Deep Sea Internet or Internet of Underwater Things (IoUT) to connect the underwater world of sensors, Unmanned Underwater Vehicles, ships and submarines

The Internet-of-Things is an emerging revolution in the ICT sector under which there is shift from an “Internet used for interconnecting end-user devices” to an “Internet used for interconnecting physical objects that communicate with each other and/or with humans in order to offer a given service”. The increasing miniaturization of electronics has enabled tiny sensors and processors to be integrated into everyday objects, making them ‘‘smart’’ , such as smart watches, fitness monitoring products, food items, home appliances, plant control systems, equipment monitoring and maintenance sensors and industrial robots. By 2025, it is predicted that there can be as many as 100 billion connected IoT devices or network of everyday objects as well as sensors that will be infused with intelligence and computing capability.

Researchers are now developing the Internet of Underwater Things (IoUT), a world-wide network of smart interconnected underwater objects that would transmit data from existing and planned roaming, autonomous vehicles and underwater sensor networks to networks above surface in real time. “We will see acoustic communications transmitting information to AUVs over long distances, while optical modems enable data transfer between sensors and vehicles over shorter distances,” says Sonardyne’s Tena. “The entire network will enable the

provision of near-real-time updates to surface-based operators.”

South Korea’s SK Telecom and Hoseo University recently announced their researchers successfully demonstrated the world’s first underwater data transmission over a sound wave, which they say is a major milestone toward a new era of commercial underwater communication.

The Objective of European SUNRISE initiative is to provide the missing tools for an unprecedented monitoring and exploration of marine environments, by extending the concept of Internet of Things to marine environments. IoUT promise oil and gas exploration, monitoring of waterways and marine environments, producing renewable energy through offshore wind turbines and sustainable use ocean’s resources.

Analogous to IoT, Military internet of things (MIOT) comprising multitude of platforms, ranging from ships to aircraft to ground vehicles to weapon systems, is expected to be developed. Military is also interested in building Military Internet of Underwater Things (IoUT) to communicate with their sensors, Unmanned Underwater Vehicles, ships and submarines. A highly valued, long sought but elusive military capability has been non-cabled, distributed, networked undersea surveillance and weapons systems. The Defense Advanced Research Projects Agency has issued a solicitation identifying technology breakthroughs that will enable fully integrated and networked undersea systems.

Underwater Challenges

Radio waves do not propagate well underwater due to the high attenuation. In fact, radio waves propagate at long distances through conductive salty water only at extra low frequencies (30– 300Hz), which require large antennae and high

transmission power. The acoustic waves are low frequency waves which offer small bandwidth but have long wavelengths. Thus, acoustic waves can travel long distances and are used for relaying information over kilometers

The acoustic communications also suffer from the large propagation delays of acoustic waves and high bit error rates of the underwater acoustic channel, multi-path propagation and time variations of the channel. In addition, acoustic waves are affected by turbulence caused by tidal waves and suspended sediments, acoustic noise and pressure gradients.

Optical communication between devices, at a very short range, could be possible by use of highly efficient LED pulses or even lasers, but ocean water has widely varying optical properties depending on location, time of day, organic and inorganic content, or temporal variations such as turbulence. Optical waves do not suffer from such high attenuation but are affected by scattering. Furthermore, transmitting optical signals requires high precision in pointing the narrow laser beams.

The available bandwidth is severely limited. Underwater sensors are characterized by high cost because of a small relative number of suppliers (i.e., not much economy of scale); Battery power is limited and usually batteries cannot be recharged; underwater sensors are prone to failures because of fouling and corrosion.

Although there exist many recently developed network protocols for wireless sensor networks, the unique characteristics of the underwater acoustic communication channel, such as limited capacity and high and variable propagation delays, require very efficient and reliable new data communication protocols.

“A big challenge is that we have legacy systems that aren’t able to talk to each other. So major issue we have to address in the next few years is standardization to enable these

assets to communicate with each other, to become fully interoperable, says Chiara Petrioli, a Professor of Computer Science at the University of Rome “La Sapienza,” is Project Coordinator of the Sunrise project.

“As these systems become able to communicate more autonomously, we’ll need strict regulations and legislation to ensure overall navigational safety and resolve potential problems that could occur in a densely populated marine environment,” she further says. Currently, there is a lack of an international legal framework encompassing the operation of unmanned vehicle systems.

SOUTH KOREA’s S K Telecom demonstrates world’s first subsea communication over sound waves

South Korea’s SK Telecom and Hoseo University recently announced that their researchers successfully demonstrated the world’s first underwater data transmission over a sound wave, which they say is a major milestone toward a new era of commercial underwater communication.

Using OFDM (Orthogonal Frequency Division Multiplexing), a new modulation technique for wireless communication, researchers put LTE frequencies on programmed sound waves to transmit text and photo data at 25 meters under the sea off a port in Incheon. The data were exchanged between two ships about 800 meters apart. Three sample color photos and a set of marine information like water temperature and salinity were also sent out successfully but their transmission speed was limited to 40Kbps similar to a current wired telephone modem, SK Telecom said.

The company and the university will continue their collaboration in developing and establishing underwater

sensors and base stations. Those sensors will gather information to be transmitted to marine communication buoys through base stations in the water and then to land communication systems via a satellite LTE network. All data signals will be transmitted over a sound wave in the water and a radio wave in the air.

Korea is the first country that has demonstrated this type of communication based on underwater base stations, said Hoseo University professor Ko Hak-lim who leads the joint research team.

In a consortium with academic and research institutions, SK Telecom is to establish the nation’s first underwater communication network. The underwater control network, which will be developed by the consortium, will collect various underwater information using sensors and send it to land through base stations in the water. The collected information can be used for maritime weather observation and ecological environment analysis, keeping track the shipping industry including route information of vessels, and for national defense of territorial waters.

Also, these underwater networks will allow not only more accurate prediction of maritime climatological observation and natural disasters by detecting sea temperature, currents, and seismic waves, but also quick response to ship accidents.

The national project is broadly divided into three areas – the development of underwater sensor nodes that can work for long hours underwater, and communication technology between stations, the design of an idealized underwater network for accurate wave propagation in the water, and the construction of a central integrative network in a bid to unite the communication networks of the land and sea.

European Initiative: SUNRISE

In Europe, a European R&D project named SUNRISE is developing Federated, Internet compatible underwater communication networks, software-defined open-architecture modem and protocol stack. The team is developing mini submarines, which have acoustic modem, environmental sensors, a computer system that allows it to navigate underwater, batteries that keep it going for eight hours and modules for radio and satellite communication. The multinational project involves partners from Italy, Germany, Portugal, Netherlands, Turkey and the United States.

The submarines transmit data to a control centre on the ground. Working prototypes have recently been tested in Portugal with scientist proving that the robots can communicate in the aquatic environment and respond to instructions sent to them from the ground as designed.

The University of Twente team has developed fully reconfigurable underwater sensor nodes for wireless monitoring and a Software Defined Acoustic Modem allowing developers and researchers to dynamically change the different settings of the modem. University of Rome ‘La Sapienza’ and its spinoff WSENSE s.r.l. have focused on SUNRISE Software Defined Communication Stack and on deployment support tools.

They have designed and developed a novel infrastructure to support the communication and cooperation of a heterogeneous network of underwater assets. The developed system will also be compliant to emerging NATO standards such as JANUS, a physical layer protocol in the process of becoming the digital underwater communications standard enabling interoperability among multi-vendor solutions

The technological challenge that SUNRISE has embraced concerns the fundamental understanding of how to improve reliability and performance of communications in the harsh submarine

environment and how to exploit cutting-edge communication technologies for interconnecting heterogeneous teams of AUVs and sensing devices into a network, allowing them to cooperate to perform complex tasks.

The project has also developed a federation of testbeds that can be accessed through a web tool, called the SUNRISE gate, developed by NEXSE, an italian systems integrator. It allows users to access the heterogeneous resources offered by the testbeds in a unified way. Five testbeds will be deployed and federated through the SUNRISE GATE to cover the most relevant marine scenarios and environments (lakes, canals, Mediterranean Sea, Atlantic Ocean, Black Sea).

SUNRISE: using underwater robots for a better understanding of the underwater world

European research project SUNRISE is developing underwater robots that will be able to work autonomously, having received instructions. They talk to each other using sound signals and send data back to computers through the Internet, regardless of swiftly changing circumstances and challenges to data transmission.

Computer Science Professor Chiara Petrioli is the project coordinator: “What you see here are underwater robots that are able to communicate and cooperate with each other, creating the so-called ‘Internet of underwater things’,” she explains. “It’s a novel concept that allows different devices, such as sensors and robots, to exchange information. This opens up new ways to monitor our oceans, lakes and rivers.”

Designing robots which can communicate in rapidly changing environments

Those changing environments are one of the key challenges the

project faces. The robots communicate to each other using acoustic signaling, as do marine mammals. But whereas a dolphin will adapt the way it signals according to what is around it, robots need to be programmed to do so, presenting researchers with the task of developing machines capable of responding to a rapidly shifting set of variables. ‘Salinity, temperature, interference in the form of waves or passing shipping, all these will change the range of effective communication,’ explains Dr. Petrioli. This unpredictable environment is one of the key ways the internet of things underwater differs from our land-based use of WiFi and the internet.

The need to respond reliably to the shifting environment means multiple robots are needed so if one can’t communicate temporarily, another will take over the signaling. Schools of robots will carry a greater number of sensors and cover a larger area, cooperating and communicating together. Those operating them will send messages through modems transmitting acoustic waves. The waves are modulated to send information – but bandwidth is limited meaning transmission rates are slow.

Their waterproof casing allows the submarines to dive to depths of up to a hundred metres. Depending on the mission, they can be configured differently to collect, record and transmit various types of data, as Ricardo Martins outlines: “Along with the acoustic modem that allows the submarine to communicate underwater, it has environmental sensors, a computer system that allows it to navigate underwater, batteries that keep it going for eight hours and modules for radio and satellite communication.”

Crucial for search and rescue operations, an on-board sonar device finds sunken objects by emitting pulses of sound and listening for echoes. It has helped to find a lost container in the port of Porto.

Lino Antunes, head of the emergency department at Porto’s port

operation and security base, speaks of the use of such devices: “They are useful for three main applications: first, for port security. Second, for environmental monitoring, which is very important to us. And third, for inspections of the ships that dock at the port,” he says.

The new technology should give us a better understanding of the silent world, as SUNRISE coordinator Chiara Petrioli explains: “From the discovery of underwater volcanoes and archeological sites to the protection of our coasts, infrastructure and ports – this technology will give us a much deeper understanding of our world. And that’s an essential element for the future of humanity.”

European Initiative: SUNRISE EXPOSURES

Low-cost underwater unmanned autonomous vehicles (UUVs) are to scan the ocean and gather environmental information for management of one of Europe’s busiest ports using ground-breaking technology from European researchers.

The Internet-connected UUVs will send observations to a geo-spatial environmental data fusion platform that prepares data for marine risk analysis allowing for rapid response impact analysis. The trial is conducted as part of research by the European Commission funded SUNRISE EXPOSURES project.

The project’s technical lead Professor Michael Boniface, Technical Director at the University of Southampton IT Innovation Centre, UK, said: “Marine industry stakeholders will collaborate to create a new data value chain that builds on low-cost drones and advanced data analytics to seamlessly connect surveyors, marine analysts and authorities. These drones are small enough to be launched by one person and cost less than 100,000 Euros allowing them to be preconfigured for marine applications, such as scour and sediment transport

analysis.

We call it the internet of underwater things," says Chiara Petrioli, professor of computer science at University of Rome La Sapienza and the Sunrise project coordinator. "What we wanted to do is not only communicate underwater, but also take the first steps to develop low-cost actuating and sensing technologies that can be interconnected with each other and can complete smart complex tasks."

"By combining the drones with Internet connectivity, geospatial data fusion, and linked data access, marine analysts will have the information they need for assessing threats such as marine accidents, extreme weather events and periodic degradation."

Underwater Robots New Language, JANUS acoustic signal will connect aquatic robots and sensors into an "Internet of Underwater Things"

JANUS is the first standard for underwater communication that creates a common protocol for an acoustic signal with which underwater systems can connect. The main role of JANUS is to bring today's acoustic systems into sync with one another. It does this in part by defining a common frequency—11.5 kilohertz—over which all systems can announce their presence. Once two systems make contact through JANUS, they may decide to switch to a different frequency or protocol that could deliver higher data rates or travel further

The JANUS standard was developed by Alves' team at NATO's Centre for Maritime Research and Experimentation in La Spezia, Italy and sponsored by NATO's Allied Command Transformation. It is the first underwater communications standard to be

defined by an international body. To create JANUS, Alves' team relied on the Littoral Ocean Observatory Network, a collection of acoustic tripods that NATO researchers have placed on the seafloor in the harbour of La Spezia, Italy. In another series of tests, researchers aboard the research vessel Alliance, a NATO ship operated by the Italian Navy, measured the performance of JANUS signals along the surface of the ocean.

Once deployed, aquatic systems could use JANUS to send data directly to each other, or to "gateway buoys" bobbing on the water's surface. The buoys could then use radio waves to relay that data to nearby control centers.

Based on their work, Alves says submarines could also use JANUS to issue calls for help to ships and rescue crews. "Using an open scheme like JANUS to issue distress calls would increase incredibly the chances of those being picked up," he says.

US: Buffalo Lab developed TCP/IP protocol for acoustic communications

In the US, a Buffalo R&D Lab has developed a variation of TCP/IP protocol suitable to acoustic communications. The proposal is based on an adaptation layer located between the data link layer and the network layer, such that the original TCP/IP network and transport layers are preserved unaltered to the maximum extent. The adaptation layer performs header compression and data fragmentation to guarantee energy efficiency.

"A submerged wireless network will give us an unprecedented ability to collect and analyze data from our oceans in real time," said Tommaso Melodia, UB associate professor of electrical engineering and the project's lead researcher. "Making this information available to anyone with a smartphone

or computer, especially when a tsunami or other type of disaster occurs, could help save lives.” Melodia, tested the system recently in Lake Erie, a few miles south of downtown Buffalo using two, 40-pound sensors into the water.

An underwater acoustic networking testbed, is being developed at the University at Buffalo under sponsorship of the US National Science Foundation. It is based on the Teledyne Benthos Telesonar SM-75 modem, which, in its many configurations, is also a key component in multiple U.S. Navy programs and of many wireless tsunami warning systems worldwide.

DARPA requires fully integrated and networked undersea systems.

The rapid world-wide growth of communications systems and networks infrastructure and capacity has been driven by both commercial and military needs. This has facilitated military capabilities such as remotely operated, unmanned air and surface platforms capable of performing missions only possible by manned platforms in the past. For many, if not most, of these missions, real time supervision by a human operator is key to achieving mission success, e.g. target confirmation and permission for weapons release.

As an example, today’s Predator Unmanned Aerial Vehicle operations are demonstrating the effectiveness of this rapidly developing capability. Similar gains of effectiveness and utility are sought for the undersea domain.

A highly valued, long sought but elusive military capability has been non-cabled, distributed, networked undersea surveillance and weapons systems. In the last decade, the deployment of air and space RF and electro-optical based communication systems has made pervasive, worldwide, wide-

band, networked communications a reality for both commercial and military systems. To fully integrate military undersea platforms and systems and enhance their tactical effectiveness, DARPA seeks solutions extending that connectivity infrastructure to the undersea environment. Toward that goal, DARPA is interested in identifying technology breakthroughs that will enable fully integrated and networked undersea systems.

Specifically, the agency wants information on technologies that could enable:

• Weapon targeting and release authorization for forward-deployed undersea platforms and weapons systems.

• Broadcast of real time, high-bandwidth situational awareness data from air and space networks to undersea platforms.

• Exfiltration of undersea sensor and platform SA and sensor data to tactical air and space networks.

• An undersea networking infrastructure to support wide area integrated operations with mobile and fixed platforms, sensors and systems—such as submarine operating in concert with autonomous underwater vehicles—while networked with space and air military tactical and strategic networks.

• Autonomous network-enabled sensor processing, such as distributed passive and active sonars

DARPA said it will welcome responses from industry, academia, individuals or other government-sponsored labs on RFI topics of interest include, but are not limited to, the following technology areas:

• Prediction of and adaptation to the undersea environment’s impact on communication link performance

• Novel undersea signaling techniques to include acoustics, optical, elector-magnetic and cabled
communication modalities
• Physical and network layer adaptations for the undersea environment
• Information assurance issues unique to the undersea environment
• Air-water interface and gateway systems to tactical or national command authority

Conclusion

The Internet of Underwater Things promises to connect the 72% of our planet still disconnected to our ground living connected world and could lead to improvements in tsunami detection by linking together buoy networks that detect tsunamis, offshore oil and natural gas exploration, surveillance, oceanographic data and pollution monitoring and even monitoring fish and marine mammals. However IoUT is expected to raise the same concerns for hacking, identity theft, disruption, and other malicious activities affecting the people, infrastructures and economy as are being raised for the IoT.

References and Resources also include:

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