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**Suitable Modulation Techniques for Transmitting  
Data in an Underwater Wireless Optical  
Communication System**

**A thesis**

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## **Abstract**

In this work, theoretical and experimental studies have been conducted on the behavior of two laser diode signals with wavelengths of 520 nm and 405 nm, each with a power of 10mW and the spot size is 0.5 mm for the green laser and 0.075mm for violet laser. for an underwater wireless optical communication system. This system operates under various environmental conditions, which include various salinity concentrations and different turbidity levels. Here, , the salinity concentrations were (10-80 g/L)while the turbidity levels were 15 NTU, 30 NTU, 45 NTU, and 60 NTU. The theoretical results showed that the interval wavelength of (400-600) nm represents optical transmission windows for the laser light due to lower absorption and scattering coefficients. The scattering process at a specific water type slightly decreases with increasing wavelength. It was found that the amount of losses in optical power at a horizontally Line-of-Sight link increases with increasing salinity concentrations due to the effect of attenuation, as well as decreases with increasing turbidity level. On the other hand, the Signal to noise ratio SNR decreases with increasing salinity and turbidity due to higher transmission losses. It was found that at 15 NTU the SNR drops from 25.730 dB at 10cm range in the receiver to 10.364 dB for 405nm Laser diode, while it dropped from 27.664 dB for 520nm Laser diode to 13.153dB after the beam passed one meter underwater link. However, increasing the turbidity of water led to a further reduction of the SNR, reaching 0.182dB in the receiver at 60 NTU based on 405nm, while it reduced to 3.247 dB in the receiver for a one-meter range at 60 NTU for 520nm. Furthermore, the theoretical refractive index for 405nm and 520nm was estimated via different temperatures, where the results show that increasing the turbidity level led to an increase in the refractive index, while it decreased with increasing water temperatures. Also, the vertical link of the Laser diodes in the water

channel was investigated practically using samples of water taken from the Diyala River.

The experimental results demonstrated that the effect of water depth significantly affects onto optical signal quality based on samples taken from the Diyala River. It was noted that the deeper water samples taken from depths of 1m and 2m provided a better optical signal quality than surface water. It was found that the best performance of Underwater Wireless Optical Communication UWOC was observed at the depth of water, which resulted from reducing turbidity, suspended particles, and disturbances of the water surface. The result confirmed that the deeper the river, the distance, absorption, and scattering were the main factors influencing the performance of green (520) and violet (405) nm laser beams based on UWOC systems.



*Chapter One:*  
*Introduction & Literature*  
*Review*



**1.1 Introduction**

Presently, UWC has become important for different applications such as industries, marine research, offshore exploration platforms, telecommunications, security, and environmental protection. However, traditional communication sources such as acoustic and Radio Frequency wave (RF) are limited by low bandwidth, very high latency, and significant interference let to limits their penetration in water [1-3]. Additionally, the low propagation speed of acoustic waves in water makes it ineffective for many applications, such as high-resolution data transfer and real-time communication [4]. Underwater wireless optical communication UWOC presents a promising alternative to overcome all proven use limitations due to its high bandwidth, high-resolution data transfer in real time, with reduced interference [5-6]. The rapid speed of light transmission in the underwater channel results in a substantially reduced physical communication latency [7]. Furthermore, the UWOC represented by (LEDs), laser diodes (LDs), and photodiodes (PDs) is less expensive and has greater power than acoustic wave (UAC) and radio-frequency (RF) based underwater communications systems. However, electromagnetic waves are affected by different parameters, including attenuation coefficient, environmental challenges, and are susceptible to various security vulnerabilities that have to be addressed to achieve high quality and secure information communication [7-8]. Based on the underwater channel, light propagation is affected by many degradation phenomena, including absorption, scattering, and turbulence, leading to signal attenuation [8-10]. However, the absorption of visible light, even though in pure water, exhibits a lower value compared to other wavelengths because of the complexity of the underwater environment. Interactions of photons with molecules and/or particulate matter that dissolve in water, such as chlorophyll and dissolved organic or inorganic material, play an important role in the UWOC system.

Therefore, it is very important to control such parameters in order to avoid light or signal attenuation for the UWOC system [9-13]. Light wavelength and the type of water quality have an impact on how much light seawater absorbs and scatters [14]. Due to contaminants in the seawater, the dispersive nature of the UOWC channel causes the unwanted effect of inter-symbol interference, which significantly reduces link reliability in addition to the possible transmission rate [15]. Random variables like variations in salinity and temperature cause optical disturbances in water [16]. The optical turbulence coefficients, which are primarily caused by wind-generated cause deformation of the light waves and finally signal attenuation [17]. Thus, getting high data transmission based on UWOC, LEDs were employed to achieve data transmission rate of several tens of Mbps as light sources [18]. However, the LED-based UWOC system with a broad divergence angle and Limited modulation, bandwidth decreased the allowed Data rates with short Transmission range [4,19]. Therefore, LD-based UWOC with very high coherence would provide wide bandwidths and lower beam divergence, leading to greater transmission performance than the LED [19-20]. Recently, UOWC, based on low-cost blue and/or green LDs, has been paid more attention as a good underwater window for long transmission distance and high-speed [21,22]. It was reported in the literature that using a blue laser of 405 nm based UWOC led to real-time transmission of 1.45 Gbit/s over a 4.8 m [21]. Using the green 520 nm LD with NRZ-OOK modulation led to achieving a rate (500 Mbps) of data over a distance of 100 m in the Tap water channels [22, 23]. In this work, the experimental and analytical study of the UOWC system based on blue 405 and green 520 nm LDs was characterized to determine a suitable laser source with high performance in different types of turbid water. It was shown in previous studies [11,12,23], the studies were conducted only in tap and turbid water without addressing other conditions,

whereas in this work, the wavelengths were studied and compared with each other in these conditions.

## **1.2 Underwater Wireless Communication (UWC) System**

Wireless communications are an essential component in a wide range of UWC applications, including tactical surveillance, pollution monitoring, oil exploration and maintenance, oil spill control, climate change assessment monitoring, and oceanographic research [24]. The UWC can be categorized according to transmission medium, i.e., Acoustic wave (AW), Radio Frequency wave (RF), and optical waves. Conventional sources of acoustic wave communications can be sent over long transmission distances. However, it is limited to a low data transmission rate of up to several kbps/Mbps. On the other hand, RF waves experience severe attenuation through propagation in underwater environments. Even though (UWOC) can be transmitted over very short transmission distances up to 100 m, it offers a significant advantage by enabling data transmission at high rates. On the order of gigabits per second (Gbps) [25]. Table 1 shows the advantages, limitations, and requirements features of the three types of UWC systems, including acoustic wave, radio wave, and optical communications [24].

Table 1.1: Comparisons of UWC technologies.[24]

Parameter	Acoustic	RF	Optical
Wave Attenuation	Distance and frequency depend (0.1-4 dB/km)	Frequency and conductivity depend (3.5-5dB/m)	0.39 dB/m (ocean) 11dB/m (turbid)
Wave Speed(m/s)	1500 m/s	$2.255 \times 10^8 \text{ ms}^{-1}$	$\approx 2.255 \times 10^8 \text{ ms}^{-1}$
Data Rate	~kbps	~Mbps	~Gbps
Latency	High	Moderate	Low
Distance	up to kms	up to 10 meters	$\approx 10\text{-}100$ meter
Band width	1kHz-100kHz	MHZ	10-150 MHz
Frequency band	10-15 kHz	30-300 MHz	$10^{12} - 10^{15}$ Hz
Transmission Power	tens of Watts	Few mW to hundreds Watt	Few Watts

### 1.3 Literature Survey

In 2015, A. Keskin, et al. investigated the impact of laser beam types (focused and collimated) on the performance of a UWOC system in varying water conditions, including fresh, salty, and turbid water (with Maalox). The system employed OOK modulation along with BCH and convolutional coding. The results showed that salinity and Maalox significantly reduced transmittance and increased BER, while focused beams demonstrated superior performance. The system achieves a data transmission rate of 2 (megabits per second) over a 1.5 meter distance, with convolutional coding offers improved (BER) performance compared with (BCH) [26].

**In 2015, Michael G. Solonenko, et al.** conducted a study to derive the inherent optical properties (IOPs) of Jerlov water types through the application of widely recognized empirical bio-optical Models based on experimental data. The researchers employed (BSA) to determine the optimal groups of absorption and scattering coefficients that best matched the spectral references of diffuse attenuation coefficient, for various (Jerlov) water types across the 300–700 nm wavelength range. Chlorophyll concentrations associated with each water type were also estimated using the same bio-Optical models. This study resulted in a consistent and self-contained data set of spectral IOPs, chlorophyll concentrations, and also Jerlov water Types. These findings offer a reliable foundation for numerous applications, particularly in underwater optical communication and remote sensing. The derived parameters provide valuable support for oceanic optical modeling and the design of optical systems that depend on specific water characteristics [27].

**In 2015, K. Nakamura, et al.** experimentally demonstrated real-time wireless transmission of optical (Im/DD),(OFDM) modulation through an underwater channel. Employing a 405 nm blue LD, they achieve a data transmission rate of about 1.45 Gbit/s over a (4.8) meter underwater path with an (EVM) of around 10%, and a (BER) of  $(9.1 \times 10^{-4})$ , which meets the (FEC) limit. The (IM/DD-OFDM) signal was produced using a (FPGA) transmitter in real-time, and successfully transmitted through both underwater and air channels. Although the underwater link was short, the low attenuation of blue light suggests the possibility of longer transmission distances by extending the path length. The study also highlights the need for further investigation into the effects of underwater channel perturbations caused by water currents and suspended particles on system performance [21].

**In 2015, H. M. Oubei, et al.** experimentally demonstrated a record high-speed UWOC system achieving 2.3 Gbit/s data rate over a 7-meter underwater link. The system employed a commercially available (TO-9) packaged pigtailed (520) nm (LD), with a (1.2) GHz bandwidth as the optical Transmitter in conjunction with an (APD detector) receiver module. And, at a bias current of 125 milliAmpere, the LD exhibited a maximum -3 dB optical bandwidth of 1.2 GHz and an emitted power of (12 milliW) at (135) milliA. The communication link used a (OOK-NRz) modulation, and transmission communication Experiments were conducted from (1 to 2.3) gegabit/s. The system achieved open eye diagrams and bit error rates (BER) compliant with forward error correction (FEC) requirements at the highest data rate. The combination of a high (LD) bandwidth, a very high-sensitivity (APD), and optimized working conditions enables very high-speed data transmission, providing an easy and cost-effective solution for next-generation (UWOC) systems [28].

**In 2016, C. M. G. Gussen, et al.** conducted a comprehensive survey on (UWC) technologies, highlighting the strengths and limitations of various methods, such as acoustic waves, optical waves, and radio frequency (RF) communications. Their analysis demonstrated that acoustic systems, while capable of long-range communication, suffer from very low Data rates and also high latency. In contrast, (OWC) systems offer high data transmission rates and low latency, making them suitable for short-range, high-speed underwater applications, particularly in clear water conditions. However, optical systems are highly sensitive to absorption and scattering effects in water, which significantly limit their effective range. RF communication, although less commonly used underwater due to high attenuation, may still be applicable in shallow water environments or for very short distances. The study concluded that no single technology is optimal for all underwater scenarios and suggested hybrid communication systems that combine acoustic, optical, and RF methods

to enhance overall network performance. This work provides a foundational understanding of the trade-offs involved in UWC system design and serves as a key reference for future developments in the field [29].

**In 2016, C. Shen, et al.** demonstrated the development of a compact and low-power (UWOC) system using a 450 nm laser diode (LD) and a silicon avalanche photodetector (Si-APD). Operating the LD at a driving current of 80 mA with an optical output power of 51.3 mW, the system achieved a data rate of 2 Gbps over a 12-meter underwater channel and 1.5 Gbps over a record 20-meter channel. The measured bit error rates (BER) were  $2.8 \times 10^{-5}$  and  $3.0 \times 10^{-3}$ , respectively both well within the acceptable threshold for forward error correction (FEC), confirming the system's efficiency for high-speed underwater optical links over medium to long distances [25].

**In 2017 T-C. Wu, et al.** employed a 450 nm blue LD with direct pre-emphasis (16 QAM) and (OFDM) data transmission modulation with a high-speed UWOC system in tap, and seawater across a very long transmission distance. The results demonstrated that maximal transmission capacity reaches 5.6–12.4 Gbps over 10.2–1.7 meters in tap water, while it reaches 47.2 Gbps over 10.26.8 meters in seawater environments. It was found that the UWOC system based on seawater displayed a greater data-rate-to-distances, Decay-ratio on the transmission capacity compared to the Tap water-based system. As a result, light scattering caused by the contaminants in the seawater attenuated the transmitted power. However, this is considered a breakthrough for taking advantage of underwater high-speed communication [20].

**In 2017, B. Cochenour, et al.** conducted an experimental study to examine how underwater environments affect high-frequency modulated optical signals. The research focused on measuring both the magnitude and phase response of modulated light in the megahertz (MHz) frequency range as it propagated

through water. The key findings include: signal strength decreases with increasing modulation frequency due to frequency-dependent absorption and scattering in water. Phase distortion becomes more significant at higher frequencies, which can degrade the performance of modulation schemes that rely on precise phase information, such as phase-shift keying (PSK). The study emphasized the importance of considering the complex frequency response of the underwater channel when designing high-speed UWOC systems. This work provided accurate experimental data that supports theoretical modeling and contributes to the development of more reliable underwater wireless optical communication systems [30]

**In 2018, H. M. Oubei, et al.** presented a comprehensive review of (UWOC) in the Japanese Journal of Applied Physics. The study highlighted that UWOC, which utilizes visible light for data transmission in underwater environments, offers several advantages over radio-frequency (RF) and acoustic communication techniques, including high bandwidth, unlicensed spectrum availability, and low power consumption. The authors provided a detailed overview of transmitter and receiver technologies, which are critical components of UWOC systems, and discussed optical channel models addressing both simple attenuation and the effects of underwater turbulence caused by air bubbles, salinity variations, and temperature gradients. In their conclusion, the researchers emphasized the strong potential of UWOC for high-capacity data transmission but also pointed out existing research challenges, such as mitigating scattering and turbulence effects to improve system reliability and efficiency [31].

**At 2018 F. Miramirkhani, et al.** conducted a study focusing on modeling and characterization of (VLC) channels in underwater environments, taking into account the impact of both natural and man-made objects, such as autonomous underwater vehicles (AUVs). The study aimed to analyze channel behavior

under complete and partial line-of-sight (LOS) blockage and shadowing conditions caused by these objects. The results revealed that communication can still be maintained even under full LOS blockage due to light scattering, although this comes with a significant increase in path loss. It was also found that using narrower transmitter beam angles or larger receiver apertures can help mitigate these losses. However, the study highlighted a trade-off between reducing the beam angle and maintaining performance, as excessively narrow angles may also block scattered rays. Additionally, the findings showed that path loss decreases near the sea surface because of the increased reception of reflected rays, whereas path loss increases near the seabed due to diffuse reflections causing further attenuation. The authors concluded that these findings provide a robust scientific basis for accurately modeling underwater VLC channels and can guide the design of more efficient and reliable (UWOC) systems in complex environments [32].

**In 2018. A. Alipour, et al.** proposed a high-data-rate UOWC system using blue–green laser light. The study analyzed key challenges of UOWC, including attenuation coefficient, absorption coefficient, scattering, and turbulence. Furthermore, they examined the system performance using two balanced formats of modulation: (RZ-DPSK) and (NRZ-DPSK). Simulations at a 500-meter link and 500 Mbps data rate showed that both formats achieved extremely low Bit Error Rates (BER) in clear ocean water, with values below  $10^{-90}$ . However, NRZ-DPSK demonstrated better overall performance, particularly for long-distance, high-speed links. The study concludes that this system is suitable for underwater applications in military and scientific fields, and suggests integrating acoustic links in future work for broader applications such as oil/gas monitoring and data collection [33].

**In 2019, J. Wang, S, et al.** developed a high-speed, long-distance UOWC system using a low-cost 520 nm green laser diode and NRZ-OOK modulation for energy-efficient transmission. A data rate of (500 Mbps) was achieved over a distance of (100) meter in tap water channels, exhibiting an attenuation coefficient similar to that of a pure seawater channel. The observed (BER) was below the (FEC) threshold. Based on the received power and signal attenuation models, the maximum transmission/ distance was estimated to be (146) meters at (500 Mbps) and (174 meters) at (100 Mbps). These results demonstrate the potential for developing low-cost, high-performance UOWC systems for future long-range underwater communication applications [23].

**In 2019, T. Kang, et al.** proposed an underwater wireless communication system using a laser, achieving data rates up to 100 Mbps in turbid water with a modified slope (PPM) scheme with a (450) nm blue LD. The system achieves a (BER) of  $5.4 \times 10^{-6}$  at 1.4 NTU turbidity, below the forward error correction limit. The sloped PPM improves bandwidth efficiency by encoding information in the pulse slope, allowing longer pulse duration or higher data rates compared to conventional PPM. The receiver simplifies detection by using multiple signal samples per symbol instead of a matched filter. Experimental evaluation considered received power, turbidity, and distance. Future work includes testing higher bandwidths, various turbidity levels, real sea trials, studying underwater turbulence effects, and comparing performance with NRZ-OOK and traditional PPM [34].

**In 2019, Z. Vali et al.** investigated the impact of underwater turbulence on the performance of UOWC systems. Their study analyzed how parameters such as transmission distance, divergence angle, receiver aperture diameter, and field of view (FOV) influence signal fluctuations caused by turbulence. Simulation results based on a previously developed turbulence model showed that

lognormal and negative exponential distributions accurately represent the received light intensity under varying turbulence conditions. The findings revealed that increasing the beam divergence angle or reducing the receiver aperture significantly worsens signal scintillation, while changes in FOV have minimal impact. This study highlights the importance of optimizing transmitter and receiver characteristics to mitigate turbulence effects in UOWC links [35].

**In 2020, S. Kumar, et al.** investigate the effect of salinity on UWOC performance is investigated experimentally. An LD of 450 nm was used, with a transmitted power of 3 mW at distance 1.8m. The results demonstrate that the received power was 2.10 mW for distance 1 m, and it is decreases as the quantity of salt in the water channel increases. The attenuation was very high in saline water than tap water, and the distance restricted to 60cm in saline water [36].

**In 2021, Ata, Yao et al.** investigated the impact of natural underwater turbulence on UWOC systems using On-Off Keying (OOK) modulation with coherent plane waves. Their study focused on shallow horizontal water channels under realistic temperature (0°C to 30°C) and salinity (0 to 40 ppt) conditions. They found that the Bit Error Rate (BER) is highly sensitive to both turbulence strength and water properties, varying by several orders of magnitude within natural ranges. The research examined key parameters such as wavelength, temperature–salinity gradient, dissipation rates, and the probability density function (PDF) of irradiance fluctuations. Different PDF models—including log-normal, Gamma-Gamma, and Weibull—yielded similar BER predictions. The study also revealed that classical Nikishov turbulence models tend to underestimate performance degradation compared to natural turbulence conditions. In conclusion, the authors emphasized the importance of accurate environmental modeling-especially of temperature, salinity, and turbulence spectra-to reliably predict UWOC link performance. Their results indicate that

plane and spherical wave propagation modes suffer significant performance loss even over short distances, highlighting the need for improved channel models to enhance underwater optical communication system design [37].

**In 2021, Li, D.-C., Chen et al.** examined the performance of a (UWOC) system using a (450)nm blue laser under various environmental conditions. The system was tested in a water tank at distances of 1.5, 3, and 6 meters, using 1.25 Gbps NRZ-OOK modulations. At room temperature and over 6 meters, a low BER was achieved. Here, the team evaluated the turbulence effect, temperature variation, and the artificial seawater effect on communication quality. They found that moderate water turbulence (via a submerged motor) had a negligible effect on BER. However, temperature variations showed that 25 °C yielded the best performance compared to 10–50 °C. Adding salt to simulate seawater reduced the transmission range to 3 meters, due to increased scattering and disturbance. The system experienced a 1 dB power penalty under turbulent conditions at the same BER level [38].

**In 2022, X. Ke and G. Li et al.** at the University of Technology of China conducted a study on the performance of (NLOS) of UWOC system using blue and green light in the wavelength range from (450–550) nm. The research focused on how depth-dependent scattering coefficients in seawater affect the received optical power and the (BER) at the photodetector (PD). The study found that green light achieves higher received power and lower BER compared to blue light. Moreover, increasing the laser's forward scattering angle expands the scattering coverage but simultaneously reduces the optical power received by the detector. Therefore, an appropriate trade-off between scattering coverage and received power is essential for optimizing NLOS UWOC performance. The authors also emphasized the importance of adjusting the transmitted laser power based on seawater depth to maintain a consistent data transmission rate over a fixed distance [12].

**In 2022, O. A. Ojediran et al.** studied the impact of salt concentration based on the UWOC system. Using table salt in water samples with varying salinity, they measured optical absorption in the 400–800 nm range. Results showed that higher salt levels increased light attenuation, especially at shorter wavelengths (blue light), while longer wavelengths (red light) were less affected. Simulations using the Optical System and MATLAB at 450 nm, 550 nm, and 700 nm revealed that communication distance decreases as salinity increases. The study concludes that salinity significantly degrades UWOC performance and suggests using longer wavelengths or multi-wavelength systems to improve transmission in salty water environments [39].

**In 2023, Ata Yalçın et al.** analyzed the performance of UWOC links under various water conditions. They considered the turbulence effect, absorption coefficient, and scattering on communication quality. A Log-normal distribution was employed to moderate weak turbulence, while a (GG) model was used for moderate to strong turbulence. The authors also derived the Rytov variance, and the scintillation index, and developed Closed-form Expressions for the (BER) using IM/DD and OOK modulation. Their findings showed that turbulence can significantly degrade UWOC performance, becoming as impactful as absorption and scattering. They evaluated system performance across different water types and parameters like salinity, temperature, chlorophyll concentration, and link distance. The study emphasized the necessity of employing mitigation Techniques, including adaptive optics and spatial diversity, to ensure reliable communication, supporting the advancement of IoUT (Internet of Underwater Things) applications [13].

**In 2023, R. Salam et al.** also proposed two new NLOS of UWOC methods using optical intelligent reflecting surfaces (OIRS) and passive mirror surfaces (PMS), compared to traditional total internal reflection (TIR)-based systems. The OIRS-assisted system showed notable improvements in spectral efficiency,

energy efficiency, BER, and outage probability. The results revealed that OIRS should not be placed too close to the transmitter or receiver for optimal performance. PMS-based systems performed similarly to conventional approaches [40].

**In 2024, AL-Din et al .** investigated the performance of modulation techniques in (UWOC) using the OptiSystem simulation software program. The primary goal was to evaluate the effectiveness of different modulation schemes under varying underwater conditions. The study found that the (NRZ-OOK) modulation combined with an APD (Avalanche Photodiode) photodetector delivered the best performance. The experimental setup involved a 532 nm green laser diode to achieve 10 Gbit/s transmissions, demonstrating the feasibility and efficiency of very high-data-rate in (UWOC) system [41].

**In 2025, R. Yuan et al.** analyzed the characteristics of UWOC channels using blue-green lasers in three water types: clear, coastal, and turbid harbor waters. Depending on Monte-Carlo ray tracing simulations, the results showed that incident angle, beam spreading, and power loss vary significantly depending on water type and transmission distance. In clear water, beam spreading is minimal, and precise alignment between the transmitter and receiver is critical, while in turbid waters, longer distances allow for more flexibility in alignment. This study highlights the importance of accounting for water conditions and transmission range when designing optical communication systems and selecting the optical field of view of the receiver [42].

**1.4 Aim of the work**

- ❖ Design two underwater optical communication systems, where each system consists of a transmitter circuit and a receiver circuit. By using two laser diodes, the optimal laser wavelength was consecrate to ensure the best transmission performance under different water conditions.
- ❖ Investigate the effect of salinity and turbidity on the UWOC system performance.
- ❖ Analyze how the salinity concentration and turbidity levels as environmental factors influence transmission parameters: absorption coefficient, scattering coefficient, attenuation coefficient, refractive index, Signal-to-noise ratio, and signal clarity.
- ❖ Utilize both experimental and theoretical approaches in this work to assess system performance. Enhance the UWOC performance to select the best LD wavelengths for efficient phase transmission in both clean and highly contaminated underwater environments.

## الخلاصه

يتناول هذا البحث دراسة نظرية وتجريبية لاداء إشارتين ليزريتين بطولي موجي 520 نانومتر و 405 نانومتر ضمن نظام الاتصالات البصرية اللاسلكية تحت الماء. يعمل هذا النظام في ظل ظروف بيئية مختلفة تضمنت تباين تركيزات الملوحة المتفاوتة ومستويات العكارة. حيث كانت مستويات العكارة 15 NTU، 30 NTU، 45 NTU، و60 NTU، في حين تراوحت تراكيز الملوحة بين 80-10غم/لتر.

أظهرت النتائج النظرية أن المجال الموجي بين (400-600) نانومتر يمثل نوافذ الإرسال البصري لأشعة الليزر نتيجة انخفاض معاملات الامتصاص و الاستطارة. كما تبين أن عملية الاستطارة في نوعية مياه محددة تنخفض بشكل طفيف مع زيادة الطول الموجي.

وقد وجد أن مقدار الفقد في القدرة الضوئية عند الاتصال الأفقي بخط البصر (Line-of-Sight) يزداد بزيادة تراكيز الملوحة نتيجة تأثير التوهين، في حين ينخفض بزيادة مستويات العكارة. من ناحية أخرى، لوحظ أن نسبة الإشارة إلى الضوضاء (SNR) تنخفض بزيادة العكارة والملوحة بسبب ارتفاع خسائر الإرسال.

أظهرت النتائج أنه عند 15 NTU انخفضت قيمة الـ SNR من 25.730 ديسبل عند مسافة 10سم في المستقبل إلى 10.364 ديسبل لشعاع الليزر بطول موجي 405 نانومتر، في حين انخفضت من 27.664 ديسبل لليزر 520 نانومتر إلى 13.153 ديسبل بعد عبور الشعاع لمسافة متر واحد تحت الماء.

أما عند زيادة العكارة، فقد انخفضت قيمة الـ SNR إلى 0.182 ديسبل في المستقبل عند 60 NTU لليزر 405 نانومتر، بينما انخفضت إلى 3.247 ديسبل عند مسافة متر واحد لليزر 520 نانومتر عند نفس المستوى من العكارة.

علاوة على ذلك، تم تقدير المعامل النظري للانكسار عند الطولين الموجيين 405 نانومتر و 520 نانومتر عبر درجات حرارة مختلفة، حيث أظهرت النتائج أن زيادة مستوى العكارة تؤدي إلى زيادة معامل الانكسار، بينما يؤدي ارتفاع درجة حرارة الماء إلى انخفاضه.

كما تم دراسة الاتصال العمودي لشعاع الليزر في القناة المائية عملياً باستخدام عينات مياه مأخوذة من نهر ديالى. أظهرت النتائج التجريبية أن عمق الماء يؤثر تأثيراً كبيراً في جودة الإشارة البصرية، إذ تبين أن العينات المأخوذة من أعماق 1متر و 2متر أعطت جودة إشارة أفضل من مياه السطح.

وأشارت النتائج إلى أن أفضل أداء لنظام الاتصالات البصرية اللاسلكية تحت الماء تحقق عند عمق تكون فيه العكارة والجزيئات العالقة واضطرابات السطح أقل. تؤكد هذه النتائج أن عمق النهر والمسافة و التوهين و الاستطارة هي العوامل الرئيسية المؤثرة في أداء الأشعة الليزرية الخضراء والبنفسجية ضمن أنظمة الاتصالات البصرية اللاسلكية تحت الماء(UWOC).



جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة ديالى

كلية العلوم

قسم الفيزياء

# تقنيات التضمين المناسبة لنقل البيانات في نظام الاتصالات البصرية اللاسلكية تحت الماء

رسالة

مقدمة الى مجلس كلية العلوم جامعة ديالى كجزء من متطلبات نيل  
درجة الماجستير في علوم فيزياء الليزر

من قبل الطالبة

حوراء عبدالله حسين

بكالوريوس علوم فيزياء طبية/ كلية العلوم /جامعة ديالى 2021

بأشراف:

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