A LoRa-mesh based system for marine Social IoT

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***Abstract*—Recently in the world of boats we hear about ”smart boats”, or 3.0 connected boats. For many years, technology has entered the world of boats, especially as regards safety, some systems have become mandatory. With the spread of IoT systems, boats could be considered as sources of information for other boats in the same sea area or for the construction of coastal IoT services. In the marine context, measurements of environmental values such as sea water temperature, wave period and height or direction of currents, are carried out using buoys of considerable size and at a great distance from the coast. In this paper we want to present a Social Internet of Things system that allows the distribution of information between boaters and the integration with fixed IoT networks consisting of buoys and coastal stations. A preliminary LoRa mesh communication test is presented showing a stable mesh network in which each node is able to communicate in the sea with a radius of 5 Km.**

***Index Terms*—marine, boats, social internet of things, LoRa, mesh**

I. Introduction

The introduction of smart objects together with the IoT scenarios has contributed to the realization of smart environments in different shapes and contexts [1], ranging from smart buildings [2], smart campuses [3]–[5], smart gardening [6], smart urban environments [7], [8], smart tourism [9], [10], smart entertainment [11], etc.

Lately in the world of boats, we hear about ”smart boats”, or 3.0 connected boats [12]. B&G, Garmin, and Raymarine are the leading companies that allow the digitization of nautical instruments. Software has also evolved: by summarizing and combining information, they help make decisions. Among the most technological systems that can be installed, there are eco-sounders capable of creating a three-dimensional image of the seabed in front of the boat, systems for autonomous parking of the boat in the port, entire home automation systems for controlling the entire boat via tablet or smart-phones and finally augmented reality is also entering this world, in particular Clear Cruise by Raymarine combines the images of the camera with AIS and cartographic information, indicating distance, information and alerts relating to everything around the boat. By purchasing a system, suppose consisting of a plotter, radar, depth sounder, instruments, and a camera, it would be possible to spend about 10-12 thousand euros excluding installation costs [13]. For this scenario, there are still several open research issues that need to be addressed, such as the integration with other fixed battery systems (e.g. buoys or coastal weather stations); long range inter-vessels communication with low cost systems and on unlicensed frequencies; the integration of vessels in recent IoT architectures that allows the creation of advanced services for mariners.

In particular, the following are the main functionalities and novelties provided by the proposed system:

- definition of an architecture IoT of digital boats;
- creation of a LoRa-mesh network of moving boats;
- experimentation through over-the-water tests in order to assess the feasibility of the proposed system.

The remainder of this paper is structured as follows. We introduce the background and the related work in Section II. Section III presents our proposed system along with a discussion of the LoRa-mesh network and the IoT architecture. We provide some preliminary results of the tests in Section IV, and finally we provide the conclusions and future works in Section V.

II. related works

For many years, technology has entered the world of boats, especially as regards safety, some systems have become mandatory. In the next sections we will talk about what are some standards that are the common thread between the various companies and that make communication between different generations, brands and models of products possible.

A. nmea 0183

This standard is developed to enable prompt and satisfactory data communication between maritime instruments, navigation equipment and communication equipment, when interconnected via an appropriate interface. This standard is intended to support the unidirectional serial transmission of data from a single TALKER to one or more LISTENERS. This is data in printable ASCII format and may include information such as position, speed, depth, etc. Typical messages can be 11 to 79 characters long and typically require transmission no more than once per second. All transmitted data must be interpreted as ASCII characters. The most significant bit of the 8-bit character must always be transmitted as zero (d7 = 0). All data can be captured from a serial interface such as a common usb.

B. AIS

AIS (Automatic Identification System) is a system used by ships, pleasure boats and traffic control stations. This tool allows you to have information regarding position, speed and route and therefore is very useful for managing ship traffic. The IMO Convention for the Safety of Human Life at Sea (SOLAS) Regulation V / 19.2.4 requires that all ships of 300 tonnes and above engaged in international voyages and all passenger ships, regardless of size, have AIS on board . There are two types of AIS:

- **Class A**: mandatory for all ships of 300 tons and over engaged in international voyages and for all passenger ships
- **Class B**: provides limited functionality and is intended for non-SOLAS vessels. Mainly used for pleasure boats

The AIS mainly operates on two dedicated frequencies on VHF channels: (i) AIS 1: works on 161.975 MHz- Channel 87B; (ii) AIS 2: 162.025 MHz- Canale 88B. These frequencies have a line of sight limit of approximately 40 miles. Here are some of the main information transmitted via AIS:

- *Static information (every 6 minutes and on request)*: Number MMSI; Number IMO; Name; Length; Type of boat.
- *Dynamic information*: Ship position with accuracy indication; Position timestamp (in UTC).
- *Travel information (every 6 minutes, when data is changed or upon request)*: Draft of the ship; Type of load; Route plan.

These devices have a price that starts from a few hundred euros for the simplest ones, up to a few thousand. It is possible to use cheaper alternatives such as RTL-SDR, which however are only able to receive data and not to transmit it; this limitation is due to the fact that this protocol works on licensed frequencies.

C. LoRa

LoRa (Long Range), is a technology mainly used in the IoT field. LoRa is based on frequency modulation, in Europe 433MHz or 868MHz are free ISM bands. By law, in Europe: [14]

- For the uplink, the maximum transmit power is limited to 25mW (14dBm).
- For the downlink (for 869.525 MHz), the maximum transmit power is limited to 0.5 W (27 dBm).
- The total Duty Cycle for channel transmission must be less than 1%.
- Maximum allowed antenna gain +2.15 dBi.

It is worth mentioning that the regulations for the use of ISM bands vary for each geographic area. LoRa uses Chirp-spread-spectrum (CSS) modulation for keep the low power characteristics for the benefit of the increase of the communication range. It is the first implementation for a low-cost infrastructure to be commercialized using CSS. CSS has been used in long-range communications by military and space agencies due to its ability to resist interference.

TABLE I
TABLE THAT RELATES THE DISTANCE TO THE POWER USED BY BLUETOOTH, WIFI, 3G / 4G AND LORA [14]

Technology	Wireless Communication	Range	Tx Power
Bluetooth	Short range	10 m	2.5 mW
Wifi	Short range	50 m	80 mW
3G/4G	Cellular	5 km	5000 mW
LoRa	LPWAN	2-5 km (urban) 5-15 km (rural) $>$15 km (LOS)	20 mW

D. LoRaMesh

The idea behind LoraMesh [15] is to connect various nodes to each other and use them to create a real network capable of covering large distances. In a mesh network, data propagates across the network through each node. In mesh networks, each node transmits the same message regardless of its final destination or route, so the message propagates along a path to its destination. Mesh networks typically use routing tables or are self-routing. [16] The advantages of a mesh network are the ability to ”self-heal” and to reconfigure itself in the event of a loss of connectivity to a node or group of nodes. A disadvantage of this topology is the relatively greater complexity compared to traditional star networks and an increase in network traffic due to the inherent redundancy of the network. The implementation used in the project exploits the pyMesh library developed by Pycom. The latter is in turn based on OpenThread [17], developed by Google, which manages the routing algorithms and provides an ipv6 layer to facilitate communication.

III. PROPOSED SYSTEM

A. Architecture

The solution we propose in this paper foresees an information sharing architecture on two levels (Fig. 1): a communication level with the creation of LoRa-mesh networks between vessels; a virtualization level that allows the diffusion between virtual counterparts of vessels that are not within the same LoRa-mesh cluster.

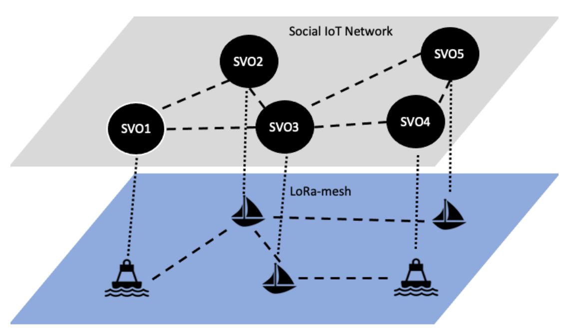

Fig. 1. The two levels of the proposed architecture: the LoRa-mesh network and the SIoT network.

In the first level, we want to create an opportunistic LoRa-mesh network that allows the dissemination of information about the state of the sea and boats if there is no cellular network that allows access to the internet. In the second level, we want to create a social network of virtual objects according to the Social Internet of Things paradigm [18]. Basically, we work on the cloud Social IoT architecture, named Lysis [19], that foresees a four-level structure: The Real World level is populated by sensors, actuators and general smart devices able to perform basic tasks; the Virtualization layer directly interfaces with the real world and is populated by the Social Virtual Objects (SVOs), entities able to establish and manage friendships and connections with other SVOs autonomously; the two upper levels concern the aggregation of data and the creation of user-centric IoT services and are not of interest for this paper.

Social network relationships may not reflect the links and topology of the mesh network. For example, in the social network SVO3 is the node with the greatest centrality. However, the corresponding boat is not the most central node in the mesh network. In fact, the most connected node is that of the boat corresponding to SVO2. In this way we can exploit LoRa-mesh to cover areas without internet coverage, and in the same way, we can exploit the SIoT network to spread information between isolated and non-communicating LoRa-mesh clusters.

B. Dynamism of the Mesh network

The creation of the LoRa-mesh network is managed by the software modules depicted in Fig. 2.

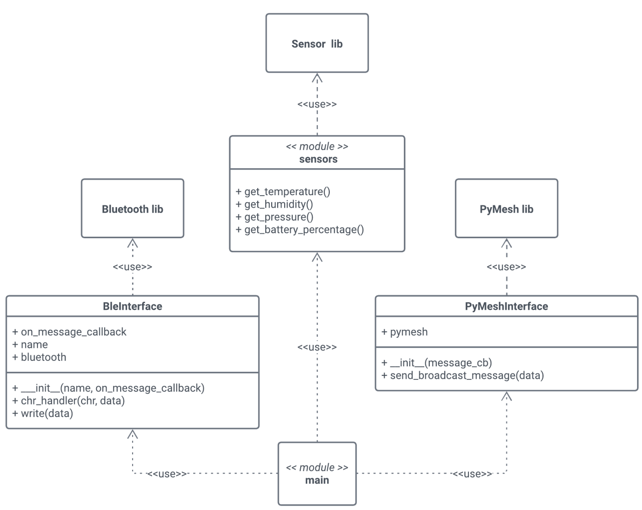

Fig. 2. Class diagram of the micropython code executed in the fipy

Due to the mobility of the boats, we faced some critical challenges: (i) The leader could lose the connection; (ii) Sudden loss of signal from router to children.

To overcome these issues, a watch-dog has been implemented that constantly monitors the network status and, in case of problems, restarts the device and therefore the portion of the network connected to it. The critical condition that causes the network to restart, in particular, is the loss of connection for more than two minutes: in fact, even if the device has no nearby nodes to connect to, it should create a distinct network waiting for other devices to connect. Unfortunately this mechanism shows problems when the conditions listed above occur. Considering that the application for which it was designed does not need an extremely stable data flow, the most practical idea was to rely on a watch-dog, even if this means a gap of about 2 minutes in communication, in the moment in which the latter is activated.

IV. EXPERIMENTAL EVALUATION

The tests were carried out using Pycom modules for the implementation of a LoRa Mesh network. By means of the PySense module, it is possible to have access to a series of sensors, in particular, an interface is provided in the code that formats the sensor data directly in json. Sensors supported by the interface are devoted to collect the following environmental data: temperature; humidity; battery level; atmospheric pressure. All sent messages (LoRa Mesh and BLE) have a JSON format. Many tests have been carried out using as reference the RSSI (Received Signal Strength Indication) which represents the power of the received signal in milliwatts and is measured in dBm. This value can be used as a measure of how well a receiver can ”hear” a signal from a sender.

RSSI is measured in dBm and is a negative value. The closer it is to 0, the better the signal. Typical values of LoRa RSSI are [14]: Min RSSI = -120 dBm; RSSI= -30dBm: strong signal; RSSI= -120dBm: weak signal. All tests were carried out with a transmission power of 14 dBm.

Fig. 3. image of the route of the boat used for the test (boat data received by the ground node)

This test was carried out on Lake Trasimeno. Two devices were used to carry out the measurements: the first was positioned on the terrace of a building located near the port and the other on the stern pulpit of the sailboat. The Table II summarizes the configuration of the test.

TABLE II
TEST LORA MESH WHILE SAILING ON THE LAKE

	Device 1	Device 2
height [m]	1	3
Moving	yes	no
environment	Lake	

Analyzing the data, as can be seen in the Fig. 3, it is clear that messages were obtained up to about 5 km between the devices, after which the signal was lost. A course change was made about 300 m later, and the signal was regained at about 4.3 km between the antennas. The outward leg, which can be seen from the image, it was covered in about 65 minutes with an almost constant speed was maintained throughout the test. The average speed were approximately between 5.1km/h and 5.7km/h.

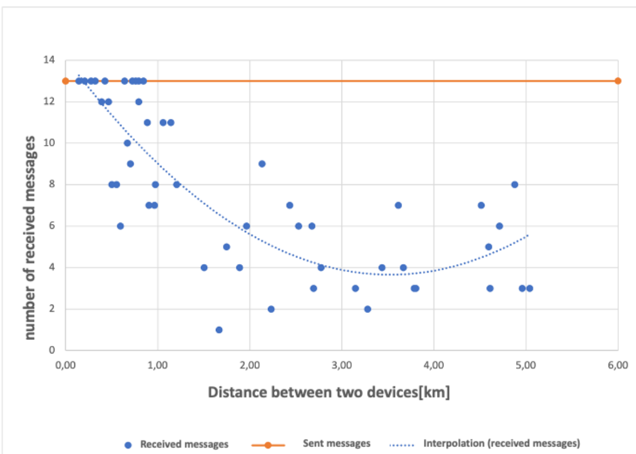

Fig. 4. message loss with different distances between two nodes

Analyzing the data, as can be seen in the Fig. 3, it is clear that the link persists up to about 3.5 km between the devices, after which the signal was lost. A course change was made about 300 m later, and the signal was regained at about 4.3 km between the devices. The outward leg, which can be seen from the image, it was covered in about 65 minutes with an almost constant speed was maintained throughout the test. The average speed were approximately between 5.1km/h and 5.7km/h. However, Fig. 4 shows that the maximum distance has a high message loss. At about 3km we have the maximum of lost messages (about 70% message loss). We plan to achieve a greater distance by placing the antenna on the masthead in the future tests.

V. CONCLUSIONS AND FUTURE WORKS

In this paper we wanted to test a new approach to communications between boats, in order to find a freer, more flexible and cheaper alternative to existing technologies. After the various tests, a stable mesh network has been created in which each node is able to keep a link in the sea with a radius of 5km. In future works, we plan to obtain a connection over greater distances by positioning the antenna higher. In addition, the software part of the boat SVOs will be developed to experience the complete system architecture on a greater number of boats.

REFERENCES

[1] A. Bujari, O. Gaggi, and C. E. Palazzi, "A mobile sensing and visualization platform for environmental data," *Pervasive and Mobile Computing*, vol. 66, p. 101204, 2020.

[2] L. Atzori, C. Campolo, B. Da, R. Girau, A. Iera, G. Morabito, and S. Quattropani, "Smart devices in the social loops: Criteria and algorithms for the creation of the social links," *Future Generation Computer Systems*, vol. 97, pp. 327–339, 2019.

[3] C. Ceccarini, S. Mirri, C. Prandi, and P. Salomoni, "A data visualization exploration to facilitate a sustainable usage of premises in a smart campus context," in *Proceedings of the 6th EAI International Conference on Smart Objects and Technologies for Social Good*, 2020, pp. 24–29.

[4] M. Bortoli, M. Furini, S. Mirri, M. Montangero, and C. Prandi, "Conversational interfaces for a smart campus: A case study," in *Proceedings of the International Conference on Advanced Visual Interfaces*, 2020, pp. 1–5.

[5] C. Prandi, C. Ceccarini, and P. Salomoni, "Augmenting good behaviour: Mixing digital and reality to promote sustainability in a campus community," in *Proceedings of the 5th EAI International Conference on Smart Objects and Technologies for Social Good*, 2019, pp. 189–194.

[6] C. Ceccarini, G. Delnevo, and C. Prandi, "Frugar: Exploiting deep learning and crowdsourcing for frugal gardening," in *Proceedings of the 1st Workshop on Experiences with the Design and Implementation of Frugal Smart Objects*, 2020, pp. 7–11.

[7] J. L. Zambrano-Martinez, C. T. Calafate, D. Soler, J.-C. Cano, and P. Manzoni, "Modeling and characterization of traffic flows in urban environments," *Sensors*, vol. 18, no. 7, p. 2020, 2018.

[8] C. De Francesco, C. E. Palazzi, and D. Ronzani, "Fast message broadcasting in vehicular networks: Model analysis and performance evaluation," *IEEE Communications Letters*, vol. 24, no. 8, pp. 1669–1672, 2020.

[9] A. Bujari, C. Bergamini, A. Corradi, L. Foschini, C. E. Palazzi, and A. Sabbioni, "A geo-distributed architectural approach favouring smart tourism development in the 5g era," in *Proceedings of the 6th EAI International Conference on Smart Objects and Technologies for Social Good*, 2020, pp. 12–17.

[10] C. Prandi, V. Nisi, C. Ceccarini, and N. Nunes, "Augmenting emerging hospitality services: A playful immersive experience to foster interactions among locals and visitors," *International Journal of Human–Computer Interaction*, pp. 1–15, 2021.

[11] A. Bujari, O. Gaggi, C. E. Palazzi, and G. Quadrio, "Are remote play streaming systems doomed to fail? a network perspective," *IEEE MultiMedia*, vol. 28, no. 4, pp. 45–54, 2021.

[12] M. Cankar and S. Stanovnik, "Maritime iot solutions in fog and cloud," in *2018 IEEE/ACM International Conference on Utility and Cloud Computing Companion (UCC Companion)*. IEEE, 2018, pp. 284–289.

[13] A. Z. Arfianto, M. B. Rahmat, F. Dhiyavia, T. B. Santoso, N. Gunantara, E. Supriyanto, and V. Y. P. Ardhana, "Autopilot unmanned smart boat vehicle (ausv) communication with lora rfm95," *JOIV: International Journal on Informatics Visualization*, vol. 4, no. 4, pp. 219–224, 2020.

[14] E. B, "Lora documentation eric b," 2019. [Online]. Available: https://lora.readthedocs.io/en/latest/

[15] Pycom, "Pymesh," 2022. [Online]. Available: https://docs.pycom.io/firmwareapi/pycom/network/lora/pymesh/

[16] Semtech, "an1200.22, lora modulation basics," 2015. [Online]. Available: https://www.semtech.com/uploads/documents/an1200.22.pdf

[17] Google, "openthread-nodi," [Last updated 2022-04-12 UTC.]. [Online]. Available: https://openthread.io/guides/thread-primer/node-roles-and-types

[18] L. Atzori, A. Iera, G. Morabito, and M. Nitti, "The social internet of things (siot)–when social networks meet the internet of things: Concept, architecture and network characterization," *Computer networks*, vol. 56, no. 16, pp. 3594–3608, 2012.

[19] R. Girau, S. Martis, and L. Atzori, "Lysis: A platform for iot distributed applications over socially connected objects," *IEEE Internet of Things Journal*, vol. 4, no. 1, pp. 40–51, 2016.