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Underwater Wireless Communication System through IR

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***Abstract:** Underwater wireless communication has become increasingly vital due to its applications in marine research, environmental monitoring, and defence systems. While traditional acoustic methods dominate the field, they suffer from significant drawbacks such as low data rates, high latency, and susceptibility to environmental interference. As an alternative, Underwater Optical Wireless Communication (UOWC) utilizing infrared (IR) technology offers promising advancements, particularly for short-range and high-speed data transfer. This review paper explores the potential of IR- based UOWC systems by examining their operational principles, advantages, and limitations. Key aspects include channel modelling, modulation techniques, and integration with modern technologies such as 6G and underwater sensor networks. The paper also highlights current challenges, including absorption and scattering losses, and proposes potential solutions like spatial diversity, hybrid communication models, and energy-efficient system designs. By addressing these challenges through enhanced modelling, real-world testing, and adaptive communication protocols, IR-based UOWC systems can significantly enhance underwater communication capabilities. The paper concludes that infrared technology is still developing, holds considerable promise for secure, reliable, and efficient underwater communication in various critical applications.*

***Keywords:** Underwater Wireless Communication, IR Communication, Underwater Optical Wireless Communication (UOWC), Channel Modelling, Modulation Techniques, Autonomous Underwater Vehicles (AUVs), 6G Integration, Signal Attenuation*

I. INTRODUCTION

The development of underwater wireless communication systems has gained significant attention in recent years due to the increasing need for efficient data transfer in marine environments. While traditional acoustic communication methods are widely used, they face significant drawbacks, including limited data transfer speeds, high latency, and vulnerability to environmental disturbances. These disadvantages have motivated researchers to investigate alternative technologies, with underwater optical wireless communication (UOWC) being a popular area of exploration. Among the different types of light waves, infrared (IR) has gained attention as a promising option for specific underwater situations, providing unique benefits.

This literature review combines recent studies on UWB systems, specifically those utilizing infrared technology, to provide a comprehensive analysis. Through the examination of theoretical models, experimental findings, and system-level integrations, this review assesses the current capabilities, limitations, and future prospects of IR technologies in underwater communication. The promise of IR-based systems lies in their ability to provide higher data throughput, energy efficiency, and enhanced reliability, particularly in short-range and secure underwater applications such as autonomous underwater vehicles (AUVS), military missions, and real-time environmental monitoring.

II. BENEFITS OF UNDERWATER WIRELESS OPTICAL COMMUNICATION

Although underwater acoustic communication is highly reliable over long distances, it is hindered by several inherent limitations. These include limited bandwidth (on the order of kilohertz), high power consumption, and considerable delays due to the slow propagation speed of sound in water. In contrast, UOWC provides gigabit-per-second (Gbps) data rates, low latency, and low power consumption (Kaushal & Kaddoum, 2016). Optical communication utilizes the transmission of light, which travels at significantly faster speeds than sound, allowing for near-instantaneous data transfer within the range of visible light, blue and green wavelengths have been extensively studied due to their minimal absorption in seawater. Despite their higher attenuation, wavelengths with higher energy levels offer advantages in specific applications. These include less scattering in turbid freshwater environments and increased security due to their limited range, which minimizes the risk of eavesdropping. To fully reap the advantages, it is essential to comprehend how IR functions in various underwater scenarios, especially when integrated with cutting-edge system designs.

III. CHARACTERIZATION OF THE CHANNEL AND IR-SPECIFIC FACTORS

Building a strong foundation for underwater communication systems is crucial, and effective channel modelling plays a key role in achieving this. Water is a complex substance, and various factors like absorption, scattering, and turbulence- induced fading have a significant impact on the quality of signals transmitted through it. Monte Carlo simulations have been extensively employed to simulate the movement of photons in different types of water, facilitating the comprehension of channel impulse response and time dispersion (Gabriel et al., 2013).

While most studies on TV channels concentrate on blue and green wavelengths, the propagation of infrared light has distinct properties that warrant in-depth examination. Light tends to absorb more, making it ideal for short-range communication. Nevertheless, its efficiency in low-turbidity water or controlled settings can be enhanced by utilizing spatial diversity and error correction methods. Jamali et al. (2016) conducted research that demonstrated the positive impact of incorporating advanced scattering models and precise environmental parameters into simulations, particularly when using IR.

IV. ENHANCEMENT METHODS AND SYSTEM REFINEMENT

The effectiveness of UOWC systems relies significantly on the modulation schemes utilized. Researchers have extensively examined techniques such as non-return-to-zero on-off keying (NRZ-OOK) due to their simplicity and energy-saving properties. Liu et al. (2017) and tian et al. (2017) showcased the capability of transmitting data at speeds of up to 2.70 Gbps over long distances, employing blue and green laser diodes with non-return-to-zero on-off keying(NRZ-OOK) modulation. Although these studies primarily focus on visible light, their findings are crucial in guiding the design of the IR system. In underwater communication systems, the implementation of IR may require modifying existing modulation techniques to accommodate higher absorption levels and lower signal-to-noise ratios. Hybrid modulation techniques and adaptive encoding could be created to ensure the performance of the system remains intact. Wang et al. (2019) conducted a study that showcased the possibility of long-distance communication using 520 nm lasers, which can serve as a foundation for further research in other wavelengths, albeit with shorter distances.

V. INTEGRATION OF UNDERWATER SENSOR NETWORKS AND 6G TECHNOLOGIES

The increasing number of underwater sensor networks (UWSNS) has created a need for advancements in communication technologies that can meet the demands of high-bandwidth, low-power, and low-latency requirements. UOWC, and by extension ir-based systems, are being investigated as potential replacements or additions to conventional acoustic communication methods. Chi et al. (2020) contend that visible light communication (VLC) and other optical techniques are crucial elements of 6g infrastructure, which seeks to combine terrestrial, aerial, and underwater networks.

Communication systems, especially when used in clusters of sensors or swarms of autonomous vehicles, provide distinct benefits. Due to their restricted range and directional nature, these devices enable secure and localized data sharing. Additionally, the integration of 6g technologies like edge computing, artificial intelligence, and block chain can revolutionize underwater operations by facilitating real-time decision-making and ensuring secure information sharing (nguyen et al., 2021).

VI. OBSTACLES AND PREVENTION MEASURES

Despite their commitment, UOWC and IR systems encounter various obstacles. Among the most significant challenges in wireless communication are absorption and scattering losses, which have a detrimental effect on the range of transmission and the quality of data. In systems that use infrared light, these challenges are amplified because the wavelength is more easily absorbed by water. Zedini et al. (2018) suggested a comprehensive statistical channel model that considers turbulence-induced fading, a crucial step in enhancing performance prediction and system resilience. Various spatial diversity techniques, including multiple-input multiple-output (MIMO) systems, have been investigated to address these problems. Jamali et al. (2015) showcased the advantages of MIMO in minimizing bit-error rates and improving system dependability. Furthermore, the incorporation of multi-hop relay nodes can enhance the reach of IR communication by dividing long distances into smaller, more manageable connections (Jamali et al., 2016).

Additionally, turbulence and water variability resulting from temperature, salinity, and biological factors contribute to the complexity of IR signal propagation. Integrating environmental sensing into the communication system design enables dynamic adaptation to current conditions, enhancing the system's overall robustness. Areas of Uncertainty and Next Steps Although the literature highlights notable advancements in the development of underwater optical wireless communication systems, there are still several gaps that need to be addressed in order to fully harness the potential of underwater optical wireless communication technologies in various applications.

1) Channel model development: current models frequently fall short in capturing the intricate details of light behaviour in dynamic underwater settings. Future research should focus on creating comprehensive models that consider the interplay between physical, chemical, and biological factors influencing the propagation of IRs.
2) Hybrid communication systems: integrating acoustic and optical (including IR) communication in hybrid systems could offer more reliable solutions. These systems had the ability to seamlessly transition between different modes of communication depending on the surrounding conditions and the specific needs of the situation.
3) Real-world testing: laboratory simulations, while valuable, cannot fully replicate the diverse range of challenges faced during actual underwater deployments. Field experiments are crucial for verifying models and uncovering practical limitations.
4) Considering the limited power supply of underwater vehicles and sensor nodes, it is essential to prioritize energy efficiency. Future studies should concentrate on developing low- power transmitters, sleep-wake protocols, and energy harvesting techniques.
5) As underwater networks become increasingly important for critical infrastructure and defence, ensuring the security of data transmission is of utmost importance. Creating lightweight, yet strong, cryptographic techniques specifically designed for UOWC and IR systems will be a crucial focus of research.

VII. CONCLUSION

Infrared-based underwater wireless communication systems hold great potential as a promising frontier in the pursuit of high-speed, dependable, and secure underwater connectivity. Despite the persisting challenges, especially in terms of signal weakening and environmental fluctuations, continuous progress in channel modelling, modulation methods, and system integration is propelling the practical implementation of IR. By conducting thorough research on channel characterization, hybrid architectures, real-world validations, energy efficiency, and data security, the potential of ir technology to revolutionize underwater communication networks could be realized. As research progresses, the significance of IR in UOWC is expected to broaden, providing innovative solutions to the increasing needs of underwater exploration, monitoring, and defence purposes.

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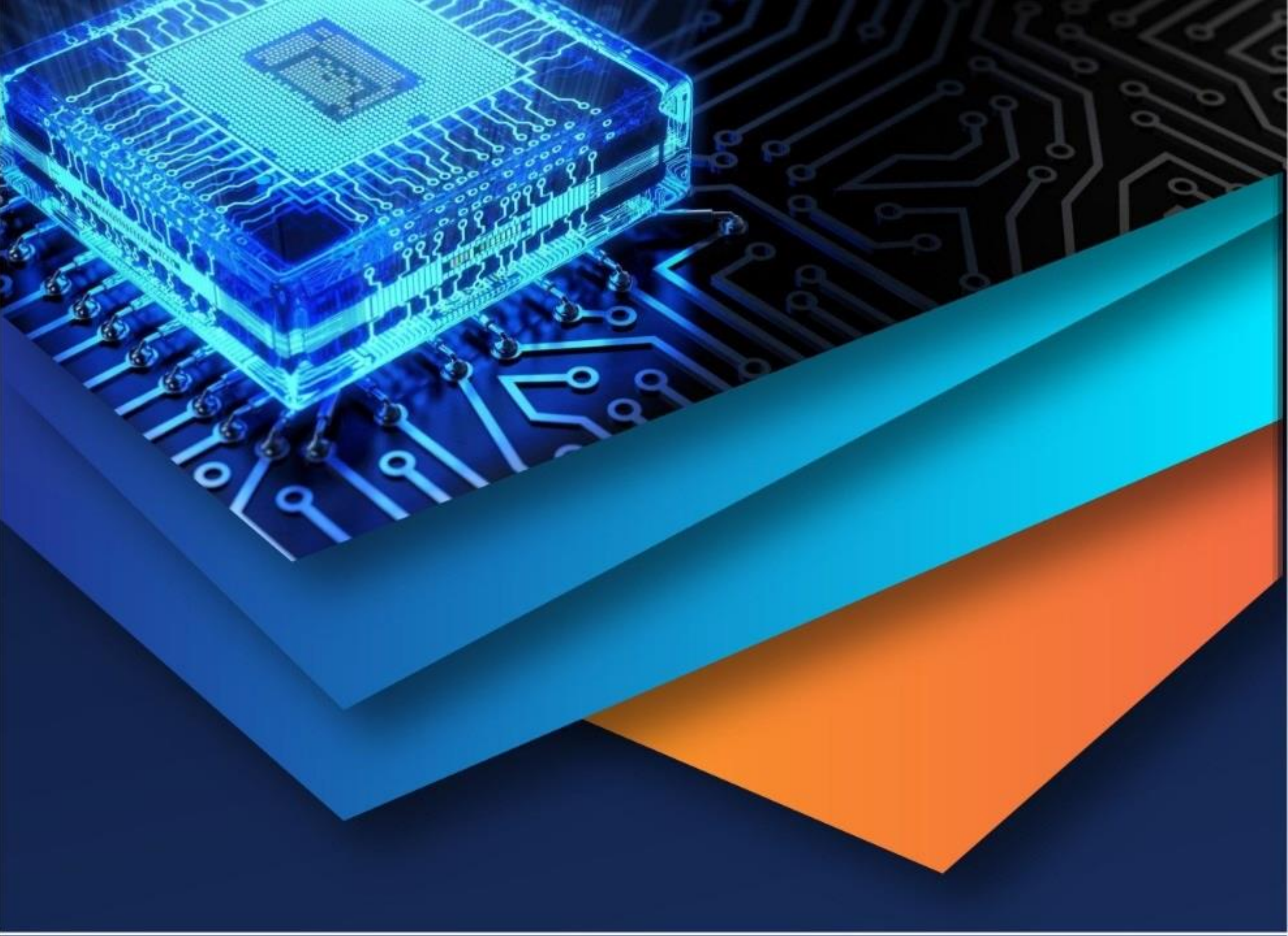

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