# Expanding the Underwater Communication Capabilities of Seafloor Ecosystem Monitoring Stand-Alone Platforms using Pop-Up Buoys

Matias Carandell[1], Steve Hernández[2], Daniel Mihai Toma[1], Enoc Martínez[1], Marc Nogueras[1], Jacopo Aguzzi[3,4] and Joaquín del Río[1]

[1] SARTI-MAR Research Group, Universitat Politècnica de Catalunya, 08800 Vilanova i la Geltrú, Spain

[2]Department of Computer Architecture and Technology, Universitat de Girona, 17003 Girona, Spain

[3] Instituto de Ciencias del Mar , Consejo Superior de Investigaciones Científicas, 08003 Barcelona, Spain

Stazione Zoologica Anton Dohrn, Villa Comunale, 80121 Napoli, Italia



*Keywords— Stand-Alone Oceanographic Platform, Seafloor Ecosystem Monitoring and Pop-Up Buoys.*

***Abstract— …***

***to be written***

## I. Introduction

Marine biodiversity has been severely affected by the impact of human activity during the last century. Industrial and transport pollution has vastly contributed to the rise of the ocean's temperature, forcing marine species to emigrate to other habitats in search of more favorable environmental conditions [1]. In addition, non-sustainable abusive fishing practises have reduced the fish stocks of some species such as tuna, depleting its population to historical minimums and risking its survival [2]. Global awareness has forced policy makers to address the protection of marine areas in order to mitigate these effects. To evaluate the effectiveness of these policies, there is a dire need to improve our understanding of the marine ecosystem by quantifying its processes, which, currently, reliy on adequate spatial-temporal multiparametric monitoring procedures. Technology plays a central role in developing these monitoring systems, as advances in enabling technologies such as remote sensing, modeling or autonomous systems are able to enhance our capacity of tracking and predicting the evolution of marine ecosystems.

Underwater cabled observatories with video capabilities as those presented in [3] are key elements in the acquisition of multidisciplinary oceanographic and biogeochemical data to monitor marine ecosystems and their species. These observatories provide knowledge on different ecological indicators such as species' richness and biodiversity. Although the advantages of these observatories are many, their high deployment and maintenance costs reported in [4] have increased the use of stand-alone platforms for ecosystem monitoring in temporary deployments. As an example, the EMSO Generic Instrumental Module (EGIM) [5] has been developed to measure oceanographic parameters of interest for the science community. Articles [6], [7] report other seafloor ecosystem monitoring stand-alone platforms including video acquisition. However, in all of these examples, the access to the gathered data is only possible once the platform has been recovered. Therefore, new real-time and in situ communication strategies are still necessary to properly monitor the status of the data acquisition and the data itself. A common solution reported in [8] is to include a moored buoy connected to the seafloor node which collects and transmits the acquired information. However, this is not the ultimate solution as it limits the deployment depth due to the fact that it relies on cabled comunications and these have a high associated cost and increased potential for failures.

To overcome these constraints, the Platform for Long-lasting Observation of Marine Ecosystems (PLOME) project funded by the Spanish Ministry of Science and Innovation aims to upgrade the underwater communication capabilities of stand-alone platforms. The main idea is to build a cooperative network that integrates several seafloor stand-alone remote stations with Autonomous Underwater Vehicles (AUVs) and Unmanned Surface Vehicles (USVs) to collect the acquired data on the seafloor and transmit it via a satellite link. With this, near-real-time data could be collected without the need for recovering the station.

One of the innovative ideas studied in PLOME is the integration of pop-up buoys to expand the underwater communication capabilities of stand-alone seafloor platforms. As reported in [9], pop-up buoys are commonly

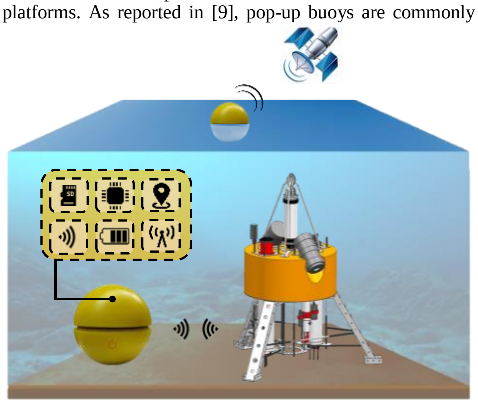

Fig. 1. Seafloor ecosystem monitoring stand-alone platforms from PLOME together with the under-design pop-up buoy and the schematic representation of its main functionalities.

This work was developed within the framework of the Research Unit Tecnoterra (ICM-CSIC/UPC) and the following project activities: PLOME (PLEC2021-007525; Ministerio de Ciencia e Innovación) and BITER (PID2020-114732RB-C32; Ministerio de Ciencia e Innovación). The first author was supported by the European Union – NextGenerationEU and the Ministerio de Universidades – Plan de Recuperación, Transformación y Resiliencia under a Margarita Salas post-doctoral research fellowship (ref. 2022UPC-MSC-94068). *Corresp. author: matias.carandell@upc.edu.

used to recover seafloor instrumentation. At the end of the deployment and using an acoustic command, a floating buoy attached to the node with a line is released to recover the instrumentation. In PLOME, the concept of a pop-up buoy is upgraded with sensing, processing, and communication capabilities. The stand-alone monitoring node (right side of Fig. 1~~Fig. 1~~) includes several pop-up buoys (left side of Fig. 1~~Fig. 1~~) that are periodically released untethered (no physical attachment to the seafloor node). During the deployment, the buoy archives scientific and engineering data acquired by the station. Once released, the pop-up buoy becomes an oceanic drifter (e.g. [10]) and transmits the stored data and its position using a satellite link. This strategy enables scientists to access part of the data before the recovery of the station and allows engineers to monitor the proper functioning of the experiment. The idea of this project arose from military applications such as those commercialized by GABLER in [11], where pop-up buoys are used to expand the communication of submarines with the satellite. However, the use of this concept for environmental applications in stand-alone observatories is something that, to the best of the authors' knowledge, has not been previously investigated.

As can be observed in the diagram shown on the top left side of Fig. 1~~Fig. 1~~, the pop-up buoy is equipped with a main microcontroller, a data storage module, a wireless communications module, and a GNSS module, all of which are powered by an independent power system. There are several technological challenges related to the development of pop-up buoys. These include the wireless underwater communication between the buoy and the observatory, the automatic release system to release the buoy, or the robust satellite communication link.

This paper describes the design of the pop-up project including preliminary tests that demonstrate the feasibility of its implementation. Since the project is in the design phase and PLOME is still in the second year of its four year tenure, this article only intends to present the concept and to outline how the posed challenges are being resolved. The article is organized as follows; section II describes the project requirements and specifications, section III details the conducted experimental tests and section IV discusses the results.

## II. System Description

### A. Project requirements

The pop-up buoy system is a technology that allows to expand the communication of stand-alone seafloor observatories through the release of unthetered buoys transmitting the data gathered from the seabed. This system has two main components. First, the pop-up buoys itself, which contains a wireless underwater communication system with the stand-alone observatory, a data storing module, a GPS positioning module, and a satellite communication antenna. The number of pop-up buoys depends on the duration of the experiment and the release interval. The second component is the pop-up server, a seafloor node connected to the observatory that is responsible for transmitting the data to the buoys and their periodic release. The technical specifications of both systems are detailed in sections II.B and II.C respectively.

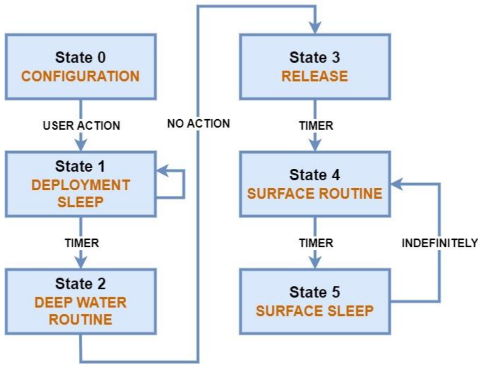


Fig. 2. Pop-up system operative states.

Fig. 2~~Fig. 2~~ shows below the operative states of the system used to detail the selected technologies to implement each process.

- **State 0.** The configuration of the system as well as the initial check before the deployment is required. Each pop-up buoy is programmed with a unique id that is required by the pop-up server to perform the release of each buoy according to a predefined timetable. After the configuration, a user action forces the system to stand by (e.g. push a button).
- **State 1.** After the deployment, the pop-up buoy wakes up periodically (e.g. once per day) and asks the server for release permission (connection described in phase 2). In the case the server does not acknowledge the buoy to be released, it returns to sleep to assure lower consumption power.
- **State 2.** When pop-up buoys receive release permission from the server (date and hour expired for its id), the buoy proceeds to download the data generated from the observatory (e.g. images or files). Commonly, underwater communications are implemented with acoustic links [12]. Doing so however, would require the installation of an external modem on the buoy making it more fragile during the drifting stage. At very short distances, low-power Wi-Fi antennas are capable of generating a connection and transmitting data underwater. At this stage, the pop-up server generates an access point (AP) and creates an FTP connection (server). Through this connection, the observatory (client) uploads the acquired data and the pop-up buoy (client) downloads it before the release, to later transmit it via satellite link. Each buoy downloads the data generated from the release of the previous buoy (all data in the first release).
- **State 3.** After the data download, the pop-up server activates the release of the buoy. An automatic release system is required for each buoy, capable of holding the positive buoyancy of the unit until its take-off. Nd magnets driven by a motor with a worm screw are used to release the buoys (further described in section II.C).
- **State 4.** Once on the sea surface, the pop-up buoys initiate the drifting stage which loops indefinitely between transmissions (state 4) and sleep periods (state

5) until the unit is recovered. During state 4, the pop-up buoys first fixes the GPS position (latitude, longitude, and satellite time stamp) and log it into a track file which is stored in the internal storage module. A timeout is implemented during the GPS fixing procedure to avoid a consumption exceedance. Secondly, both the GPS position (to recover the unit) and part of the data, gathered from the stand-alone observatory are transmitted using Kinéis infraestructure. Kinéis is the new generation of Argos-4 nanosatellites network [13] which allows users to transmit small packages (up to 62 hex characters - 248 bits) with worldwide coverage, at a relatively low-cost and low-power. As the coverage is intermittent, a satellite pass prediction is required to optimize the transmission. The implementation of the transmitted messages (position and underwater data) will be developed in future works.

- **State 5.** Between transmissions and depending on the satellite coverage, the pop-up buoy stays in a sleeping state, to keep the power consumption low and to ensure its autonomy until its recovery.

### *B. Pop-Up buoy specifications*

Fig. 3~~Fig. 3~~ shows a detailed schematic of the pop-up system, where the stand-alone seafloor observatory is represented in red, the pop-up server in blue and several pop-up buoys in yellow.

The ESP32 (*EzSBC* Xtensa-LX6/32-bit/240 MHz) works as the buoy's main microcontroller as it incorporates a low-power Wi-Fi antenna and an internal RTC timer. Through this timer, sleep states are implemented with power consumptions as low as 10 µA. Through a serial port and using AT commands, the ESP32 communicates with the Kinéis module (*CLS* - KIM1), in charge of transmitting data to the satellite. Through a second serial port, the ESP32 communicates with the GPS module (GY-NEO6MV2) to acquire the position and the satellite time stamp. The communication with the SD module is implemented through an SPI bus. The oceanographic seafloor data, as well as the GPS track, are stored in this SD.

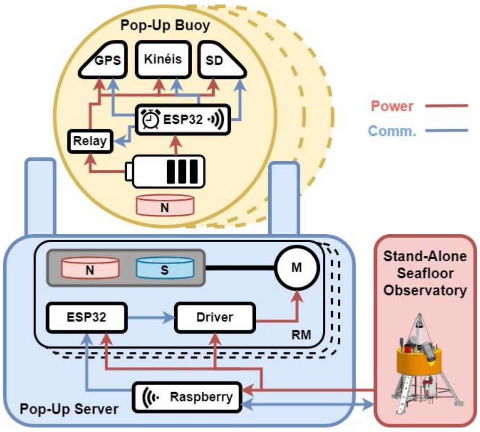


Fig. 3. Pop-up system connected to a stand-alone seafloor observatory (red). Below, the pop-up server (blue) with a Raspberry as a main controller and, above, several pop-up buoys (yellow) with an ESP32 as a main controller.

A power bank feeds the pop-up system. A low-power relay (*Crydom* - CN024D05) is also used to disconnect the power from all the peripherals (except from the ESP32) to keep the consumption low during the sleep states. The relay is controlled with a digital pin of the ESP32.

### *C. Pop-Up server specifications*

The Raspberry Pi 4 (*Raspberry* Cortex-A72/64-bit/1.8 GHz) works as the pop-up server's main microcontroller. It generates an AP through which the buoy connects and asks for release permission. Furthermore, it implements the FTP server from which the buoy (client) downloads the oceanographic seafloor data.

The pop-up server shares the power supply with the stand-alone observatory platform. A cabled communication bus enables the popup server to communicate with the observatory. This one can also access the FTP as a client through this connection to upload the oceanographic data daily.

Finally, a Nd magnet with the Nord facing downwards is added to the bottom of the pop-up buoy. Thanks to a Nd magnet with the South facing upwards and placed at the pop-up server, the buoy is held (during states 1 and 2) despite its positive buoyancy. For each pop-up buoy there is a specific release module (RM in Fig. 3~~Fig. 3~~). These modules are based on an ESP32 that receives the release command from the Raspberry through a serial port. Then, the ESP32 controls a stepper motor (*Stepperonline* NEMA17) and its driver (*Cozyroom* TB-6600) to move a magnet pack backwards and forwards (worm screw). For the release, a Nd magnet with the Nord facing upwards facilitates the take-off of the buoy. The magnet repulsion helps to eliminate any buoyancy resistance produced by biofouling generated around the support and the buoy during the deployment.

## III. Experimental Tests

The pop-up project is still under design, so this article only aims to present the project and to discuss and validate the technologies selected for each of the challenges posed. This section presents four isolated tests that validate the functionality of four key parts; the underwater Wi-Fi communication, the release operation, the GPS tracking and the satellite transmission. Each subsection presents 1) the methodology used in each test as well as 2) its results.

### *A. Underwater Wi-Fi communication*

This first test validates the underwater Wi-Fi communication for the pop-up project data transmission during the deep-water routine (state 2). Specifically, the objective is to determine the maximum distance that the ESP32 low-power antennas allow communicating packets through seawater. The results of this experiment are presented in [14].

#### *1) Methodology*

An ESP32 with a 9V battery pack was placed in a pop-up buoy shell (8 cm $\phi$) and another ESP32 was placed in a waterproof box with a cable gland, allowing its connection to an external PC. The buoy's ESP32 set an AP and a TCP connection (server). The box's ESP32 functioned as a TCP

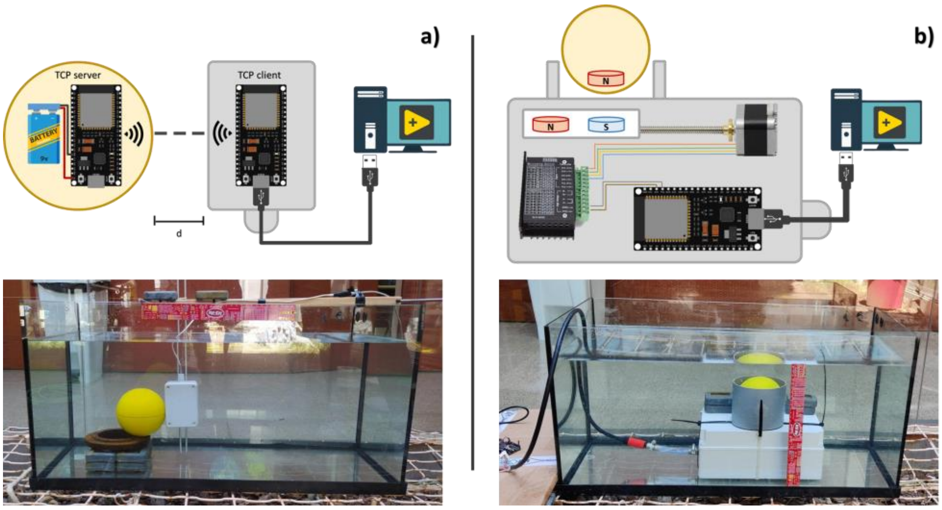


Fig. 5~~4~~. Experimental set-up for tests a) underwater Wi-Fi communication and b) release operation. The top part of both figures shows a schematic of the experimental set-up and the bottom a picture of the test.

client. A LabView application set at the PC monitored the test through a serial connection to the ESP32 TCP client (waterproof box). The top of Fig. 4~~Fig. 3~~.a) shows the experimental set-up while the bottom shows a picture of the test.

While the pop-up buoy was moored at the bottom of the water tank, different distances (d – saltwater thickness) were set by moving the waterproof box. For each distance, the signal's RSSI was measured five times. The test was repeated with the following Wi-Fi signal transmission powers: 20, 17, 15, 11 and 7 dBm. The salinity of the water was measured at 36.5 ppt.

*2) Results*

Fig. 5~~Fig. 4~~ shows the experimental results for the underwater Wi-Fi communication test. Each line represents a different

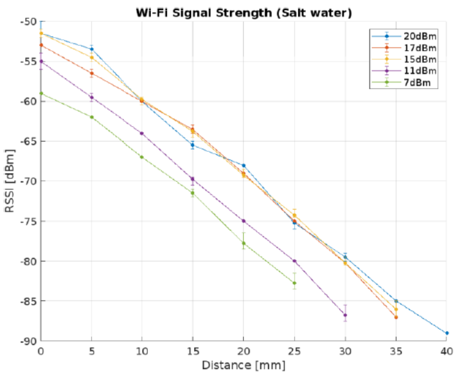


Fig. 4~~5~~. Experimental results for the underwater Wi-Fi communication test. Different lines are used for each signal transmission power. The vertical axis shows the RSSI, in dBm, and the horizontal axis the salt water thickness, in mm.

Wi-Fi signal transmission power, the vertical axis shows the signal's average RSSI between the five measured points and the horizontal axis represents the distance (d).

At a first look of the results, the intensity of the signal decreases linearly with the distance while higher powers improve the RSSI at equal distances. The distance from which communication is lost is 25 mm and 40 mm for powers of 7 dBm and 20 dBm respectively.

Further tests were made with fresh water and with Bluetooth antennas (instead of Wi-FI) and a full report of the results can be found in [14].

### B. *Release operation*

This second test validates the feasibility of using magnets to maintain and release pop-up buoys from stand-alone seafloor platforms. Specifically, the magnets were tested to prove that these could hold the positive buoyancy of the 8 cm diameter spherical shells. Further, the release mechanism, consisting of a worm screw motor with a ND magnet attached, was validated in an water scenario. The results of this experiment were presented in [15].

*1) Methodology*

An ESP32 was placed in a waterproof box with a cable gland, allowing its serial connection to an external PC. Again, a LabView application controls the test. The ESP32 was connected to a driver and this was then connected to the motor to provide the PWM signal and direction. All the motor and driver specifications are presented in section II.C. The top of Fig. 4~~Fig. 3~~.b) shows the experimental set-up while the bottom shows a picture of the test.

The waterproof box was filed with oil to avoid water leakages and was secured at the bottom of the water tank. The pop-up buoy with a magnet inside was placed on the top of the waterproof box, moored at the water tank.

*2) Results*

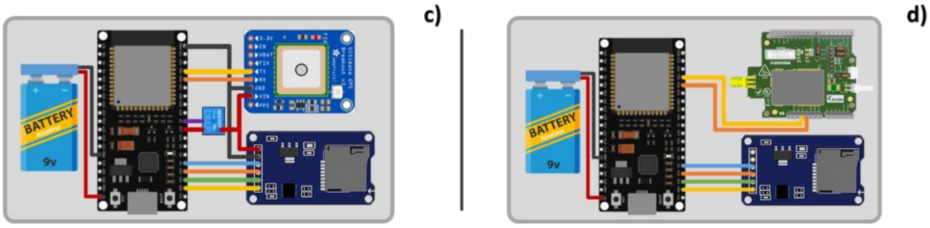


Fig. 6. Experimental set-up for tests c) GPS tracking and d) satellite transmission.

The LabView application sent a command to initiate the release of the pop-up buoy. The driver activated the motor and it moved the magnet pack backwards. Then, the magnet with the Nord facing upwards ejected the buoy successfully.

### *C. GPS tracking*

This third experiment tests the acquisition and logging of the GPS position as well as the low-power, deep-sleep cycles of pop-up buoys through states 4 and 5 shown in Fig. 2Fig. 2.

#### *1) Methodology*

An ESP32 was placed in a waterproof box and connected to the GPS and SD modules using the serial and the SPI ports respectively. The ESP32 was set to acquire the position periodically with a GPS-fixing timeout of 60 seconds. Both the position and the satellite time stamp were then saved to the SD card and the whole system was later sent to sleep one minute using a power relay (switching off the GPS and SD modules). Fig. 6Fig. 6.c) shows the experimental set-up, including a 9V battery pack to feed all the components.

#### *2) Results*

Fig. 7Fig. 7 shows the results of placing the system on a car and conducting a trip between Can Carbonell (Spain) and Girona (Spain) the morning of the 6$^{th}$ of April, 2023. Note that two different roads were used in order to have more spatial data dispersion.

As expected, the system acquired 25 datapoints in the 31 minutes of outbound trip, and 20 datapoints in a return trip of 24 minutes. Note that the system obtained almost one point per minute so the average GPS acquisition time was around 13 second even though the module was switched off every cycle. As we previously reported in [16], switching off the GPS may reduce the autonomy of the whole system (increasing the GPS fix time), so further investigation into this topic will be required.

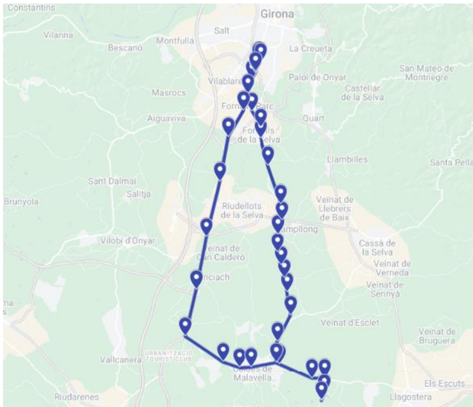


Fig. 7. Experimental results for the GPS tracking test. The pinpoints indicate the fixed locations on the trip between Can Carbonell (Spain) and Girona (Spain) the morning of the 6th of April, 2023 .

### *D. Satellite transmission*

This fourth test evaluates the feasibility of using the Argos-4 satellite network to transmit short messages from anywhere in the world using the low-power Kinéis modules. The objective is similar to what was previously achieved in [17], where SigFox (low-power, wide-area network) was used to monitor coastal areas, but, this time, with worldwide coverage. Specifically, the percentage of transmissions received with Kinéis as well as the percentage of erroneous messages are evaluated. A complete description and analysis of this test was presented in [18].

#### *1) Methodology*

An ESP32 was placed in a waterproof box and connected to the KIM1 and SD modules using the serial and the SPI ports respectively. The ESP32 was set to transmit a message of six hexadecimal characters every 30 seconds through Kinéis network with the transmission power set at 1 Watt (maximum transmission power). The first four hexadecimal characters were random, while the two final ones were used for the CRC8, calculated on the ESP32 to later validate the data. Then, the ESP32 also saved the message together with the time stamp obtained from the internal RTC on the SD card.

#### *2) Results*

TABLE ITABLE I reports the results of the satellite transmission test. The system working for 16 hours and 53 minutes and transmitted a total number of messages of 1691 (stored in the SD card). This results in an average time between transmissions of 35 seconds.

By using the satellite area coverage information provided on the Kinéis webpage and crossing the data found in the SD card with those stored on the database, the total number of messages sent with satellite coverage was determined in 412. Further, the total number of messages received was 111, 14 of which were erroneous (CRC8 incorrect). We concluded that 24% of the total messages were sent with satellite coverage and just 27% of those messages where received. Moreover, the percentage of erroneous messages received was 13%. In total, just 5% of the transmitted messages were properly received.

## IV. Discussion

This paper presents the initial design of the pop-up project to expand the underwater communications of stand-alone seafloor platforms under the umbrella of PLOME project. This development involves several challenges such as: the underwater communication between the pop-up buoy and the pop-up server, the mechanical release of the buoy, and the satellite data transmission. In this article, the technical solutions for these challenges have been presented and their feasibility experimentally demonstrated.

The pop-up project consists of two main parts. On the one side , the pop-up buoy, which includes the microcontroller (ESP32), the SD and GPS modules, the satellite transmission antenna (Kinéis) as well as compact power system. On the other side the pop-up server, developed with a Raspberry as the main microcontroller, plus several release modules (one for each buoy) including an ESP32 and a motor with its corresponding driver.

With the first experiment, it has been demonstrated that the maximum distance to be able to transmit data using low-power Wi-Fi antennas through salt water is 40 mm (20 dBm). Therefore, as long as the buoy is just above the server box (attracted by the magnet), the communication of oceanographic data would be satisfactory.

The second test demonstrates the feasibility of using magnets to hold and release the pop-up buoys. The pop-up server must be scaled to include one release module for each pop-up buoy, which would depend on the experiment duration and the communication period desired

The third test gives inputs about how fast the fix of the GPS in a sleep-alive routine can be for the tracking of the buoy on states 4 and 5. It is mandatory to properly design these routines, with special attention given to the average GPS fix time and timeout, in order to maintain an acceptable autonomy of the buoy.

Finally, the satellite transmission of small data packages using the Argos 4 network has been tested in the fourth experiment. We concluded that just around 5% of the total messages sent were properly received (transmitting continuously every 35 seconds). This demonstrates the necessity of implementing an intelligent satellite pas prediction algorithm, to maintain an acceptable autonomy of the buoy, and the importance of transmitting each message several times with the implementation of an error-detecting check (CRC8 in this work).

## Acknowledgment

The authors would like to thank the collaboration of all PLOME project (PLEC2021-007525) partners; Universitat de Girona (UdG), Universitat de las Islas Baleares (UIB), Universidad Politécnica de Madrid (UPM), Instituto de Ciencias del Mar (ICM) and IQUA Robotics S.L.

## References

[1] P. Petsas, A. Doxa, V. Almpanidou, and A. D. Mazaris, "Global patterns of sea surface climate connectivity for marine species," *Commun. Earth Environ.*, vol. 3, no. 1, 2022.

[2] J. M. Fromentin and J. E. Powers, "Atlantic bluefin tuna: Population dynamics, ecology, fisheries and management," *Fish Fish.*, vol. 6, no. 4, pp. 281–306, 2005.

[3] J. Del-Rio *et al.*, "Obsea : A Decadal Balance for a Cabled Observatory Deployment," *IEEE Access*, vol. 8, pp. 33163–33177, 2020.

[4] A. Witze, "Oceanography's billion-dollar baby," *Nature*, vol. 501, no. 7468, pp. 480–483, 2013.

[5] N. Lantéri *et al.*, "The EMSO Generic Instrument Module (EGIM): Standardized and Interoperable Instrumentation for Ocean Observation," *Front. Mar. Sci.*, vol. 9, no. March, pp. 1–17, 2022.

[6] D. Pelletier *et al.*, "Kosmos: An open source underwater video lander for monitoring coastal fishes and habitats," *Sensors*, vol. 21, no. 22, 2021.

[7] J. K. Choi, T. Fukuba, H. Yamamoto, Y. Furushima, T. Miwa, and K. Kawaguchi, "Pinpoint and safe installation of a standalone seafloor observatory," *2018 Ocean. - MTS/IEEE Kobe Techno-Oceans, Ocean. - Kobe 2018*, pp. 1–4, 2018.

[8] E. Fanelli *et al.*, "Towards naples ecological research for augmented observatories (NEREA): The NEREA-fix module, a stand-alone platform for long-term deep-sea ecosystem monitoring," *Sensors (Switzerland)*, vol. 20, no. 10, 2020.

[9] J. H. Haxel, R. P. Dziak, and H. Matsumoto, "Obtaining baseline measurements of ocean ambient sound at a mobile test berth site for wave energy conversion off the central Oregon coast," *Ocean. - MTS/IEEE Kona, Progr. B.*, pp. 8–12, 2011.

[10] D. M. Toma, M. Carandell, and J. Del Rio, "Performance of WAVY Ocean Lagrangian Drifters for Surface Characterization of Ocean Dynamic Structures," in *2022 IEEE International Workshop on Metrology for the Sea - Naples*, 2022, pp. 133–137, doi:10.1109/metrosea55331.2022.9950995.

[11] G. N. Technology, "Expendable communication buoys." [Online]. Available: https://www.gabler-naval.com/subsea-communication/#ECB.

[12] M. Y. I. Zia, J. Poncela, and P. Otero, *State-of-the-Art Underwater Acoustic Communication Modems: Classifications, Analyses and Design Challenges*, vol. 116, no. 2. Springer US, 2021.

[13] X. André, B. Moreau, and S. Le Reste, "Argos-3 satellite

TABLE I. Kinéis satellite transmission test results

| Configuration | Result |
|---|---|
| Total messages sent | 1691 |
| Messages sent with satellite coverage | 412 |
| Messages received | 111 |
| Erroneous messages | 14 |
| Total time elapsed | 16h 53' |
| Average time between messages | 35'' |

communication system: Implementation on the Arvor oceanographic profiling floats," *J. Atmos. Ocean. Technol.*, vol. 32, no. 10, pp. 1902–1914, 2015.

[14] A. Arias, "Caracterización de sistemas de comunicación RF y ópticos en aplicaciones submarinas," *Bachelor Thesis. Univ. Politècnica Catalunya*, 2022.

[15] C. Lobelles, "Sistema de liberación de 'pop-up bouy' en estación submarina," *Bachelor Thesis. Univ. Politècnica Catalunya*, 2022.

[16] M. Carandell, D. Mihai, J. del Río, K. Ganchev, and J. Peudennier, "Evaluation of Sigfox LPWAN technology for autonomous sensors in coastal applications," in *8th International Workshop on Marine Technologies - Oporto*, 2018, pp. 1–2, ISSN1886-4864.

[17] M. Carandell, D. M. Toma, C. Artero, M. Gasulla, and J. del Rio, "Real-time Wave Monitoring on Coastal Areas Using LPWAN-Based Embedded Systems," in *IEEE International Instrumentation & Measurement Technology Conference - Glasgow*, 2021.

[18] M. Ledesma, "Dispositiu de seguiment i transmissió de dades amb tecnologia Satèl·lital Argos Kineis i LPWAN Sigfox," *Bachelor Thesis. Univ. Politècnica Catalunya*, 2021.