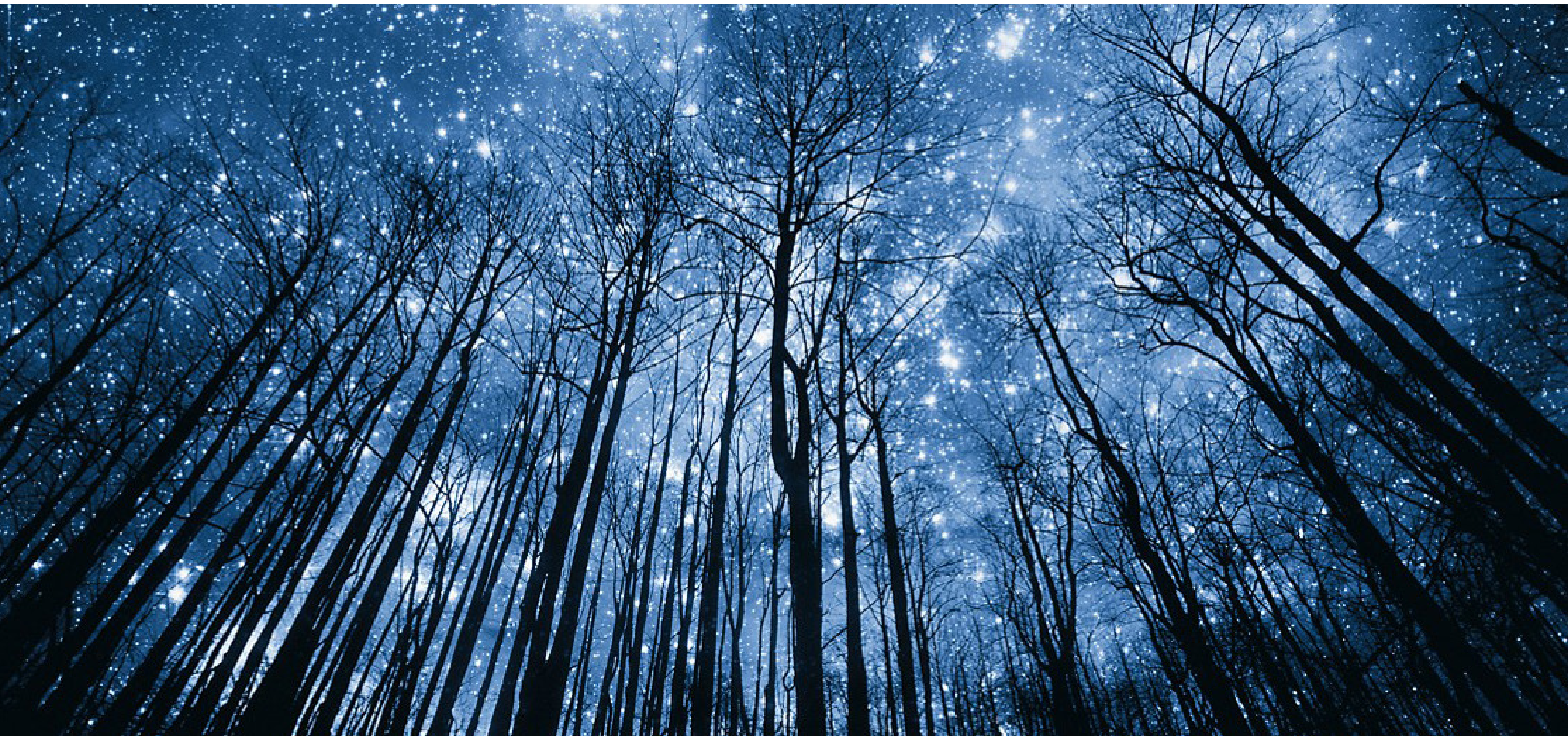
INTERNET OF UNDERWATER THINGS



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ABSTRACT

There is a tremendous amount of data generated that is used in the evolution of Information Technology together with the Internet aiming in transforming lives. The fusion of human vision and the efficacity of machines led to the digitalization of things. One such digitalization led to the Internet of Things (IoT), the underlying structure of the data over the Internet. The IoT connects devices on 29% of the Earth's surface. The IoT is transforming the way of living in many sectors of terrestrial ecosystems. The data is born from the sensors or smart devices. The data is converted to a digital payload packed with protocols and sent on the network. This is the IoT network's edge, from which the data 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 process it. Greater usage of the IoT in the cloud has acted as a catalyst for the development and deployment of scalable IoT applications and business models.

The interest and advancement in IoT technologies across many industries have led to exploring the remaining 71% of the earth: Water. A novel type of IoT, the Internet of Underwater Things (IoUT). The IoUT is a domain of automation creating a network 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.

The IoUT began when researchers were studying the Southern California Current (SCC), a current of water flowing from San Diego to Oregon. They discovered that by placing sensors in the ocean current they could gather data on weather patterns, tides, and currents. This data helped to make more informed decisions to predict earthquakes more accurately than ever before. Although there are some similarities between IoT and IoUT, we demystify the characteristics that make IoUT stand out among other technologies in the aquatic ecosystem. For the potential benefit of humanity, vast constructive and prospective applications are being introduced and worked together to create new technologies. This article focuses on the benefits of IoUT, enabling to the exploration of the underwater world.

IoUT provides Internet connectivity for remote access to data related to the underwater habitat anytime, anywhere. It has made its place in various sectors such as intelligent boats, smart shores, ocean positioning, environmental monitoring, underwater exploration, disaster prevention, and so forth. It is expected to enable numerous applications in smart cities. In this article, we will be exploring the application scenarios briefing on the component interactions.

As we speak, there is a huge amount of data that is analyzed and processed for various applications. Artificial Intelligence (AI) algorithms can process these data and make quick decisions independently. The data extraction requires meticulous complex computations. Cloud computing provides agility and flexibility from the point where data is collected from the various devices and sent to the cloud server in capturing data. This allows us to understand the underwater environment over long periods, crossing seasonal timescales, and analyze the data retrieved from the cloud server using Machine Learning (ML) algorithms. In this article, we show how Cloud computing and Artificial Intelligence play a significant role in the Aquatic ecosystem.

The challenges due to unreliable transmission medium, unstable radio signals, inborn noise, low transmission rate, limited resources, and battery capacity is noticed, and researchers are working to make them efficient.

INTRODUCTION

With the advancement in technology, we are experiencing faster communications, accurate information, and can collaborate around the world. Among the list of innovative and game-changing technologies, IoT technology is transforming various industries by storing and processing data with enhanced productivity. The smart connected devices can gather, share, and analyze information and act accordingly on terrestrial and aerial ecosystems.

Have you ever wondered what happens in the marine world, how the devices talk to each other while connected to the Internet?

Many turns of events have led to the unfolding of a unique form of IoT technology. This helps us to understand the conditions underwater, creating an “Internet of underwater things.” The IoUT - a network of heterogeneous devices and vehicles that improve water data collection and communication, leading to a more connected world. With access to the Internet, we can predict future phenomena and plan strategically as these devices sense, interpret, and react to the surroundings with the help of sensors and powerful tracking technologies. Each underwater physical object is accompanied by a rich, globally accessible virtual object that contains both current and historical information about that object’s physical properties, origin, and the sensory context in real-time.[1] It is a network of objects with self-learning and intelligent computing capabilities that enable the automatic operation of subsea components without human intervention. The gathered data can be interconnected with terrestrial things like smart gadgets and transferred to remote base stations to perform various activities.

IoUT ARCHITECTURE

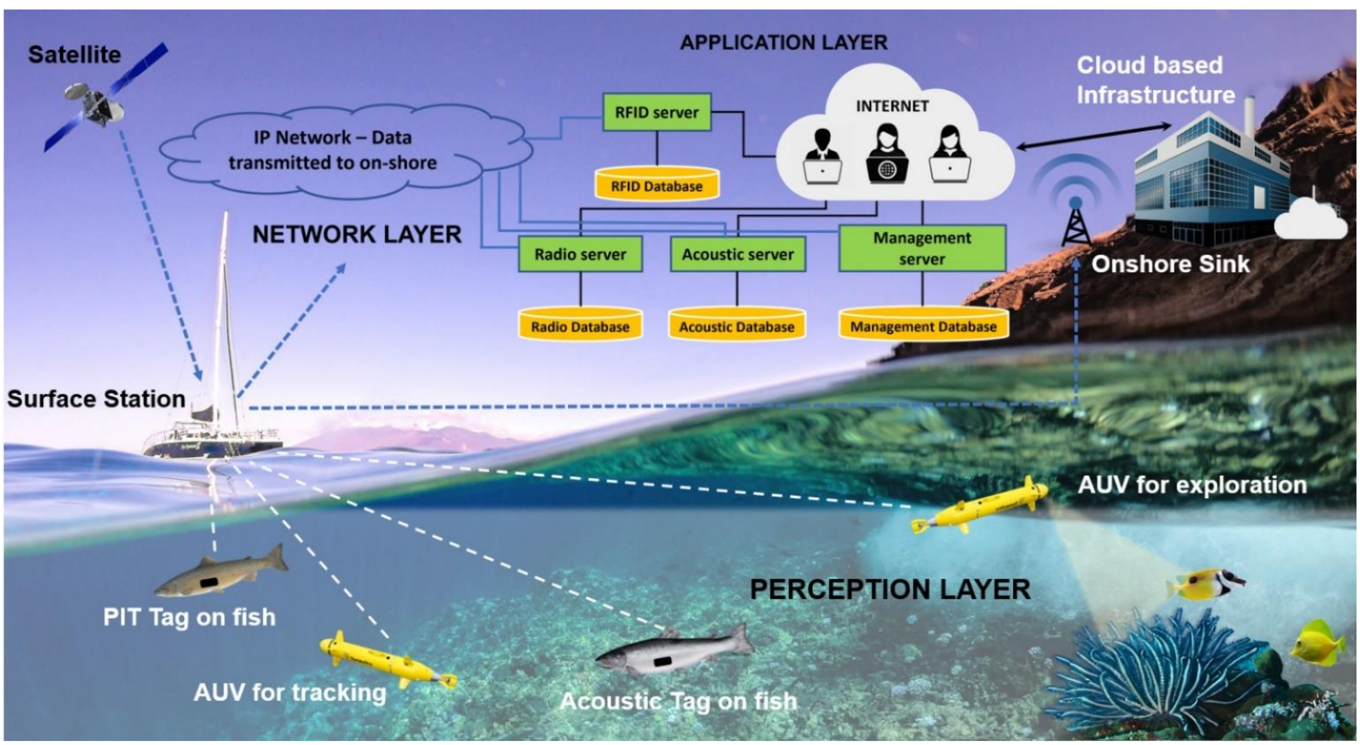

Fig. 1 IoUT Architecture with Perception, Network and Application layer

The Internet of Underwater Things is a derived version of the Internet of Things. Hence, both share a similar architectural layout. The Transmission Control Protocol/Internet Protocol (TCP/IP) is the universally agreed upon network architecture. Hence, the most basic and widely accepted format is a three-layer architecture for IoUT – Perception layer, Network layer, and Application layer as shown in Fig.1.

1.1 Perception layer

A physical layer where the sensors and connected devices identify objects and gather information. This layer includes edge devices, cameras, underwater sensors, actuators, underwater vehicles, monitoring stations, sinks (surface stations), tags (data storage tags, acoustic/radio/PIT tags, and so forth) that interacts with the environment and gather data regarding water properties, aquatic life, and underwater objects.[2]

Fig. 2 Autonomous underwater vehicle (AUV)

Fig. 3 Acoustic Tag

Fig. 4 Passive Integrated Transponder (PIT) Tag

Fig. 5 Data storage tags

An autonomous underwater vehicle (AUV) as shown in Fig. 2 is a smart unmanned underwater vehicle that works with no human intervention. It can navigate, control, and communicate using underwater sensors interacting according to the interest of specific applications. There is a surface station (sink) floating on the ocean surface to which the sensed data from the AUV is transmitted using long-distance radio communication. The transmitted data is sent to an onshore station to perform the required analysis using the data.[1]

Acoustic tags as shown in Fig. 3 are small sound-emitting devices that allow the detection and remote tracking of organisms in aquatic ecosystems. Acoustic tags are commonly used to monitor the behavior of fish. Due to the high salinity of seawater, radio waves do not transmit well. So, radio tags are used above the water and acoustic-radio tags are used to track subjects moving between both salt and freshwater.[1]

Passive Integrated Transponder (PIT) tags, as shown in Fig. 4, are transponders that consist of a tag, antenna, and transceiver implanted onto a fish. PIT tags have a unique alphanumeric code or ID for identifying the movements of the fish.

Data storage tags, as shown in Fig. 5, use internal memory to gather time, temperature, salinity, and depth data.[1] These tags are placed either internally or externally on the fish. This data is later used for analysis by the researchers.

1.2 Network layer

The data collected by all the above-mentioned devices (perception layer) is transmitted to terrestrial smart objects, servers, and network devices and then processed. This layer is responsible for bi-directional data packet handling between each endpoint that is handled through data routing and Internet protocol.[2] The data packets transverse over servers, the Internet, wireless and wired links, and cloud platforms. The data from the perception layer is transmitted to the surface station (sink). Various access networking technologies such as satellite communications, General Packet Radio Service (GPRS) and so forth, are used to send the transmitted data to the onshore command center. Such heterogeneous networks are essential to maintain connectivity and service.[1]

1.3 Application layer

This layer is where the users can interact with applications specific to services through a Graphical user interface (GUI). The sensor information such as the ID, location, type of sensor that is available, data gathering, processing information, and delivering commands,[2] is analyzed in the application layer. The applications can also be built using Representational State Transfer (REST) architecture where the applications can be decoupled, shared, and reused. The devices can be controlled from the shore using the Internet. For applications that require real-time state updates (like sensor data sharing), HTTP streaming is used for data transmission.[1] As shown in Fig. 1, servers are hosted to run operations based on the application. The data from an acoustic tag such as the location and travel time of an object is sent to the acoustic server. The database stores the required information after processing the data. A Radio/PIT tag transmits the data to the radio and RFID database servers and store the relevant information. Monitoring stations receive the graphs and reports to monitor for any changes required. Each server is deployed for specific applications for different users as per their interests and requirements. Each operates consistently in the application layer through various network protocols.

CHARACTERISTICS and BENEFITS of IoUT

Although IoT and IoUT share similar architecture and functions, due to significant differences in environmental conditions there are some variations in communication and characteristics that make IoUT stand out among other marine technologies.

1. **Communication or Transmission Media** - IoT uses radio waves or electromagnetic waves to communicate between IoT devices/terrestrial equipment for data transmission. 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 the water's surface and for smaller distance transmissions. Most of the communication in IoUT is done 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 generated directly from biodegradable substrates during the metabolic activities of bacteria in water. Solar energy can be used for on-the-surface water devices, and piezoelectric energy is still being exploited for effective communication of underwater devices.
3. **Tracking technologies** – In IoT, Radio Frequency Identification (RFID) is predominantly used for tracking devices. On contrary, IoUT uses Acoustic tags, Radio tags, and Passive Integrated Transponder (PIT) tags for tracking underwater things. Usually, these tags are implanted to study the behavior of the fish, these tags impose minimum to no harm on the implanted sea creatures.
4. **Localization techniques** - Global Positioning System (GPS) is used to locate the smart devices in IoT. This technique cannot be implemented 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 locate the underwater devices. Many techniques are still being researched for efficient and accurate localization of underwater things.

IoUT APPLICATIONS

IoUT provides Internet connectivity for remote access of data that is related to the underwater habitat anytime, anywhere. This access has led to vast constructive and prospective applications. It has made its place in various sectors such as intelligent boats and ships, smart shore and ocean positioning, environmental monitoring, underwater exploration, disaster prevention, military, aquatic education, oil and gas pipeline monitoring[2] and expected to enable numerous applications in smart cities. Let us look at a few important applications that are in practice.

1.4 Underwater exploration

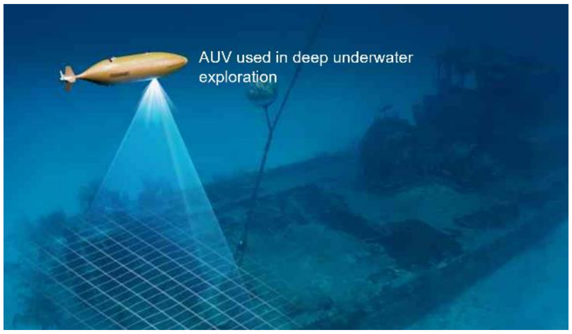

Fig. 6 Underwater exploration using AUV

The ocean dwells with beautiful creatures, amazing sights, and findings of the planet and technology have led us to experience such bliss effortlessly. IoUT is used to study underwater species, discover lost-treasures, and underwater natural-resource discovery such as coral reefs, metals, and minerals.[2] Autonomous underwater vehicles (AUVs) are used in underwater exploration that can operate without real-time control by humans. They carry sensors, cameras, sonar, magnetometers, fluorometers, dissolved oxygen sensors, conductivity, temperature, pH sensors, and so on. AUV can only acquire a GPS signal while at the surface as radio waves cannot travel well through water. Whether the AUV is collecting data on the surface or deep in the ocean, the data is either stored within AUV or transmitted to a communication satellite. After the data is collected, the scientists can conduct experiments that are based on the data that is retrieved from the AUV.

1.5 Aquatic animal tracking

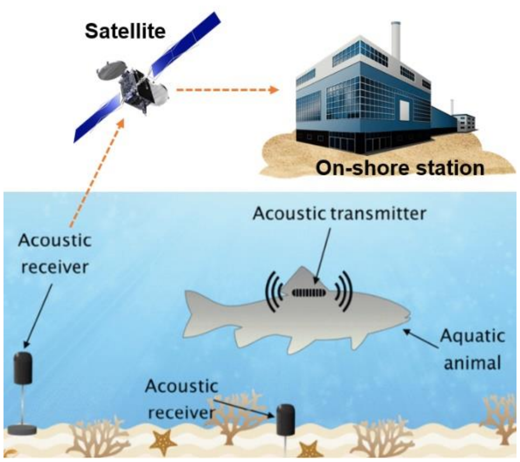

Fig. 7 Sea Animal Tracking using Tags

As many aquatic lives are threatened with extinction and few may have listed endangered, technology or IoUT helps in tracking such animals using underwater devices like acoustic tags. These tags are implanted into the sea animals which transmit acoustic waves in water, water buoys receive these waves, and the data is transmitted to the shore stations through satellite communication and further analyzed. IoUT objects such as mobile transceivers are placed on the animals, collecting data that includes the location of the animal, body temperature, pulse rate, and pressure. This data is analyzed to make the right decisions and care for or treat the sea animals accordingly.

1.6 Environmental monitoring

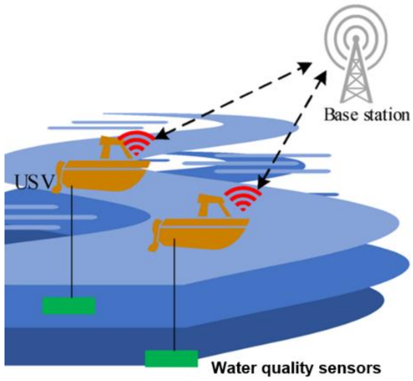

Fig. 8 Water quality monitoring

IoUT leads a way for a cleaner blue ecosystem as human activities of polluting and increasing carbon footprint have triggered harmful effects of climate change. Sensors can be used for environmental monitoring such as oil and gas, temperature, pressure, thermal pollution, biological and chemical pollution, and water quality.[2] For instance, in water quality monitoring, to detect contamination, the sensors are placed in water resources and the data such as salinity, temperature, conductivity, pH, and pressure of the water is captured. After the data is captured, it is transmitted to the host, and analyzed to measure the degree of contamination to maintain the water quality.

1.7 Aquarium

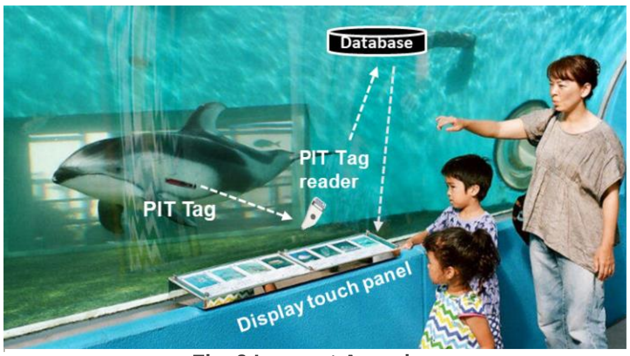

Fig. 9 Learn at Aquarium

Aquariums is a place where people especially children can learn the behavior and habits of many sea creatures. Learning is made easy in real-time with the addition of technology, Passive Integrated Transponder (PIT) tags are implanted onto the fish and tag readers are deployed around. When a fish swims near the reader, a specific ID is shared with the reader. This ID is used to fetch the species name, and characteristics of the fish from the RFID database. This helps to educate the visitor using a touch screen of a computer. The medical history and other required information are used by the animal keepers to monitor the fish.

IoUT using MACHINE LEARNING and CLOUD COMPUTING

Today a huge number of devices are connected to the Internet and large amounts of data are contributed by IoT and IoUT ecosystems forming a pool of data called big data. To extract knowledge from these raw data, Machine Learning (ML) was introduced to transform our lives and help us understand the universe deeper. ML has also marked its path in various underwater applications as discussed in the applications of IoT section.

We understand that for data acquisition, marine sensors are the initial component that activates other data acquisition tools like cameras, hydrophones, data storage microchips, and actuators.[3] Now, this data is transmitted over communication channels, this process is called data aggregation. The raw data that is collected from different components results in a combined dataset and is stored in a database; this is called data fusion. The collected marine data, time-series marine data like temperature, depth, wind, images, live videos, and ready-to-use video data[3] is processed and accessed using applications. Many high-quality software applications and services have been developed for processing or performing analytics on huge data.

Machine Learning is considered a powerful tool consisting of software algorithms to perform predictive, and prescriptive operations by training with patterns on the received data. When we focus on the harsh underwater environment, with high attenuation, absorption, and scattering; that can affect the acquisition of clean data. It is interesting how state-of-the-art algorithms can empower intelligent machines to improve their performance [3] and deliver meaningful output or predictions. Algorithms like Convolutional Neural Networks (CNN), Deep Belief Networks (DBN), and Recursive Neural Tensor Networks (RNTN) are used for fine-tuning the data in IoUT to procure clean data. The challenges in IoUT such as quality of service (QoS), network security, data transmission, event detection, and object targeting,[2] can be mitigated with the integration of machine learning algorithms.

We understood how data is converted to information and transmitted from the water bodies to the terrestrial devices for analysis. As we speak, there is a humongous amount of data is generated and accessed over the Internet. The need to store, manage, protect, and process huge data is made possible by enabling cloud computing. Cloud computing provides scalability, on-demand access to the network, and flexibility, helping the business to thrive towards transforming and growing at a faster rate.

The valuable raw data are transmitted from the oceans to the edge servers that are on the surface for analysis and the rest is sent to Internet cloud servers or seashore control centers over radio communications.[4] The complexity in extracting information from the raw data of the marine ecosystem is tedious as compared with the terrestrial environment, using cloud computing researchers can perform complex computations along with AI/ ML algorithms. As an extension of cloud computing, fog computing is more time-sensitive, which is a highly virtualized platform that provides computing, storage, and networking services between end devices and traditional cloud servers.[4] Data that is time-sensitive cannot be transmitted to the cloud immediately, edge servers that are installed on the shores or even placed underwater, and quick decisions can be taken by performing analysis on the data. Edge computing in underwater is also in practice for effective communication, lower latency, and data transmission.

CHALLENGES

There have been several studies and experiments conducted in IoUT. A few challenges are:

1. Due to high signal attenuation in seawater, it is primarily restricted to acoustic communication for long distances (in kilometers), but they are affected by the turbulence of tides. Optical communication is used for short-range communications but is affected by scattering.
2. Usually, batteries in underwater devices are difficult to recharge and are prone to fail due to corrosion. Researchers are coming up with effective energy harvesting techniques.
3. There are many legacy underwater devices that are not smart enough to talk to each other, new standardizations are implemented to make systems communicate with each other for interoperability.
4. GPS signals (radio waves) cannot propagate through salt water, navigation, or tracking of underwater objects becomes difficult.

Researchers and scientists are working on alternate solutions for the above-mentioned challenges.

CONCLUSION

In this article, we studied a technology that is used to explore the underwater – Internet of Underwater Things (IoUT). As organizations are digitally transforming and data has become more essential than ever, digital solutions like IoT for terrestrial and aerial ecosystems and IoUT for the marine ecosystem. Big Data with intelligent Machine Learning algorithms along with Cloud-based infrastructure are incorporated for innovative and efficient transmission and finally, take the right decisions to thrive in business. With the introduction of IoUT, a cluster of smart underwater devices are connected over the Internet to gather data. This gathered data is transmitted to the stations deployed onshore with many servers or to a cloud-based solution through satellite communication. Complex operations are performed on the data to gain patterns and trends. With the help of algorithms to store or archive the data for further analytics enabling to the discovery of constructive applications and new technologies. This article is a brief on how IoUT is making a positive impact in this data era. As this is an ongoing concept, and many challenges are stacked up for the researchers to look for new ways to make this work successfully.

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