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PR2: Curriculum for Vocational Training in the field of blue digitalization profile
Title: Internet of Things

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1. Introduction:

The creation of marine knowledge begins with observation and monitoring of the seas and oceans. Knowledge is necessary to achieve good environmental status of seas and oceans that make up 71% of our planet's surface and is an engine for sustainable growth in the interconnected global economy. (European Commission, 2010)

Significant amount of data generated that is used in the advancement of Information Technology together with the Internet aiming in transforming lives. The fusion of human vision and the efficiency of machines led to the digitalization of things. One such digitalization led to the Internet of Things (IoT), in which the data over the Internet is the fundamental structure. The IoT connects devices on 29% of the Earth's surface. The IoT is altering the way of living in many sectors of terrestrial environments. (Vijayan, 2023) The data is born from the sensors or smart devices. The data is transformed to a digital payload is collected and transmitted to the IT network over the operational technology network. The data is transferred to the public cloud and then to a database, where analytics software or Artificial Intelligence analysis it. More usage of the IoT in the cloud has acted as a cornerstone for the development and deployment of scalable IoT applications and business models. (Vijayan, 2023)

The interest and progress in IoT technologies across many sectors have led to exploring the remaining 71% of the earth: Water, a new type of IoT, the Internet of Underwater Things (IoUT). The IoUT is a domain of automation creating an ecosystem of smart interconnected underwater objects controlling devices and sensors that monitor, react, and control equipment. It is a smart network with self-learning and intelligent computing capabilities. (Vijayan, 2023)

IoUT provides Internet connectivity for distant access to data related to the underwater habitat anytime, anywhere. It has made its place in various sectors such as smart boats, smart shores, ocean positioning, underwater investigation, disaster prevention and in the crucial sector, for the protection of life below water, which is environmental protection. (Vijayan, 2023)

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2. Learning Outcomes

2.1 Knowledge

- Define what the Internet of Things is.
- Recognize the difference between the Internet of Things (IoT) and the Internet of Underwater Things (IoUT).
- Name the marine applications of the IoUT.
- Illustrate the system and component requirements and tasks to be performed when designing, developing and deploying an IoUT system.
- Illustrate the different types of communication and features that make IoUT stand out between other marine technologies.
- Describe the critical challenges faced in the implementation of IoUT systems.
- Name the possible solutions to overcome the challenges faced in the implementation of IoUT systems.
- List practical applications of IoUT systems.

2.2 Skills

- Distinguish the technicalities between the IoT and the IoUT
- Identify the various equipment used in IoUT
- Distinguish the various data types that the IoUT technologies provide through marine observation activities

2.3 Attitudes

- Argue on the merits of IoUT technology on the achievement of a sustainable blue economy.
- Defend the need for further research on the field of IoUT technology, so as to overcome current challenges.

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3. Description of the Unit:

In **Unit 2.1 Internet of Things (IoT)**, definitions and evolutions in the field have been provided in section 4.1, as a starting point for the general understanding of the examined topic.

However, due to the specific orientation of the BlueDivet training program towards technologies for blue economy digitalization, the **Internet of Underwater Things** (IoUT) is being introduced **as a new IoT category** that seeks to fill the knowledge and information gap in the marine environment, since you "can't sustainably manage and protect what you don't monitor and measure". (Liquid Robotics, 2020)

Continuing with the analysis, in sections 4.2 and 4.3 of the unit the **marine applications** of the Internet of Underwater of Things have been presented, along with the **features and differences** that this category has in contrast to the terrestrial IoT.

After a clear (distinction) understanding of the IoUT category has been (established) achieved, the analysis continues in section 4.4 with the **characteristics and benefits** of IoUT, while the **challenges faced and solutions provided** in this technological field, through further research work, have been discussed in section 4.5 of the unit.

In section 4.6, the **recent developments** on this technology have been presented, giving particular attention, among others, to the role of Autonomous Underwater Vehicles (AUVs), Sea Gliders as a technology that has particular interest in its payload capabilities, the cabled observatory platforms and satellite oceanography. All the developments have been selected as prominent examples for the transition attempted from analog systems to digitally-enabled systems of ocean management.

The theoretical content of the unit is completed in section 4.7, discussing the **integration of the IoUT (with) in other technologies**. Specific technologies were selected among others in the given sub-sections, namely: Big Data, Blockchain and Intelligent Reflecting Surfaces, since they demonstrate the complementarity and synergy that IoUT technology could have with the other technologies for blue economy digitalization promoted in the BlueDivet training curriculum.

Finally, the two (2) case studies provided in section 5 have to do with real-life applications and projects that are currently taking place in the environmental protection and marine observation sector, presenting the practical benefits they have from moving from **blue economy** to a **sustainable blue economy.**

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4. Theoretical Content of the Unit:

4.1 Definition and Evolution of the Field

As technology proceeds and the number of smart devices continue to grow substantially, need for ubiquitous context-aware platforms that support interconnected, heterogeneous, and distributed network devices has given rise to what is referred today as the Internet-of-Things. (Khodadadi et al., 2017) Officially, the term was introduced for the first time during a presentation in 1999 regarding supply chain management. (Ashton, 2009)

Since that time considering the wide background and the numerous required technologies from sensing devices, communication subsystems, data aggregation and pre-processing to object instantiation and finally service provision it is apparent that generating an unambiguous definition of the "IoT" is not a trivial task. On that aspect, the IERC definition states that IoT is: "a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network". As a consequence, IoT is as multidimensional and multi-faceted as the many things that form it therefore the main issues and challenges have to be addressed comprehensively and from many angles. (Vermesan and Bacquet, 2017)

It can be clearly stated that the Internet of Things (IoT) has reached many different players and gained further recognition. Out of the potential Internet of Things application areas Energy and Environment Protection as part of a future IoT ecosystem have gained high attention. (Vermesan and Friess, 2013) As a result, IoT-based technologies can certainly be applied to the monitoring and protection of marine environments while different sectors' applications use different IoT system architectures, sensing and control technologies, and communication technologies. (Xu et al., 2019)

4.2 Marine Applications of IoT: From the Internet of Things to the Internet of Underwater of Things

The projection of the IoT concept onto the maritime industry and the expansive and irreversible nature of its implementation, together with the fundamental nature of human maritime activity, will ensure radical growth and the long-term development of promising maritime technology sectors. **Thus, IoUT provides Internet connectivity for remote access to data related to the water surface and underwater habitat with no spatial and temporal limitations.** (Vijayan, 2023) On that regard, it is possible to identify the following two (2) main applications of **IoUT** technologies: scientific and industrial Fig. 1.

Scientific applications are associated with marine environment observation, i.e., the monitoring of the geological processes on the ocean floor, the marine environment, and marine life. Examples of IoUT based marine environmental monitoring applications include:

1. Ocean sounding and monitoring- a general system for monitoring the marine environment, formerly a long-established system using oceanographic and hydrographic vessels;
2. Water quality monitoring-generally for tracking water conditions and quality, including water temperature, Ph, turbidity, conductivity, and dissolved oxygen content in ocean bays, lakes, rivers, and other bodies of water;
3. Coral reef monitoring- tracks coral reef habitat and the environment;
4. Monitoring deep-sea fish farms- tracks water state and quality, including temperature and Ph, measures fecal waste and uneaten food, as well as fish condition, including number of dead species;
5. Wave and current monitoring-measures waves and currents for safe and reliable navigation;
6. Ocean pollution monitoring- includes chemical and biological analysis of ocean pollution and temperature analysis;
7. Analysis of pressure and temperature changes of given areas;
8. Monitoring oil and gas field areas and pipelines

Figure 1. Application of the IoUT (Mohsan et.al.,2023)

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Furthermore, IoT technologies allow the implementation of new models of underwater research in the tasks of underwater archaeology, seabed mapping, natural resource search, and many other applications. Within the framework of maritime accident and disaster prevention, IoT technologies make it possible to implement subsystems, e.g., flood warning, earthquake and tsunami warning and maritime navigation. Monitoring and research tasks based on IoT technologies can be applied on both small and large scales, from the implementation of fish observations in the aquarium to the tasks of monitoring large water areas of the seas and oceans. **The mentioned application scenarios usually refer to Internet of Underwater Things (IoUT) or Underwater Internet of Things (UIoT) technologies.** In Annex 1 are summarized the existing Maritime Internet of Things applications (Kabanov and Kramar, 2022)

4.3 Features of IoUT and Differences between IoUT and IoT

The design, development, and deployment of IoUT-based marine research and exploration systems are necessary to achieve several critical objectives, including increased autonomy, adaptability, scalability, and ease of implementation. When designing, developing and deploying IoUT-based marine environmental exploration and development systems, the following system and component requirements specific to the marine environment and tasks to be performed should be taken into account:

1. The heterogeneity and versatility of the system elements determine that the system must provide intermediary communication, providing interaction between underwater surface, air and ground elements (underwater robots, surface ships, buoy systems and underwater stations, UAVs, coastal operator stations);
2. Various possibilities of communication channels (especially bandwidth) require the development of a special model for the information interaction of system elements;
3. Computational limitations for data processing operations by on-board computers;
4. Low power consumption and the ability to generate and store energy leads to the need to apply energy conservation, generation, and storage measures in the system elements;
5. Increased needs on equipment reliability, imposes even higher demands on equipment reliability due to aggressive marine environment. Sensors, actuators and other assemblies are required to have a very high level of watertightness. There is a need for auxiliary devices, such as buoys and mooring devices etc.

The Internet of Underwater Things or Marine Internet of Things have some similarities with their Internet of Things counterpart, for example, in terms of structure and function. However, there are also differences, which are primarily reflected in the communication technologies used. In Annex 2 are summarized the key differences between IoUT and IoT. (Kabanov and Kramar, 2022)

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4.4 Characteristics and Benefits of IoUT

While IoT and IoUT share analogous architecture and functions, due to significant variations in environmental conditions there are some dissimilarities in communication and features that make IoUT to be distinguished among other marine technologies. (Vijayan, 2023)

1. **Communication or Transmission media**- IoT utilizes radio waves or electromagnetic waves to communicate among IoT devices/terrestrial equipment for data communication. However, high attenuation is found when electromagnetic waves are used for water communication and radio signals would be absorbed in water. So, radio waves can be used to communicate on water's surface and for lesser distance transmissions. Most of the communication in IoUT is performed using acoustic, magnetic induction and optical waves
2. **Energy harvesting technologies**- IoT uses solar energy and piezoelectric energy harvesting technologies. In IoUT, microbial fuel cell (MFC) is being explored, where electrical energy is produced straight from biodegradable substrates throughout the metabolic activities of bacteria in water. Solar energy can be used for on -the-surface water equipment, and piezoelectric energy is utilized for effective communication of underwater devices.
3. **Tracking technologies**- In IoT, Radio Frequency Identification (RFID) is mainly used for tracking devices. On the other hand, IoUT uses Acoustic tags, Radio tags, and Passive Integrated Transponder (PIT) tags for tracking underwater things. Frequently, these tags are implanted to study the behavior of the fish, these tags impose minimum to no damage on the implanted sea animals.
4. **Localization techniques**- Global Positioning System (GPS) is used to detect the smart devices in IoT. This method cannot be applied underwater due to the Doppler effect, long propagation delays, multipath, and fading. GPS uses radio waves to locate devices that cannot propagate well in seawater. In IoUT, AUVs are used to trace the underwater devices. Many practices are still being researched for efficient and precise localization of **underwater things**. (Vijayan, 2023)

4.5 IoUT Challenges and Solutions

During the course of time, many challenges have been identified in the application of IoUT due to the differences amongst terrestrial wireless sensor networks and underwater sensors. Moreover, the IoUT also encounters problems in terms of the dynamic topology of the ocean, energy efficacy, the dynamic water environment, and low link reliability. (Mohsan et.al., 2023) Critical challenges with the possible solutions provided below:

1. **Communication** - Diverse technologies are used for communication in underwater habitats, such as optical, radio frequency (RF) and acoustic waves, etc. In communication outside water electromagnetic waves (EM) prevail as they offer high bandwidth, low power, and longer transmission range. However, EM waves due to

absorption face limited transmission range in seawater. On the other hand, acoustic waves even though they show better performance underwater achieving transmission distances of over a hundred kilometers this method suffers from low data rates, path loss, noise, multipath, Doppler spread, and high propagation delay. As a consequence, hybrid communication technologies represent a plausible solution to the above-mentioned challenges so to enhance reliability, energy autonomy, and transmission speeds of IoUT systems. (Mohsan et.al., 2023)

2. **Energy storage and consumption** - energy storage and utility are critical concerns since IoUT, acoustic and optical communication channels require significantly more power than radio frequency (RF) communication. Moreover, energy harvesting is difficult due to the impossibility of using solar power in the IoUT environment. Due to the natural behavior of the IoUT environment, it is difficult to maintain or recharge such systems. This could have the potential to reduce battery life and cause data loss. To overcome these challenges, research is taking place so wireless power transfer techniques or solar energy to be used and autonomous recharging methods to be utilized so to prolong the life span of IoUT networks. (Mohsan et.al., 2023)
3. **Mobility and reliability** - The movement of water particles, internal waves, and water currents severely influence the location and topology of underwater sensor nodes (static and dynamic). These mobility challenges are more critical in shallow than in deep water. Such kind of challenges tend to result in higher latencies and broken connectivity, leading to delays, data transmission errors, or the failure of the entire network. Novel mobility models are being examined by the researchers to tackle these issues. (Mohsan et.al., 2023)
4. **Latency** - for the successful implementation of IoUT latency is a critical concern. IoUT systems mostly use acoustic signals with low transmission speed for underwater communication, in comparison to the terrestrial IoT. This factor has a severe impact on the real-time deployment of the IoUT. On the other hand, optical communication systems can ensure real-time deployment of the IoUT due to lower latencies that they offer. This fact has paved the way for researchers to study further optical modems and their application to marine environments. (Mohsan et.al., 2023)
5. **Sparse and High maintenance sensing devices in the IoUT** - environmental conditions severely impact the performance of sparsely distributed sensing devices. The distinct nature of the ocean and sparse deployment result in high maintenance costs for IoUT networks. Essentially, maintenance activities should tackle the challenges of erosion, corrosion, sediments, and pollution. Self-management capabilities such as self-evaluation, self-adjustment, self-configuration, self-storage, self-charging and autonomous reports to operating bodies are all compelling approached to deal with the aforementioned challenges of the underwater things. (Mohsan et.al., 2023)
6. **IoUT security issues** - acoustic communication and extended propagation delays make underwater sensors weak. In addition, it seems difficult to use current access control,

privacy, and security methods for underwater sensors. Existing security mechanisms cannot guarantee secure network services due to a lack of standardizations, security features, and privacy strategies. (Zhao et.al.,2019) The IoUT faces several critical issues, such as flooding, spoofing, blackholes, sinkholes, wormholes and jamming. (Yisa et.al.,2019) When faced such attacks, network data can be stolen, and complete network failure can also happen. Moreover, sensitive data can be stolen during communication between nodes through tapping or eavesdropping attacks. Thus, the development of robust and strong security mechanisms for the IoUT is an imperative in terms of confidentiality, integrity, availability and quality of service features to protect nodes from possible threats.

7. **Lack of standardization**- presently there is an absence of standardization in the IoUT, and the heterogeneity of IoUT objects, technologies, and applications is a major concern. Interoperability requirements of IoUT network entities is a crucial factor to overcome the issue. Thus, work is on process by academics and regulatory bodies to standardize IoUT objects, applications, and services which in parallel will accommodate privacy and security issues.
8. **Localization**- resilience to mobility when deploying an underwater network should be considered since it is the basis of ocean monitoring activities and target tracking. Although the mobility of various underwater vehicles is measured and supervised; however, unrestrained mobility due to dispersion and water currents severely impacts floating underwater sensor nodes. (Li et.al., 2021) Presently, most node localization algorithms consider fixed node location and calm seas; yet, underwater nodes drift due to the motion of currents. Due to the given challenges more advanced models based on temporal and spatial correlation of mobility patterns are being explored while node dynamic prediction algorithms are another option to be used to cope with localization issues. (Mohsan et.al., 2023)
9. **Unreliable channel conditions**- in comparison with the terrestrial IoT, IoUT sensor nodes communicate through various types of acoustic channels. This situation results in significant levels of error data, substantial power need, prolonged propagation delays. Moreover, in underwater networks, channel noise, e.g. ambient and environmental noise can negatively impact the performance of the IoUT communication. (Mohsan et.al., 2023)

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4.6 Recent Developments

4.6.1 Role of Autonomous Underwater Vehicles (AUVs) in IoUT

The Autonomous Underwater Vehicles occurred as key enablers of the IoUT which can cope with the rapidly growing demands of underwater observations. For instance, AUVs have superior battery endurance than sensor nodes and can be used to connect sensors to other devices or the Internet. (Mohsan et.al., 2023) Moreover, due to the unstable and harsh underwater environment, it is difficult to generate energy-efficient routing protocols. In this regard, AUVs could substantially decrease both data collection time and latency. (Han et.al., 2017) On the challenging issue of localization, and especially node localization which becomes very difficult due to underwater mobility, water stratification and the absence of GPS sensors. (Yan et.al., 2020); on that aspect, AUVs can be used to dive into the water to obtain location information and thus offer high accuracy compared to traditional localization methods (Mohsan et.al., 2023) Furthermore, void challenges which create difficulties in link connectivity and data delivery can be mitigated by AUVs that can be used to forecast the routine voids to be repaired in any network. (Jin et.al., 2020). Network topology which is severely affected by the rapid mobility of underwater nodes can be improved by a topology optimization strategy using AUVs which improves the robustness and the adaptability of the network. (He et.al.,2017) Finally, specific models of such vehicles travel horizontally to gather data from IoUT objects located on the seabed and forward the data to vehicles which in turn move vertically to forward the data received to a surface station. This smart strategy can decrease energy consumption while providing uninterrupted data collection. (Mohsan et.al., 2023)

4.6.2 Sea Gliders

Wave gliders represent the IoUT nodes that gather data either on the surface or underwater via various sensors such as depth sensors, compasses, and hydrophones. (Lan et.al., 2020) Sea gliders can offer oceanic parameter measurements over long ranges. The data collected by the gliders is sent to the data center using relay nodes such as satellites. The information is then extracted and distributed among certain users. As for mobility, gliders travel via electrically driven propellers and can travel thousands of miles within the underwater medium for several months to attain accurate observation and monitoring. As for the payload of sensors the inner sensors in any sea-glider control the direction of the vehicle while external sensors are used to scan the marine environment for data collection. (Mohsan et.al., 2023)

4.6.3 Cabled Underwater Observatory Systems

Numerous cabled underwater observatory systems have been installed such as the European Multidisciplinary Seafloor and water column Observatory (EMSO), Ocean Networks Canada

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(OCN), and the Monterey Accelerated Research System (MARS) in USA. (Jiang S., 2019) All of these systems are dependent on sea-floor cables for both electrical power supply and data communication, providing expanded real-time monitoring related to hydrosphere, biosphere, and geosphere interactions. (Mohsan et.al., 2023) Sensing devices to monitor seabed movements, water circulation, salinity, Ph, temperature etc. are hosted in these high-technology architectures. By this way they can monitor both environmental sensing data and underwater acoustic data. These installations Fig. 2, are a foundation of multidisciplinary ocean research and also support services to the industrial sector. Therefore, they offer opportunities for research and development as well as technological breakthroughs. However, these systems offer stability but not flexibility, in other words, they are costly and difficult to move around. (Mohsan et. al., 2023)

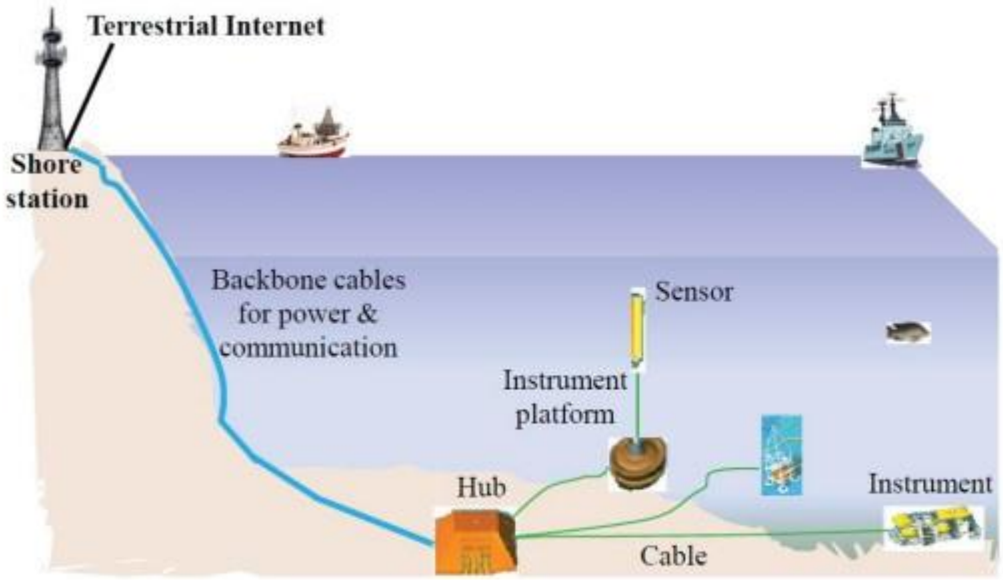

Figure 2. Overview of the MARS platform

4.6.4 Satellite Oceanography

Satellites are the most effective means of communication in the IoUT since they play a crucial role in sharing ocean data with the base station. Satellites are used to quantity ocean surface temperatures and weather patterns and to capture images. Moreover, they operate as a medium of communication among offshore stations and underwater media to transmit information for further analysis. Thus, the IoUT for remote sensing and smart satellites can be utilized for ocean observations and disaster forecast (earthquakes, floods, tsunamis), making it feasible to issue warnings to evacuate a potential disaster area. Furthermore, IoUT- empowered systems can analyze data about coastal inhabitants and coral reefs using satellite oceanography. (Mohsan et.al., 2023) What is attempted to be achieved is the transition from analog observational frameworks (like on-board human observers) which are hampered by relatively small sample sizes and post-hoc reporting; to a digitally-enabled form of ocean governance utilizing more robust observational mechanisms and real-time reporting. (Bakker, 2022)

4.7 Integration of the IoUT in other Technologies

Internet of Things continues to develop, further potential is estimated by a combination with related technology approaches and concepts such as Cloud computing, Future Internet, Big Data, robotics and Semantic technologies. The idea is apparently not new as such but becomes now evident as those related concepts have started to reveal synergies by combining them. (Vermesan and Friess, 2013)

4.7.1 Big Data Analytics

A first example of such technology is Big Data analysis. The rapid developments and operations of marine technologies to explore and monitor the underwater environment have led to creation of extensive quantities of data, or **big marine data** (BMD). These datasets are considered heterogeneous information collected from underwater platforms. Chemical, biological, or environmental data is gathered from different sources, such as sensors, tags, drones or cameras. The typical features of big marine data, including incompleteness, complexity, and multi-source, surpass the storage and recovery capabilities of old-style systems. Due to all these issues with regards big data and its ocean data management challenges, collaborations between marine experts and data scientists should have to be established. (Addison et.al., 2018)

4.7.2 Blockchain in IoUT

Blockchain is a decentralized and distributed technology which has the capacity to handle security challenges in the IoUT. It can securely and efficiently store IoUT data with no dependency on a third party and can effortlessly verify data and process them prior adding them to the blockchain, removing third party involvement in data processing. As a result, blockchains can offer functional resilience, immutability, and transparency and can reduce fraudulent operations. (Mohsan et.al., 2023) On that aspect, robust, transparent, and energy-efficient blockchain-based IoUT mechanisms have been introduced in various works. However, handling IoUT big marine data is still a challenging endeavor (Hammi et.al., 2018)

4.7.3 Intelligent Reflecting Surfaces (IRS)

In an underwater environment, acoustic wave propagation is likely at larger transmission distances. However, it encounters suspended particles, uneven surfaces, and scattering, leading to reduced data rates and high path loss; Intelligent Reflecting Surfaces (IRS) can be used to mitigate these problematic areas. (Mohsan et.al., 2023) IRS is a novel paradigm in wireless communication which ensures the smart, secure and reconfigurable propagation of radio waves. (Mohsan et.al., 2023) IRS provides exclusive solutions to overcome interference and fading issues, cost savings, energy efficiency, avoidance of antenna noise and self-interference, improved reliability and capacity. (Wu et.al., 2021) Below a figure it is provided presenting an IoUT scenario employing Intelligent Reflecting Surfaces (IRS).

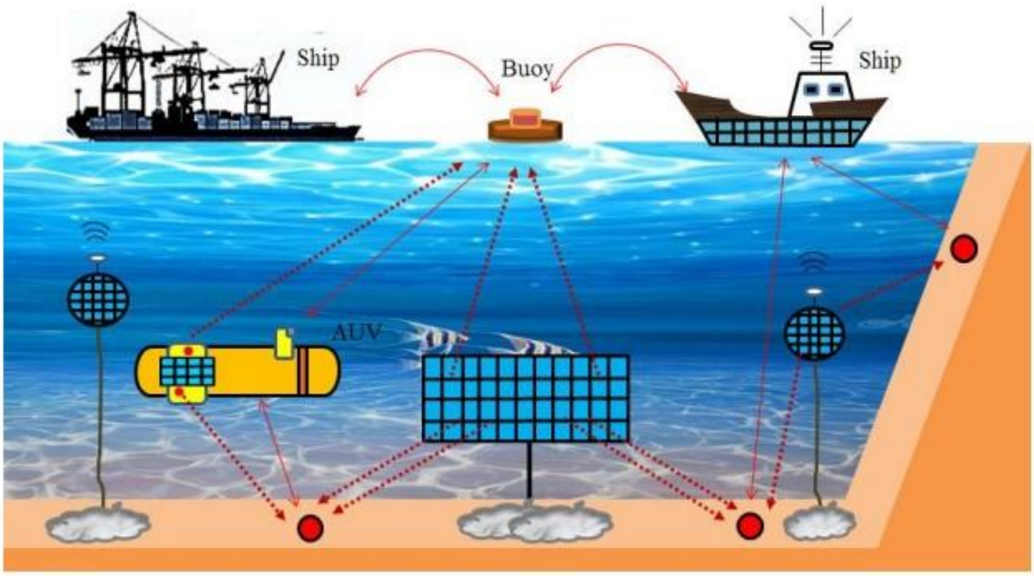

Figure 1. Intelligent Reflecting Surfaces assisting IoUT

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5. Practical Examples/Case Studies:

5.1 Wave Glider: General Information and Scope of the Project

Liquid robotics is helping to **close the ocean knowledge gap** with the Wave Glider platform. Wave Gliders are long- duration ocean robots that help scientists, businesses, and governments gain new insights and improve decision making. Operating at the surface, they provide the essential link between sea, air, and space, transforming subsea sensors into real-time information sources, and **bringing a data and access gap previously inaccessible.** The Wave Glider platform is at the forefront of the ocean transformation, helping to monitor and coordinate activity across platforms. It can autonomously operate in a range of ocean conditions, dynamically respond to changes, and provide real-time access to critical data- all at a fraction of the cost of traditional **environmental monitoring solutions.** For the first time, commercial operators can cost effectively collect data throughout the lifecycle of projects- from base line assessments through to decommissioning surveys- to **mitigate their environmental impact.** This data can also be used to improve operational efficiency, performance and safety, helping operators achieve key business objectives.

5.1.1 Platform Architecture and Principle of Operation

Wave Glider is a hybrid sea-surface and underwater vehicle in that is comprised of a submerged "glider" that is attached via a tether to a surface float. The vehicle is propelled by the conversion of ocean and wave energy into forward thrust, independent of wave direction, Fig.1.

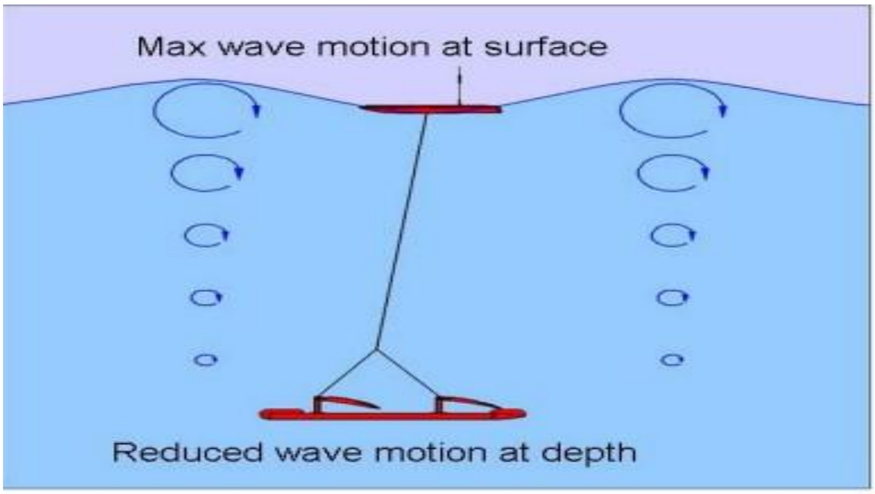

Figure 2. The Wave Glider Ocean robot

The wave energy propulsion system is purely mechanical; no electrical power is generated by the propulsion mechanism. Just as an airplane's forward motion through the air allows its wings to create an upward lifting force, the submerged glider's vertical motion through the comparatively still waters at the glider's depth allows its wings to convert a portion of this upward motion into a forward propulsion force. As waves pass by on the surface, the submerged glider acts a tug pulling the surface float along a predetermined course. Separation of the glider from the float is a crucial aspect of the vehicle design. (Wilcox et.al., 2009)

5.1.2 Communication, Command and Control

Wave Gliders are controlled via a simple web-based command and control interface, Fig.2. Each Wave Glider vehicle communicates with the shore-based web server by initiating an Iridium modem messaging session which is received at an Iridium network ground station where the data is redirected onto the Internet. These sessions occur at configurable intervals, typically every five and fifteen minutes. Using the web-based command and control interface, any number of operators (with the appropriate authorizations) can control any Wave Glider vehicle from any Internet-enabled computer, PDA, or mobile phone. Similarly, subscribers can monitor vehicle status and data on an as needed basis. (Wilcox et. Al., 2009)

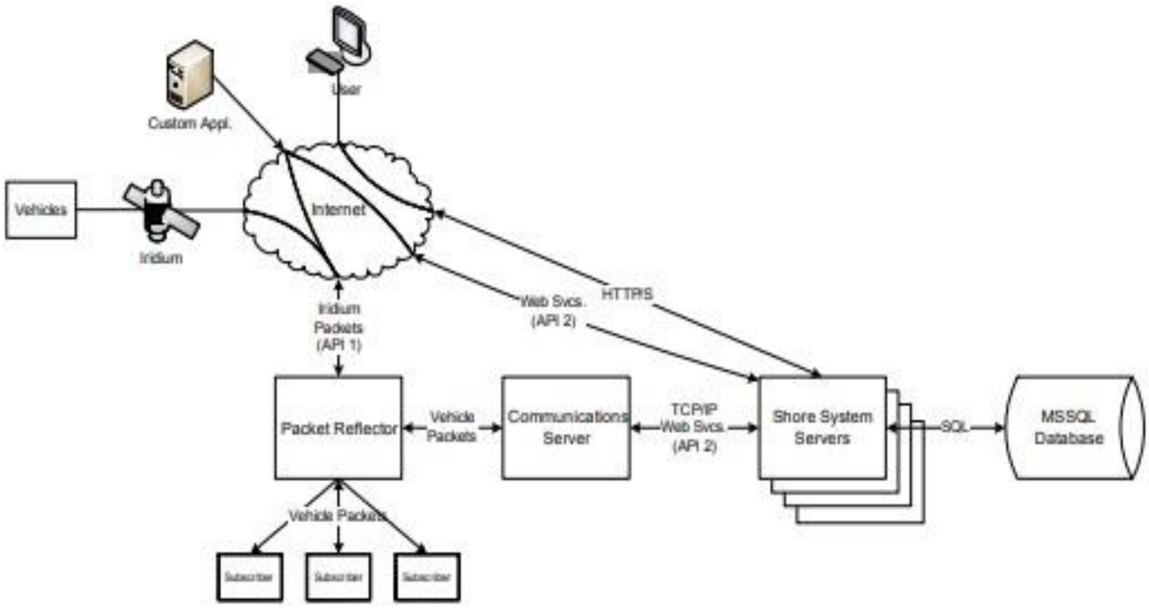

Figure 2. Wave Glider Communications and Control Scheme

5.1.3 Payloads

The Wave Glider has modular mechanical, electrical, and software interfaces to accept a wide variety of payloads modules, Fig.3. All command and control, communications, and navigations

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electronics are contained in a core electronics module, which also houses the batteries and their charging electronics. Dedicated forward and aft payload modules house most payload **sensor systems** and support electronics. Several payload modules have been demonstrated on the Wave Glider, including passive hydrophones and towed hydrophone arrays, marine weather stations, still cameras, and video cameras, and acoustic Doppler current profilers (ADCPs). The current generation of the Wave Glider has more recently demonstrated towing an instrumented buoy that was itself towing an acoustic modem at the end of a long cable. More recently, the acoustic modem payload and its support electronics have been integrated onto the Wave Glider float. Future planned payloads include **hydrographic sensors**, such as conductivity, temperature, and depth (CTD) sensors and single beam **sub-bottom profiling sonars**. In collaboration with the NOAA Pacific Marine Environmental Laboratory (PMEL), we are working to integrate a carbon dioxide partial pressure and sea water Ph sensor package into the Wave Glider platform. As a result, important **carbon science** is planned to be conducted with the development and integration of this payload onto a network of such Wave Glider vehicles. (Wilcox et. Al., 2009)

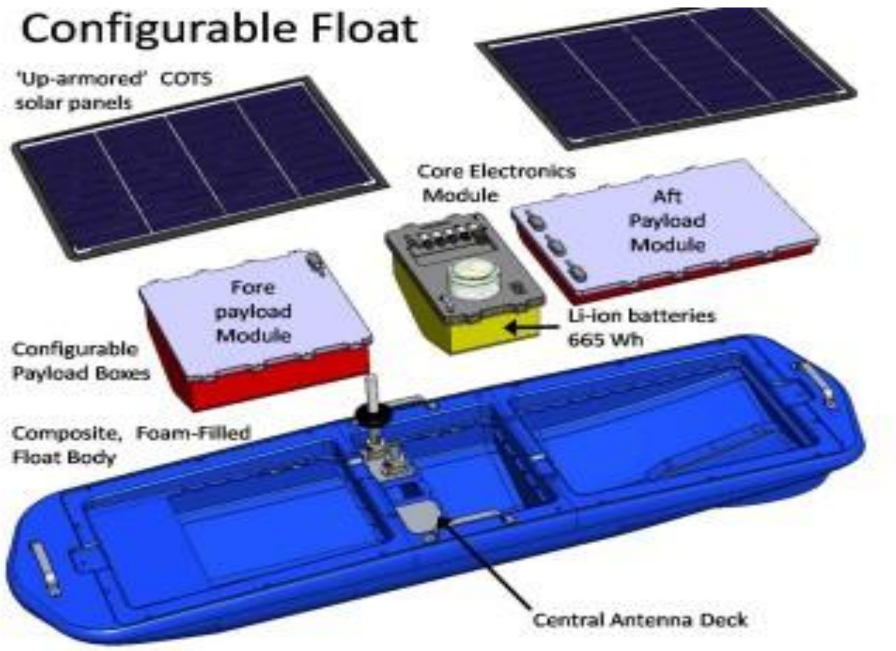

Figure 3. The Wave Glider float is highly modular, with two dedicated modular “dry-boxes” for easy integration of payloads

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5.2 The Ocean Cleanup: General Information and Scope of the Project

The Ocean Cleanup is a promising multi-national initiative developing technologies to rid the world's ocean of plastic. The final aim of the non-governmental organization, is to deploy a full fleet of systems to clean up 50 per cent of plastic in the Great Pacific Garbage Patch every five years. The first device of its type, System 001 or "Wilson" has been undergoing trials in the Pacific Ocean since November 2018. Concerns have been raised by some within the scientific community about the potential effect this system may have on marine life and the success at achieving this ambitious objective. However, the Ocean Cleanup has organized a suite of technology and organizations to observe the system's performance and collect an abundance of vital data within the infamous "plastic soup" plaguing the Pacific Ocean, Fig.1. (Eco Magazine, 2019)

Figure 3. Ocean plastic concentrations

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5.2.1 Environmental Monitoring of the Ocean Cleanup by AutoNaut USV

A 5-metre AutoNaut accompanied the Ocean Cleanup in environmental monitoring missions of up to 50 days period in the Pacific Ocean. The primary role was the acquisition of data on ocean current, meteorological and oceanographic variables. Both in close proximity to the plastics removing device- “Wilson” and in the far-field for supporting data. The ultimate aims being to better understand the local environment and the interactions between aggregations of plastic litter and the Ocean Cleanup barrier. Transmission of these data streams was conducted in near real-time over Wi-Fi and Iridium RUDICS. A secondary task was for AutoNaut to visually inspect the system and surrounding environment-equipped with cameras both above and below the water-line. Crucially, the information collected has supported understanding of interactions between aggregations of plastic litter and the Wilson barrier (AutoNaut, 2019)

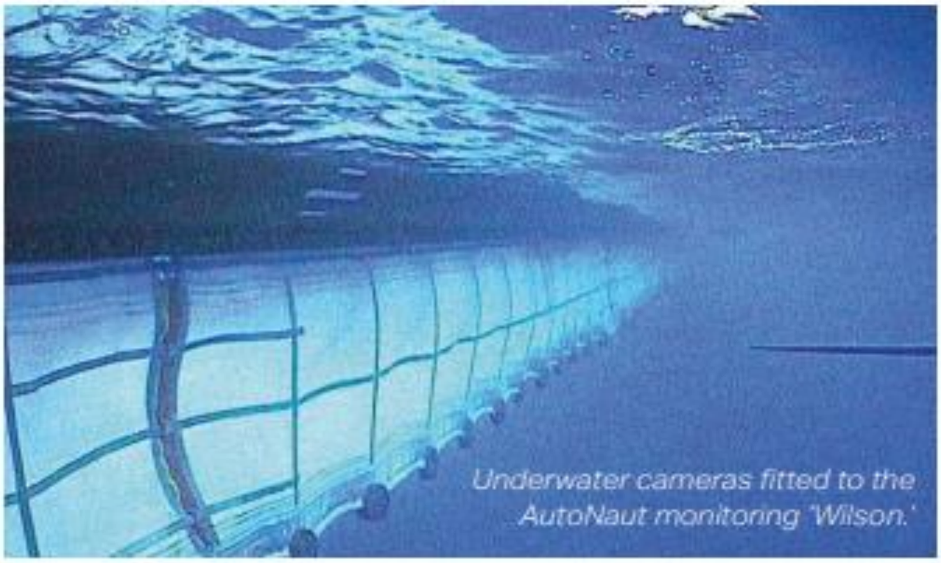

Figure 2. Inspection of the Ocean Clean up initiative

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5.2.2 Capabilities and Future Developments

An Internet of Things innovative technology the USV is enabled to follow a "track-and-follow" approach, by using transceivers on the offshore asset and autonomously tracking by use of dynamic waypoints generated onboard. This allows the AutoNaut to maintain a safe and consistent distance to a moving offshore installation, without necessity for human intervention. (Eco Magazine, 2019) A highly desirable future function of the AutoNaut is the ability to automatically take water samples and either analyze them onboard (autonomously), or to bring them back to shore for laboratory analysis. In this project the objective is to make such a payload based on bio-optic sensors (spectrometers) that can measure the absorbance spectrum of the water mixture in order to detect and classify the signatures of phytoplankton, suspended matter and dissolved organic matter in the water samples. (AutoNaut-prosject, 2021)

6 Additional Resources:

Please refer to the reference list

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8 Glossary:

Table of the terms used in the unit:

Terms	Definitions
Text or number	Text or number
Internet of Things (IoT)	a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network.
Internet of Underwater Things (IoUT)	The Internet of Underwater Things or Marine Internet of Things have some similarities with their Internet of Things counterpart, for example, in terms of structure and function. However, there are also differences, which are primarily reflected in the communication technologies used.
Payload	The electronic systems and equipment that an autonomous marine vehicle carries to perform monitoring and observation activities
Big Marine Data	Marine technologies explore and monitor the underwater environment have led to the creation of wide quantities of data, or big marine data (BMD).
Sea Gliders	Long-duration Ocean robots that help scientists, businesses, and governments gain new insights and improve decision making. Operating at the surface, they provide the essential link between sea, air, and space, transforming subsea sensors into real-time information sources, and bringing a data and access gap previously inaccessible.

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9 Evaluation:

Question 1: Which are the two (2) main fields of application of the Internet of Underwater Things included in this unit?

a. Scientific
b. Military
c. Industrial
d. Coastal tourism

Question 2: During the design, development, and deployment of IoUT-based marine research and exploration, systems are necessary to achieve several critical objectives including _____________.

a. increased autonomy
b. adaptability
c. scalability
d. ease of implementation

Question 3: Many challenges have been identified in the application of IoUT, which are mainly due to the differences between terrestrial wireless sensor networks and underwater sensors.

a. True
b. False

Question 4: Which are the (tracking) technologies that IoUT uses for tracking underwater things? (you can select more than one option)

a. Acoustic tags
b. Radio tags
c. Passive Integrated Transponder (PIT) tags

Question 5: Due to the harsh ocean environment, maintenance activities should tackle the challenges of __________. (You can select more than one option)

a. erosion,
b. corrosion,
c. sediments
d. pollution.

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Question 6: Currently, lack of standardization in the IoUT as well as the heterogeneity of IoUT objects, technologies and applications have become a major concern.

a. True
b. False

Question 7: Internal sensors in sea gliders determine the direction of the vehicle, while external sensors are used to scan the marine environment for data collection.

a. True
b. False

Question 8: As the Internet of Things continues to develop, further potential is estimated by a combination with related technology approaches and concepts such as ______.

a. Cloud computing
b. Future Internet
c. Big Data
d. Robotics

Question 9: Which are the distinctive features of big marine data? (you can select more than one option)

a. incompleteness
b. complexity
c. multi-source

Question 10: The analog observational frameworks (like on-board human observers) are hampered by relatively small sample sizes and post-hoc reporting.

a. True
b. False

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2. Annexes

2.1 Annex I – Marine Internet of Things Applications

Reference	Key Features	Perspectives	Main Research Objects	Country
Binnerts et al. [20]: IEEE: MTS/IEEE Kobe Techno-Oceans (OTO)	Development and demonstration of live data-streaming capability using an underwater acoustic communication link	It is planned to collect more representative channels at open sea for further testing and optimization	Acoustic communications	Netherlands
Lu et al. [21]: arXiv	The cognitive ocean network (CONet) is proposed and described	Using next-generation artificial intelligence technology	IoUT architectures	China
Saha [22]: IEEE Xplore	IoT-based automated fish farm aquaculture monitoring system	To develop a better way to capture images and use better image processing techniques to provide better results	Sensor nodes, ocean monitoring	Bangladesh
Li et al. [23]: Journal of the World Aquaculture Society	The major challenges and future trends of underwater object counting in aquaculture are discussed	To implement new counting tasks in aquaculture	Ocean monitoring	China
Wang et al. [27]: IEEE Communications Surveys & Tutorials	The concept of machine-type communication (MTC) for maritime IoT and its services, requirements, and challenges	To avoid the potential pitfalls in the development and standardization of maritime MTC technology	IoUT architectures, MTC	USA
Xia et al. [28]: IEEE Wireless Communications	An intelligent energy control scheme named the residence energy control system (RECoS) is proposed	To provide the sufficient attention of MIoT that it deserves in the 5G community	AI, ocean energy	China
Yang et al. [29]: IEEE Network	Explanation on how various AI methods can facilitate the operation of the parallel-network-driven maritime network	To speed up the AI methods	AI, IoUT architectures	China

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	environmental monitoring	formations in tropical areas		
Manjula et al. [9]: IEEE Xplore	A scheme for sensor deployment design aimed at optimal coverage of the monitoring area with minimum number of sensor nodes	To consider other space filling structure	Sensor nodes, UWSNs	India
Khaledi et al. [10]: Systems and Information Engineering Design Symposium (SIEDS)	Design of an underwater mine detection system	Reducing the approximate system cost	AUVs, sensor nodes	USA
Cayirci et al. [11]: Ad Hoc Networks	A new wireless sensor network architecture is introduced for underwater surveillance systems where sensors lie in surface buoys when nodes are first deployed	–	UWSNs, sensor nodes	Turkey
Cardia et al. [13]: Mobihoc' 19	System that supports real-time monitoring of divers' positions and health conditions, at the same time allowing unprecedented enhanced visits of the sites	–	UWSNs	Italy
Coutinho et al. [14]: Q2SWinet' 19	The challenges for the design of TC (topology control) algorithms for IoUTs	New research directions will be tackled when considering the new advancements and characteristics of IoUTs	Network topology	Canada
Marini et al. [17]: MDPI(Marine Science and Engineering)	H2020 ENDURUNS project that describes a novel scientific and technological approach for prolonged underwater autonomous operations of seabed survey activities, either in the deep ocean or in coastal areas	To develop new applications in seafloor exploration and surveying	Monitoring systems, AUVs	Italy
Qin et al. [18]: IEEE Access	An autonomous underwater vehicle (AUV)-assisted hierarchical information acquisition system composed of a marine stationary sensor layer and an AUV motion layer	To involve new AUV path planning strategies	AUVs, sensor nodes, UWSNs	China
Lin et al. [19]: Chinese Journal of Mechanical Engineering	The future trend of the ocean observation systems with docking technology and sustained ocean energy	–	Ocean energy, AUVs, monitoring systems	China

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Salhaoui et al. [1]: MDPI (remote sensing)	AUV model system that overcomes latency challenges in the supervision and tracking process by using edge computing in an IoT gateway	Extension to hybrid cloud/ edge architecture	AUVs, AI	Spain
Jahanbakht et al. [2]: IEEE Communications Surveys & Tutorials	Architectural challenges analysis	To cover new tools and techniques, as well as to make informed decisions and set regulations related to the maritime and underwater environments around the world	Big Marine Data (BMD)	Africa
Kong et al. [3,15,16]: IEEE Photonics Journal, Hindawi	The first underwater optical wireless sensor network prototype. Real-time digital video surveillance	Popularization of the future human–robot interaction applications	Sensor nodes, underwater visual monitoring	China
Domingo et al. [4]: Journal of Network and Computer Applications	The IoUT is introduced and its main differences with respect to the Internet of Things (IoT) are outlined	Detailed description of application scenarios that illustrate the interaction of IoUT components	IoUT architectures	Spain
Xu et al. [5]: MDPI (sensors)	The potential application of IoT and Big Data in marineenvironment protection	Description for potential application of IoT and Big Data in marine environment protection	BMD	China
Kao et al. [6]: MDPI (sensors)	Investigation and evaluation of the channel models	The channel models to further investigate the design of different IoUT communication protocols, such as the MAC protocols and routing protocols will be used	Underwater Wireless Sensor Networks (UWSNs)	Taiwan

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2.2 Annex II – Communication differences between IoT and MIoT

Features	MIoT	IoT
Communication technologies	Most communications in the IoUT are based on acoustic links.	Mostly radio waves.
Tracking technologies	In the MIoT, things (usually fish) are tracked with different technologies: acoustic tags, radio tags, passive integrated transponders.	The IoT uses basic radio frequency identification (RFID) for tracking.
Battery recharge	Battery capacities are limited and it is difficult (sometimes impossible) to recharge or replace them.	As part of the IoT, replacing batteries is not difficult.
Energy-harvesting technologies	Piezoelectric energy harvesting can also be exploited in the IoUT. The IoUT also benefits from specific underwater energy-harvesting techniques such as ocean thermal energy.	Two of the most promising energy-harvesting technologies for IoT devices are solar energy and piezoelectric harvesting.
Network density	The IoUT is deemed to be sparse due to the cost and challenges associated with underwater deployment.	In the IoT, it is expected that a very large number of devices communicate if all the 'things' join the network.
Localization techniques	Terrestrial localization approaches: the localization with directional beacons (LDB) scheme.	The location of mobile devices in the IoT is afforded by global positioning system (GPS) satellites

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