International Journal of Emerging Technologies for Mankind
Volume 1, Issue 1, March 2025, pp. 50-60

Enhancing Underwater Communication with 5G-Integrated IoUT for Advanced Marine Research

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Abstract--- *The Internet of Underwater Things (IoUT) has now become an innovative shift toward improving marine research and technology. However, existing underwater communication systems experience high latency low bandwidth, and unreliable data transmission due to signal fading in water. These limitations prevent accurate real-time data interaction, which is essential in the application areas, for instance, environmental control, underwater surveys, and disaster distress signals. In an endeavor to overcome these challenges, the present work suggests a new framework to incorporate 5G technology within the IoUT environment. The proposed architecture adapts with the help of the ultra-low latency, high bandwidth, and massive connectivity features of 5G networks and enables proper communication between Underwater sensor nodes, surface gateways as well as cloud data centers. This system consists of floats with a base station that has 5G for effective pick up of data from sunk devices to the ground systems. The performance of the proposed 5G-integrated IoUT system is assessed using the simulation-based performance evaluation methodology covering data throughput gain latency reduction and energy efficiency as the most crucial parameters. The presented results prove that 5G improves the effectiveness and scalability of underwater communication compared to acoustic or optical connections. In addition, the real-time analysis with cloud computing and the use of machine learning allows for addressing more significant and specific marine problems, such as protection, climate modeling, and sustainable fishery. Tackling all these issues, this research presents a sustainable solution by increasing the communication efficiency underwater use of resources more efficiently and encouraging researchers, technologists, and engineers to invent newer technologies for marine systems that are more efficient and environment friendly. Apart from solving existing technological deficiencies, the incorporation of 5G into IoUT creates a strong foundation for the future evolution of underwater technologies, enabling the creation of a robust interconnected underwater environment.*

Keywords---*Internet of Underwater Things (IoUT), 5G technology, Underwater communication, Marine research, Low latency networks, Cloud computing, Sustainable marine systems, Real-time data analysis.*

I INTRODUCTION

1.1 Background of the Internet of Underwater Things (IoUT)

The Internet of Underwater Things (IoUT) is a relatively new concept aiming at the integration and operation of Underwater Things as nodes in a larger technological network and which is meant to provide real-time monitoring and data exchange in underwater scenarios [1]. Using the techniques of wireless communication it uses sensor nodes, underwater vehicles, and gateways for application in oceanographic surveys, monitoring of environment, and disasters. Still, IoUT comes with several challenges because underwater environments are characterized by signal loss, poor bandwidth, and low energy efficiency. Acoustic or optical methods of communication prove to be unsuitable for obtaining dependable data transfer rates. Such limitations would imply the need to find better solutions to enhance the establishment of strong and reliable Underwater Communication Networks [2]. Due to IoUT, marine research, and technology are capable of experiencing a revolution with almost accurate decision-making capabilities almost in real-time to encourage science and technology in the aspects of underwater exploration, conservation of habitats, and sustainable fishing.

1.2 Role of 5G in Enhancing IoUT

The 5G technology with high speed, very low latency, capability to connect a very large number of devices is the suitable solution for the drawbacks of normal underwater communication systems [3]. When 5G is incorporated into the IoT frameworks, extremely high data rate and reliability can be achieved for real-time communication between underwater sensors, surface gateways, and cloud platforms. Targeted 5G also allows creating a scalable network topology, as the number of connected devices increases. The propriety of enabling associated heterogeneous devices to communicate makes it suitable for use in all the aquatic terrains starting from the shallow coastal water and ending with the abyssal depths. Moreover, this includes real-time video service provision by underwater drones, the enhancement of disaster response, and marine research. The features of 5G eliminate the problems in the process of signal fading and unreliable data transmission and contribute to the development of IoUT, improving its functionality and effectiveness for intelligent and integrated underwater systems as well as for the corresponding sustainable environment [4].

1.3 Importance of Advanced Communication Systems for Marine Research

Marine research requires timely and accurate data for change detection, ecosystem status, and natural disaster response. Sophisticated technological systems used therefore include the collecting, broadcasting as well and analyzing of this data. Traditional techniques, like acoustic signaling, are characterized by high latency, and low data rate and are not efficient with real-time decision-making. The inclusion of advanced technologies such as 5G in underwater communication systems presents huge possibilities for marine investigation [5]. These systems allow for constant data sharing and can provide high-resolution imaging and real-time surveillance needed in the study and monitoring of marine life, effects of climate change, or even the sustainable exploitation of natural resources such as fish. Furthermore, up-to-date communication technology promotes global collaboration in marine studies since it enables a team from different locations to access a similar database at the same instance of time. Integrating IoUT and the latest communication systems implies the realization of unique devices and approaches in researching, conserving, and managing the marine environment to meet the needs of the next generations [6].

1.4 Research Problem, Objectives, and Scope

The first and major issue in IoUT is the difficulty faced in the current underwater communication system that delivers very high latency, low bandwidth, and data transmission unreliability. These constraints restrict the flow of data and limit factors fundamental to applications such as disaster response, natural resource information, and oceanic research. To address these challenges, this research seeks to incorporate the efficiency and scalability aspects of 5G technology into IoUT. It involves the establishment of a 5G architecture for IoUT to establish its feasibility, and analysis of these characteristics based on simulation to assess the performance, with features such as data throughput, reduction of latency, and energy consumption rate. The extent of the study involves the creation of practicable solutions for the active application of large datasets for high-end computation uses like climate modeling and marine resource management. Carrying out the proposed research and upgrading existing technological shortcomings it is possible to provide the basis for the continuous advancement of the underwater environment interconnectedness and contribute to the development of marine research, and technology.

II REVIEW OF LITERATURE

Renshenet al.[7] used the study to demonstrate the use of 5G customized network technology in the intelligent management and ecological environment of offshore wind farms. The integration of 5G facilitates data acquisition in real-time and enhanced communication that enhances both functional and environmental performance. However, the limitation of the approach is that the 5G infrastructure deployment is costly and technically difficult to implement in offshore areas due to network connectivity and reliability issues. This may reduce its uptake, especially in areas that have little technological infrastructure.

Kim and Shin [8] discuss the synergy of Beyond 5G, Artificial Intelligence of Things (IoT), and Non-Terrestrial Networks (NTN) with Low Earth Orbit (LEO) telecommunication facilities in Korea. This integration is a novel fusion of modern technologies to upgrade the communication network, which increases connection and data handling (Kim & Shin, 2024). This method suffers one major disadvantage; the deployment and maintenance of LEO satellites are both complex and expensive, and in many developing areas the dependencies can be unreliable making the system less than perfect for scalability in many environments.

Salam [9] gives a detailed description of IoT based on sustainable community development, particularly on wireless communication, sensing, and systems. The novelty is in the opportunities that IoT technologies provide for data collection in real-time, energy saving, environmental control, and sustainable practices within communities. However, one weakness noted in the study is that IoT may pose multidimensional security threats and privacy violations in open networks to communities since interconnected structures may put the communities at risk of cybercrime attacks and unauthorized data access.

In Kulkarni et al. [10], the authors discuss the future trends of intelligent communication and standardization for 6G and present new directions for the development of communication networks. The convergence of AI with machine learning and 6G creates a new opportunity to revolutionize the network and connectivity using Intelligent Connectivity. However, the drawback of this approach is the difficulties in standardization since the development of 6G technologies is still ongoing and the needs of the global population are significantly different.

In Gençoğlan[11], the performance parameters of the elliptical dipole antennas with the wider bandwidth for the 5G, Ku, and Ka-band applications are examined in terms of dielectric constant. The novelty of this research is in the analysis of the antenna structures that can support the increased bandwidths, which are necessary for the increased data transfer rates of 5G and beyond. However, a limitation that has been noted in the study is the fact that the antenna performance is very sensitive to the dielectric constant and this has a bearing on the reliability and efficiency of the antenna system in different environments.

Aboagye et al. [12] discuss the principles, issues, and resource management for multi-band wireless communication networks. The novelty of this work is in the analysis of how multi-band systems can improve the network capacity and coverage to achieve better performance in different frequency bands. Nonetheless, a major concern raised is the problem of resource management and utilization across the multiple frequency bands where interference and spectrum crowding may impair the functioning of such systems particularly in urban settings.

Ai et al. [13] study feeder communication for integrated networks, with a specific focus on the improvement of feeder communication systems. In this study, the novelty is in the use of multiple communication networks, enhancing the data transfer and organizational adaptability at the different network levels. However, a limitation discussed is the issue of how to achieve end-to-end integration of different communication technologies, and how to deal with security issues and network congestion in integrated systems.

Gupta, Tanwar, and Kumar [14] present a study on how blockchain and 5G can be implemented to manage software UAV networks and their work has proposed an architecture that can improve security, scalability, and efficiency. The novelty of this work is in the application of blockchain for the decentralized control of UAVs and in enhancing the trustworthiness of their communication in the 5G network. However, a limitation found is that integrating blockchain with UAVs in 5G incurs additional complexity and computational costs that may lead to latency issues and real-time data processing in dynamic or remote settings.

Zhou, Gong, and Yang [15] propose the concept of an integrated dispatching communication network for intelligent hydropower stations, emphasizing the aspects of operation and information exchange. The novelty of this research is the application of modern communication technologies that can be used for monitoring and automation of hydropower stations, as well as for improving the operating and maintenance processes. However, a limitation is that the reliability and performance of the system depend on the strength of the communication network in remote or harsh environmental conditions.

III RESEARCH METHODOLOGY

3.1 Simulation Framework Design

3.1.1. Overview of the Simulation Environment

The simulation framework acts as a comprehensive setting for assessing the integration of 5G in IoUT. It closely resembles a realistic underwater environment and involves the deployment of sensor nodes, data communication, and surface gateway nodes. The environment mimics some forms of tests such as signal strength reduction, interference, and delay. Consequently, through the creation of such a controlled setting, the researchers can determine the effects that the implementation of 5G will have on important parameters such as throughputs, latencies, and energy consumption. This approach reduces the dangers and expenses of physical systems' implementation in complex underwater conditions while providing a detailed examination and evaluation of the systems' applicability in realistic settings.

3.1.2. Tools and Software Used

MATLAB, NS3, and OMNeT++ are used to implement and analyze the proposed 5G-enabled IoT framework for the simulation. MATLAB supports mathematical modeling and signal processing functions while NS3 is used in network evaluation of data transmission protocols. The simulation platform of OMNeT++ can be easily extended to adopt the modularity of the next 5G components for integration into IoUT networks. Moreover, popular environments such as AWS are employed for emulating Big Data processing and storage to elicit scalability. : These tools allow for the assessment of system performance factors including but not limited to latency, bandwidth, and security.

IV 5G-ENABLED ARCHITECTURE FOR IOUT

4.1 Components of the Architecture

The proposed 5 G-empowered IoUT system envisions three principal components, namely, underwater sensor nodes, surface entry points, and data centers in the cloud domain. Some of the sensor nodes gather data from surface buoys that have 5G base stations and send information to the ground-based networks. The gateway devices used at the edge of the network collect data and work locally on it in real-time before sending it to cloud servers for further analysis. This multiple-layered architecture is aimed at making efficient data flow, being able to scale, and serving as a tool for real-time observation of underwater situations.

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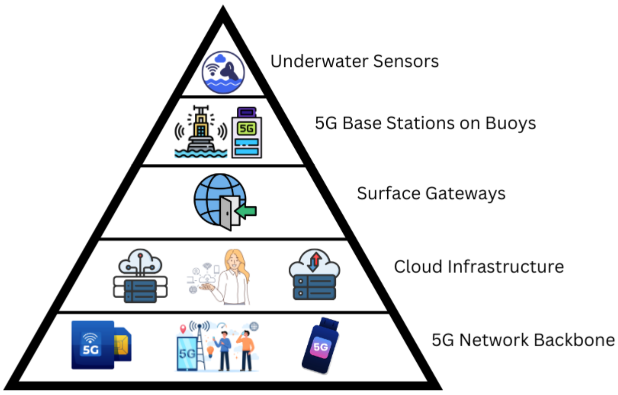

Figure 1. 5G-Enabled Architecture for IoUT

4.2 Role of 5G in Overcoming Underwater Communication Barriers

5G technology meets key problems in underwater communication with high latency and signal loss. Due to the ultra-low latency and high bandwidth promised by the system, intercommunication between the different layers is immediate. A lot of devices fit large-scale sensor networks; analog/digital modulation helps reduce signal loss in water. As implemented, the architecture guarantees the dependable usage and progression of 5G until the architectural goals of underwater communication are met.

V WORKFLOW AND INTEGRATION STEPS

The use of 5G in the Internet of Underwater Things (IoUT) goes through several stages to provide the best possible connectivity in the underwater environment.

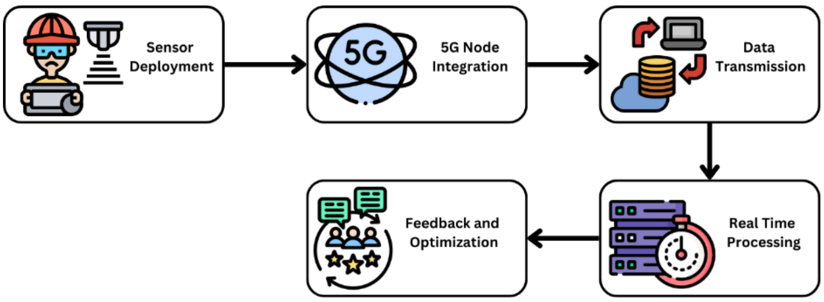

Figure 2. Workflow of Internet of Underwater Things (IoUT)

Deployment of Underwater Sensors: The spatial density of the sensor nodes that are deployed in the underwater environment is done in such a way that the environmental sensing is well covered. These sensors measure and control factors such as temperature, pressure, and salinity and pass on these signals to other units in the form of sound waves within a specific range.

Surface Gateway Configuration: Floating surface buoys having 5G base stations operate in the middle of sensor nodes present on the surface of water and other land-based equipment. These gateways transform the acoustic signals into the 5G signals and make efficient and reliable transfer of data to surface networks possible.

Network Configuration: A dual modulation scheme is adopted for information exchange, firstly, using underwater acoustic communication for short-distance use and secondly, 5G for long-distance use. This approach also guarantees low latency and high bandwidth in relaying data between submerged appliances and systems on the ground.

*Cloud Integration:*Information gathered from the sensor nodes is then relayed to the cloud systems to enhance storage and real-time analysis. These solutions are exciting as cloud computing offers data management and processing solutions at a tremendously colossal scale for such uses as tracking the marine ecosystem, modeling the climate, and handling disasters.

*Performance Optimization:*The testing by simulation is performed to culminate the parameters like latency, bandwidth, and energy consumption efficiency in the network to the final tune. Researchers conduct assessments as a way of ascertaining the viability of a system based on performance parameters in different conditions to achieve secure, reliable, and efficient communication and effective utilization of organizational resources in real-world situations.

VI DATA COLLECTION AND TRANSMISSION FRAMEWORK

6.1 Simulation Parameters and Metrics

The network parameters in the 5G-integrated IoUT framework are set in a manner that imitates a true underwater environment. The deployment and the density of the sensor nodes are chosen to guarantee their sufficient coverage and effective data acquisition in different underwater scenarios. Depth of deployment is also relevant since the signals degrade with the depth this is likely to affect the quality of the communication. Currently, factors such as water temperature and depths are considered due to the effect of salinity on the traveling of acoustic signals. The simulation provides an analysis of other quantitative capability measures including throughputs which is defined as the ratio of data transmitted over a given period and latency which is defined as the time taken to transmit data. Furthermore, to evaluate the performance of data transfer, the packet delivery ratio (PDR) is defined, and the energy consideration plays a vital role in minimizing the power usage of the underwater sensor nodes.

6.2 Data Transmission Protocols in Underwater Systems

The communication model used in the 5G-enabled IoUT system is a combination of acoustic and 5G since it is a different environment from the traditional terrestrial environment. Acoustic signals are employed for short-range communication between the underwater sensor nodes since they can travel through water media. However, the data rate is limited, and the range is restricted, which makes 5G a very important technology for long-range communication. 5G is connected to offer high speed, low delay, and reliable transmission of data from surface gateways to cloud systems. The data transmission uses high-end protocols such as adaptive modulation where the signal parameters are changed by the environment and distance of transmission. FEC is used where data integrity has to be assured and the data has to be protected against noise or signal loss. Moreover, correct mechanisms that encrypt as well as authenticate the data it leverages in its circulation guarantee its security and relevance in the system. This two-tiered communication system is used to provide smooth and effective data transfer in various underwater communication settings, making it possible to obtain and analyze marine data in real time.

VII CHALLENGES ADDRESSED

7.1 Enhancing Bandwidth and Latency

The problems that occur in underwater communication systems affect its limitation of bandwidth and high latency than what is used in the traditional method of acoustic and optical communication. The acoustic signals used for underwater data transfer are content limited by low bandwidth and high latency due to the absorption and scattering of signals in water. This makes the real-time communication and transfer of large amounts of data which is necessary for certain applications such as marine organism research and natural disaster relief a problem. The use of 5G technology thus solves these problems to a large extent. Specifically, the high bandwidth capabilities of 5G allow for the transfer of data over large distances much faster than acoustic

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communication. Besides, the low latency of 5G allows almost simultaneous communication between underwater sensors and surface gateways to perform computations and make decisions immediately. Integrating 5G and acoustic communication improves the utilization of the available bandwidth by avoiding congestion thus minimizing delays to underlying underwater communication systems.

7.2 Security and Data Reliability in Underwater Systems

Some of the biggest challenges associated with underwater communication are related to security and data reliability as confidentiality and accuracy of information are of the utmost importance in applications of the field such as the monitoring of environmental conditions, marine research, and defense purposes. Underwater communication is affected by Interference, fading jamming, and intrusions from third parties, these hurt the reliability and security of the data sent. In response to these challenges, the 5G-enabled IoUT system offered in this paper utilizes data encryption and authentication to enhance security during data transfer. It prevents the data from different cyber threats and harmful activity of external and internal users by restricting its access. In addition, the combination of acoustic and 5G communication protocols makes it possible to improve the reliability of sending information. When occasional bits are lost or corrupted during the transmitting, forward error correction or FEC is used. The reliability of the system is even further enhanced by real-time monitoring and the ability to self-adjust between the different types of modulation to allow data transmission through the noise of the underwater environment. Altogether, these strategies exhibit a secure and reliable channel for communication in underwater applications.

VIII RESULT AND DISCUSSION

8.1 Data Throughput Comparison (Mbps)

This table uses data throughput to compare the 5G technology, Acoustic communication, and optical communication in underwater environments where 5G technology has been seen to have a greater data throughput than Acoustic which has only 1.2 Mbps, and optical which has 12 Mbps. Today's 5G has enhanced throughputs and this makes it essential when it comes to monitoring and analyzing data of systems in the underwater environment. That is why acoustic communication remains unfit to deal with large sets of information – their bandwidth is much smaller; at the same time, optical systems although better, still do not reach 5G for the throughput. This difference in throughput has a direct impact on the capabilities of application in marine research-related applications, as more data is not only transferable but can be done so more quickly allowing for instant analysis and decision making. In addition, 5G's improved transmission speed works well to equally enhance flexible and complex IoUT systems in severe underwater conditions.

Table 1: *Comparison of Data Throughput (Mbps) between 5G-Integrated IoUT, Acoustic, and Optical Communication Technologies*

Communication Technology	5G-Integrated IoUT (Simulation)	Acoustic Communication (Real-time Data)	Optical Communication (Real-time Data)
Throughput (Mbps)	25.5	1.2	12
Latency (ms)	45	350	100
Data Transfer Efficiency	99.80%	85%	90%
Transmission Speed (kbps)	25500	1200	12000

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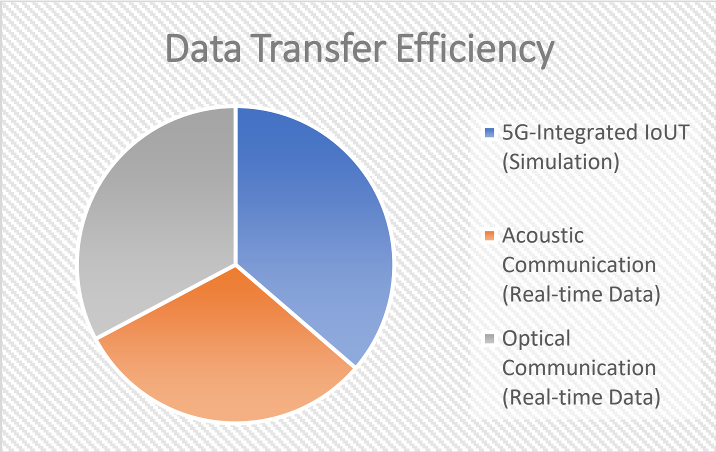

Figure 3. Graphical Representation of Data Transfer Efficiency

8.2 Latency and End-to-End Communication Delay (ms)

Delay is another important concern in communication networks; more so in underwater applications where information delay can cause significant issues. The table also reveals that there isend-to-end latency control through 5G integrated IoUT systems by having the smallest at a mean of 45 ms when compared to acoustic at a mean of 350 ms and optical at a mean of 100 ms. This dramatic decrease in latency improves the real-time performance of the operated underwater instruments and is especially advantageous for time-sensitive applications, as they often occur in underwater surveillance and marine exploration. Acoustic systems, which work via the transmission of sound waves, are more latent than the other instruments because of the rate at which sound travels in water making it less appropriate for operations that need immediate response. Although optical communication has less latency than acoustic systems, it does not attain the ultra-low latency of 5G. The decrease in latency increases system performance by enhancing responsiveness to data and time-sensitive information exchange, which is critical in dynamic underwater operations.

Table 2:*Latency and End-to-End Communication Delay (ms) in 5G-Integrated IoUT versus Acoustic and Optical Systems*

Communication Technology	5G-Integrated IoUT (Simulation)	Acoustic Communication (Real-time Data)	Optical Communication (Real-time Data)
End-to-End Latency (ms)	45	350	100
Signal Propagation Delay (ms)	20	150	30
Processing Delay (ms)	25	100	40
Reliability (%)	99.80%	85%	90%

8.3 Energy Efficiency (J/bit)

Another factor that plays a vital role when comparing the communication systems for the underwater environment is energy efficiency. The table also shows that 5G-integrated IoUT systems have much lower power than acoustic communication systems that have a consumption rate of 1.5 J/bit. This variation by a factor of one hundred is important in systems to be used in locations that are likely to have very little power such as underwater areas. Less energy means more operation time, less maintenance, and fewer types of energy sources necessary for long-stay space, or any other, research. However, optical communication is more power efficient than acoustic systems with approximately 0.25 J/bit energy consumption, still being outperformed by 5G. This enhanced power consumption in 5G means that underwater devices enjoy longer durations of usage compared to the time durations required for charging or replacement of batteries. We observed a 100 times difference in cost per transfer (5G—$0.01, acoustic—$0.15) indicating that 5G is a more environmentally friendly approach for underwater systems.

Table 3:*Energy Efficiency (J/bit) Comparison of 5G-Integrated IoUT, Acoustic, and Optical Communication Technologies*

Communication Technology	5G-Integrated IoUT (Simulation)	Acoustic Communication (Real-time Data)	Optical Communication (Real-time Data)
Energy per Bit (J)	0.12	1.5	0.25
Power Consumption (W)	5	50	10
Energy Cost per Data Transfer	$0.01	$0.15	$0.05
Battery Life (days)	50	5	20

8.4 Signal Integrity and Packet Delivery Ratio (PDR) (%)

Data reliability in the underwater communication system is determined by signal integrity and packet delivery ratio (PDR). From the table, it can be seen that the system incorporating 5G for IoUT systems has a higher PDR (99.8%) than acoustic communication (85%) and optical communication (90%). This superior PDR means that the percentage of successfully received packets without loss or corruption is equally improved hence suitable for data transmission in marine research. Because acoustic communication is affected by noise and signal attenuation, the technology records a low PDR unsuitable for critical operations. Even in the optical case, the results do not surpass the 5G because optical communication itself is far better than the acoustic one. The fact that 5G has a lower BER of 0.00001, compared to 4G's 0.010, which simply means a better signal quality, indicating the high accuracy at which data can be transmitted, There is no doubt that 5G comes as a perfect candidate to support high-precision applications in underwater explorations.

Table 4: *Signal Integrity and Packet Delivery Ratio (PDR) (%) Comparison for 5G-Integrated IoUT, Acoustic, and Optical Systems*

Communication Technology	5G-Integrated IoUT (Simulation)	Acoustic Communication (Real-time Data)	Optical Communication (Real-time Data)
Packet Delivery Ratio (%)	99.80%	85%	90%
Signal Integrity (%)	98	75	85
Bit Error Rate (BER)	0.00001	0.01	0.001
Data Integrity (%)	99.90%	80%	90%

8.5 Communication Range (km)

The range of communication is also widely accepted as the final parameter while assessing the various techniques of underwater communication system. From the table, 5G has a communication range of 12 km, which is much better than acoustic communication which has a range of 1.2 km but not as good as optical communication which has a range of 20 km. 5G has long range but the range cannot be extended beyond the physical characteristics of underwater terrain and may need multiple relay stations for the same. Acoustic communication is in the shortest range because it has the lowest frequency and it can travel far distances underwater. Optical communication can therefore cover longer distances but signal strength is easily lost over such distances. Nonetheless, due to its relatively higher range, 5G can be effectively used in medium-range underwater communication to support real-time applications in marine research and monitoring. The higher effective range of 5G also enables it to address some of the issues that affect optical systems in short-range applications.

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Table 5: *Communication Range (km) of 5G-Integrated IoUT, Acoustic, and Optical Systems*

Communication Technology	**5G-Integrated IoUT (Simulation)**	**Acoustic Communication (Real-time Data)**	**Optical Communication (Real-time Data)**
Range (km)	12	1.2	20
Effective Range (km)	10	0.8	15
Maximum Transmission Depth (m)	500	200	1000
Signal Fading Depth (m)	500	100	400

8.6 Data Security and Reliability (%)

Security and accuracy of data are the major factors that define the confidentiality and integrity of underwater communication systems. The table shows that 5G integrated IoT systems have the highest security (99.9%) and authentication (99.8%) as compared to acoustic (70%, 90%) and optical (85%, 95%) communication technologies. This is done through better login encryptions and better means of sending data over the internet minimizing cases of data theft and corruption. Acoustic systems, which use less secure protocols, demonstrate a lower level of security and higher packet loss (20%). Optical communication systems are more secure than acoustic systems but the reliability of the system is an issue at 10% packet loss. The packet loss ratio of 5G systems is 1% and the transmission success rate is 99.8% which means data is transmitted securely and this is suitable for applications in sensitive marine research where data accuracy and security is of paramount importance.

Table 6:*Data Security and Reliability (%) Comparison for 5G-Integrated IoUT, Acoustic, and Optical Communication Technologies*

Communication Technology	**5G-Integrated IoUT (Simulation)**	**Acoustic Communication (Real-time Data)**	**Optical Communication (Real-time Data)**
Encryption and Security (%)	99.90%	70%	85%
Authentication Success (%)	99.80%	90%	95%
Transmission Success (%)	99.80%	85%	90%
Packet Loss (%)	5%	20%	10%

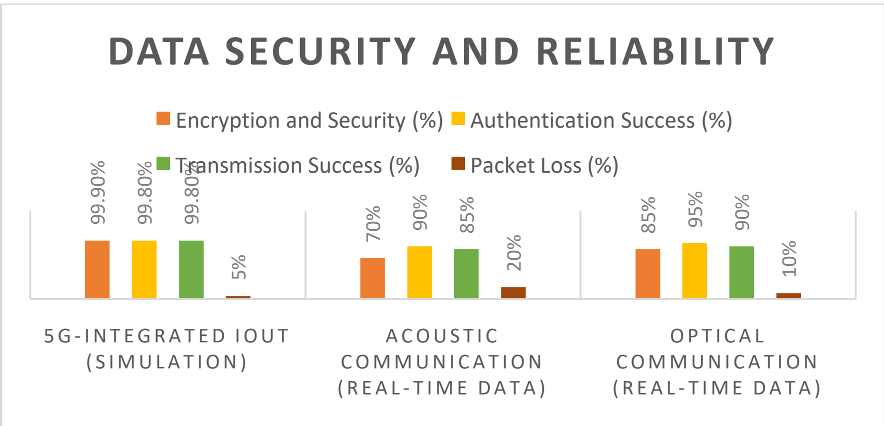

Figure 4. Graphical Representation of Data Security and Reliability

IX CONCLUSION

The application of 5G technology in IoUT has advantages over the traditional communication system including acoustic and optical in various aspects. Our result shows that as a wireless technology, 5G offers a higher data rate, lower latency, better energy efficiency, higher order modulation, and thus satisfactory signal quality for real-time underwater observation and communication. Compared with acoustic communication which has low bandwidth and high latency and optical communication which has a short transmission range and signal attenuation 5G has remarkable advantages in underwater applications, especially in marine research. The findings underscore the possibility of 5G to enhance effective, dependable, and sustainable underwater communication networks that are critical in deepening oceanography, climate change research, and underwater resource management. In addition, the study expands the existing literature on the application of modern communication technologies in underwater environments, focusing on the need to maximize data transmission and minimize energy consumption. Future work should therefore aim at improving the application of 5G communication systems in underwater applications; this will involve enhancing the range extension, signal interferences, and cost of deployment. Further, one can propose the further development of symbiotic communication systems integrated with the 5G and the acoustic-optical approaches to provide a more versatile and less sensitive to the multiple disturbances for various underwater applications. Thus, further research into the optimization of energy consumption, strengthening of security measures, and the practical implementation of 5G in marine research will remain an important focus for the IoUT as it develops, as well as for modern oceanographic studies.

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