoding: To reduce errors, encode sensor data for transmission and decode it at the receiving end. Error Detection and Correction: To increase reliability, use algorithms to find and fix faults in data that has been transferred. An essential component of the UWOC system, the Communication Protocol Module controls dependable and effective communication between sensors, relay nodes, and the central monitoring station. This module overcomes the particular difficulties presented by underwater optical communication by putting strong modulation, data encoding, and error management techniques into practice, ensuring smooth data exchange. optimizes bandwidth use and reduces mistakes by converting digital sensor data into optical signals for transmission and vice versa. On-Off Keying (OOK) is a straightforward binary modulation method in which 1s and 0s are represented by light that is either on or off. ideal for gadgets with little power. Better energy efficiency is provided by pulse position modulation (PPM), which encodes data according to the location of a light pulse over a period of time. By dividing data into several frequency bands, orthogonal frequency division multiplexing (OFDM) improves transmission capacity and resilience in noisy situations.

## 2.3 Successive Interference Cancellation

In communication systems, SIC is used, especially when there is interference from several transmissions. SIC's main objective is to lessen the effects of interference and enhance system performance generally, particularly in situations where signals may overlap like in wireless communication. Several signals are sent across the same channel or frequency spectrum in a communication system. The quality of the received signals may deteriorate as a result of these signals interfering with one another. The receiver receives the incoming signals, which include both the desired signal and interfering signals. Usually, these signals are received in a specific priority or order. Decoding or demodulating the signal with the highest priority, typically based on the SINR or decoding

complexity levels, is the first step in the interference cancellation process. The whole received signal is then reduced or eliminated by the decoded signal. The previous step is repeated. The remaining signals are processed in the same way after the initial signal has been cancelled. This process keeps going until either a predetermined threshold is met or all of the major interference has been eliminated. The remaining signals, which now have less interference as a result of the sequential cancellation process, have finished their final decoding. When dealing with situations where the interference pattern is known or the signals have different intensities, SIC works well. It takes advantage of the fact that not all signals interfere with one another in the same way. The subsequent signals can be deciphered more precisely if the more prevalent interference is eliminated first. While SIC can significantly improve the performance of communication systems in the presence of interference, it is essential to note that it introduces complexity to the receiver, especially in terms of processing power and latency. The success of SIC depends on the accuracy of interference estimation and the order in which signals are processed.

### 2.4 Routing Protocol Module

Create and oversee effective routes for data packets to take as they pass through relay nodes and arrive at their destination. Underwater-specific routing protocols, such as depth-based, energy-efficient, or location-based routing, are implemented using the routing algorithm. Path optimization lowers latency and energy usage by modifying routing routes in response to current network conditions. The ability of the network to adjust to relay node failures or unfavorable channel conditions is known as fault tolerance. In underwater wireless optical communication (UWOC) networks, the Routing Protocol Module is intended to create and maintain effective routes for data packets to travel through relay nodes and arrive at their destination. In order to guarantee dependable and effective data transport, this module tackles the difficulties associated with underwater environments, including limited energy resources, dynamic situations, and relay node failures. uses routing methods designed especially for underwater conditions to guarantee reliable and effective data transfer. forwards packets to a destination or the surface using the nodes' depth information. removes the requirement for global topology knowledge, which lowers control overhead.

### 2.5 IOU Monitoring And Data Aggregation Module

Data from underwater sensors should be gathered, combined, and sent to a central monitoring station. Data

Collection: Models how sensors (such as temperature, pressure, and pollution levels) collect data. Data storage and aggregation: stores data for later processing and visualization and aggregates data for effective transmission. Evaluate the system's performance under different scenarios. evaluates parameters such as latency, energy consumption, bit error rate (BER), signal-to-noise ratio (SNR), and data rate. By gathering, analyzing, and transmitting sensor data to a central monitoring station, the IoUT Monitoring and Data Aggregation Module is an essential component of the underwater wireless optical communication (UWOC) system.

### RESULT & DISCUSSION

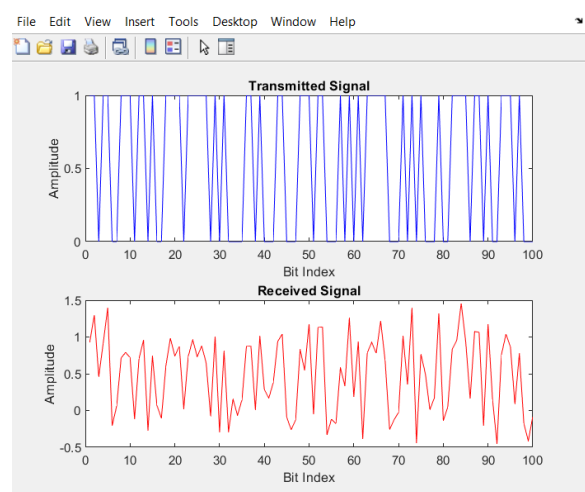


Fig.2. Input Signal

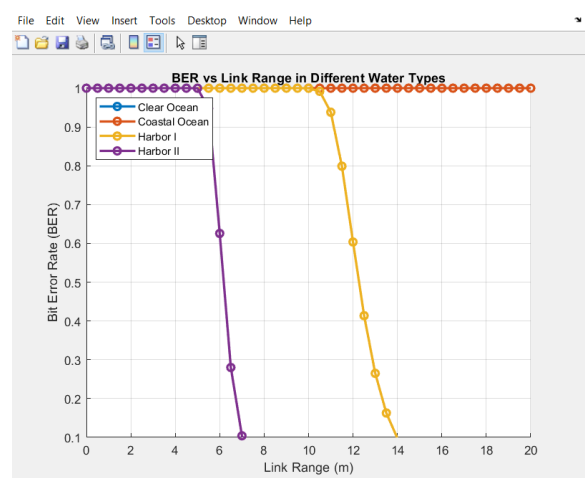


Fig 3: BER vs Link Range in different water types

Because different water habitats display varying levels of absorption, dispersion, and attenuation, the kind of water has a substantial impact on the Bit Error Rate (BER) in underwater communication. Signals can travel farther with comparatively low BER in pure water, which has few pollutants and low attenuation. This enables an optical connection range of 50–100 meters or more, as well as an audio range of several kilometers. A link range of roughly 10 to 50 meters for optical communications and 500 meters to a few kilometers for acoustic signals with a modest BER is reduced by coastal water's increased scattering and absorption due to its moderate amounts of organic and inorganic particles. The optical communication range is severely limited to less than 10 meters in turbid water, where high concentrations of sediments, algae, and pollutants cause severe signal degradation. Even acoustic signals suffer from strong attenuation, which frequently limits the range to a few hundred meters while producing a very high BER. The overall BER performance is also influenced by a number of important factors, including temperature, salinity, modulation schemes, and wavelength selection. In optical underwater communication, blue-green light (450–550 nm) offers the best transmission. In difficult underwater settings, advanced signal processing techniques, adaptive modulation, and error correction approaches can assist reduce BER and increase communication dependability.

## CONCLUSION

A relay-based underwater wireless optical communication system is suggested in this study to keep an eye on the various types of data. abbreviations and acronyms used in the paper about submerged ecosystems and the undersea environment. The system had combining approaches including EGC, MLC, and SC to detect diversity gain. The system's viability, dependability, and effectiveness for real-world uses were assessed in a simulated underwater environment. To keep an eye on the underwater environment, the device was also equipped with an underwater sensor. Overall, the experimental assessments validated the suggested system's feasibility for SMP and IoUT applications. Acceptable performance findings for a communication link longer than 7 meters were obtained from the current trials.

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