

Experimental Characterization of WSNs Applied to Swarms of Aquatic Surface Drones

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Abstract—The aim of the HANCAD project is to develop and study technologies and communication protocols for swarms of inexpensive aquatic surface drones. The long-term goal is to enable maritime tasks such as sea-border patrolling and environmental monitoring, while keeping the cost each drone low enough to facilitate large-scale deployment. The exchange of information between the drones within the swarm is essential in several mission scenarios. Our current prototypes use a Raspberry Pi 2 as the on-board computer, and we are experimenting with XBee-PRO S1 hardware to allow for low-power, long-range communication. In this paper, we report on preliminary field trials conducted to validate the potential of the proposed solution, in terms of coverage, range, and multi-hop capabilities, in maritime scenarios.

Keywords—WSN, swarms, aquatic drones, USV, ASC

I. INTRODUCTION

Unmanned Maritime Systems (UMS) have potential applications to many tasks that are currently performed by manned vessels, e.g., sea-border patrolling, search and rescue, environmental monitoring, and so on. In [1], we proposed to use swarm systems composed of large numbers of autonomous surface drones. To obtain a cost-effective solution, we study swarms of relatively simple and

inexpensive drones, and we focus especially on communication and control aspects. Potential applications of swarms of aquatic drones can be divided into monitoring tasks and mission-oriented tasks, see Fig. 1.

Several autonomous surface crafts (ASC) have been developed, but most have been applied exclusively either to research or to military scenarios [2]. Moreover, to the best of our knowledge, no other ASC platform at the scale of a swarm (ten drones or more) has been developed, aside from a recent system developed by the U.S. Navy consisting of 13 autonomous boats [3].

Communication at the sea surface is challenging due to high humidity, waves, and the presence of two mediums. Moreover, different types of missions have different requirements. These issues, combined with the need of dynamic ad-hoc network topologies, call for a heterogeneous communication approach [1].

The rest of the paper is organized as follows. Section II introduces the scenarios and characterizes the communication in swarms of aquatic drones. Section III briefly addresses aspects of the configuration of XBee modules used in a system where only a subset of the drones are required to carry long-range communication equipment. Section IV presents results from the preliminary field trials. These preliminary trials were conducted to assess the proposed solution, in terms of coverage, range, and multi-hop capabilities, in maritime scenarios. Finally, Section V discusses the lessons learnt from this experimental characterization study.

II. COMMUNICATION IN SWARMS OF AQUATIC DRONES

In many real-world tasks, a heterogeneous communication architecture can be advantageous [1]. An example scenario from the HANCAD project [1] is shown in Fig. 2. A swarm of ASCs collects environmental data. In HANCAD, all drones have short-range communication capabilities used for local coordination, while few are equipped with long-range

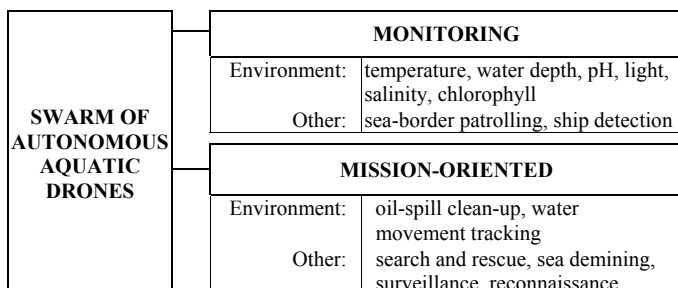


Fig. 1. Potential applications of swarms of aquatic drones.

communication capabilities. The drones with long-range communication capabilities serve as gateways between human operators at a base station and the swarm, as shown in Fig. 3.

Two methods of localization are considered: (i) using Global Positioning System (GPS), and (ii) using received signal strength indicator (RSSI). The current drones built as part of the HANCAD project use GPS. The accuracy of GPS is satisfactory, but receivers have a relatively high cost in terms of energy consumption. In order to improve energy efficiency, we are experimenting with local localization and coordination based on RSSI measurements together with triangulation based on few extra pieces complementary information, namely details from topology control magnetometer readings, and odometry data. Unfortunately, RSSI-based localization is inherently inaccurate because of signal propagation issues, such as fast and slow fading.

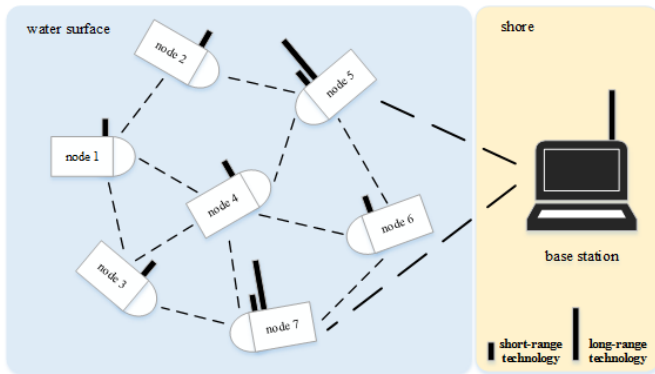


Fig. 2. A HANCAD scenario where a swarm of drones, deployed on the water surface, collects environmental data.

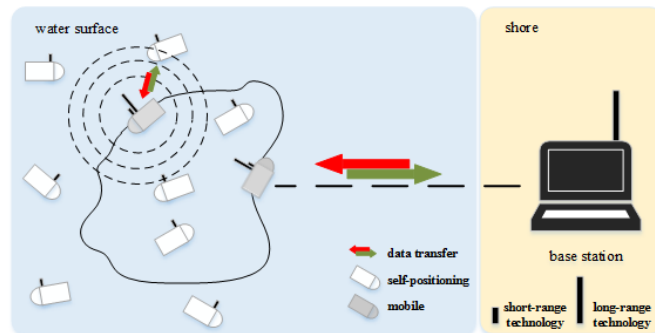


Fig. 3. Self-positioning buoys and mobile nodes (aquatic drones).

The objective of the HANCAD project is to development and study communication in swarms of surface drones. Given that the cost of each drone should be as low as possible (a low as a few hundred euros in certain scenarios), the operating communication band should preferably be unlicensed. Also, the communication system should allow the drones to maintain intra-swarm connectivity, and to maintain a stable connection to the base station. The base station can be located on the land, or on a manned vessel. Operators at the base station should be able to receive data from the swarm, and to issue high-level commands, such as to reconfigure the mission area or mission priorities.

IEEE 802.15.4, ZigBee/XBee and WiFi are considered short-range communication technologies. Ideally, a swarm is deployed over the large area, which requires communication ranges of over hundreds of meters. WiFi does not meet such requirements, and in the HANCAD project, we are therefore experimenting with alternatives, and in particular with an XBee platform. For environmental monitoring applications, data rate of 250 kbps provided by XBee is generally sufficient.

Authors from [6], [7] developed autonomous inexpensive vessels, called SCOUTs (Surface Craft for Oceanographic and Undersea Testing), to serve as relays between autonomous underwater vehicles (AUV) and control station. In the HANCAD project, we aim to adapt the concept of vessels performing as self-positioning buoys presented in [7], in order to facilitate applications such as water quality or water movement monitoring, coral reef monitoring, fish farm monitoring, and to collect environmental data, such as temperature, salinity, and water depth.

Considered scenarios include the following: (i) a set of buoys (self-positioning or anchored boats) with long-range communication capabilities deployed in the mission area serve as gateways during a mission; (ii) a set of buoys (self-positioning or anchored boats) with short-range communication capabilities is deployed in the mission area. Surface drones with more processing power and long-range capabilities are mobile and move among buoys, gather information, and send the gathered information to the base station, as illustrated in Figs. 2 and 3.

III. XBEE IMPLEMENTATION

XBee [8] are RF modules produced by Digi International, designed to satisfy IEEE 802.15.4 standards with the minimum of power used. A solution using XBee-PRO (XBee PRO S1 2.4GHz) modules, which are power-amplified versions of XBee modules, has been implemented.

As XBee supports various topologies, such as peer-to-peer, in the experiments reported in this paper, it was decided to use modules with XBee® DigiMesh protocol. A significant advantage of the protocol is no need for configurations or for organization of nodes within the network. In practical terms, the essential parameters of XBee are MAC/PHY settings: Operating Channel and Network ID. In the configuration of the transceivers, it must be assured that they are the same in each node to enable communication within a group.

IV. PRELIMINARY TESTS PROPAGATION ASPECTS

In the recent past, aquatic drones consist of Raspberry Pi 2 as processing unit, communicating within WiFi standard as short-range technology. The next version using XBee modules with the DigiMesh protocol (based on AODV protocol) is now in development, which expands the range ideally up to hundreds of meters.

Preliminary tests have been conducted to assess the range of single-hop communication, on the beach of Figueira da Foz, Portugal. Results from these field trials are summarized in Table I. The number of packets sent from the transmitter to the

receiver, at distances between 10 m and 1.4 km in appropriate steps, has been 50, 100 and 200 packets. Transmitter (Tx) power was considered as the parameter. The objective was to determine the maximum communication range for each Tx value, labelled as Tx(0), Tx(1), Tx(2) and Tx(3). We were unable to conduct the field test for Tx(2) / 14 dBm due to unfavourable weather conditions.

TABLE I. COVERAGE RANGE RESULTS FOR THE INITIAL TESTS.

Tx power parameter	Max range [m]
Tx (0) / 10 dBm – min	65
Tx (1) / 12 dBm	120
Tx (3) / 16 dBm	1200
Tx (4) – 18 dBm – max	1400*

RSSI measurements were recorded during each transmission. Table II and Fig. 4 present the average of the RSSI values recorded at each distance step for minimum Tx power, Tx(0) / 10 dBm. Both communication devices were located on the same height (~1.2 m) above the ground, in LoS, static and their position was not changed during transmission.

TABLE II. RSSI MEASUREMENTS AS A FUNCTION OF THE DISTANCE FOR Tx(0) – 10 DBM TRANSMITTER POWER.

Distance [m]	1	10	15	20	25	30	35	40	45
RSSI [dBm]	-41	-61	-55	-58	-68	-65	-64	-62	-60
Distance [m]	50	55	60						
RSSI [dBm]	-69	-71	-73						

The decrease in reception power with increase of distance is compatible with the Friis propagation model [9], assuming unitary gains for the transmitter and receiver antennas in the computation in this comparison.

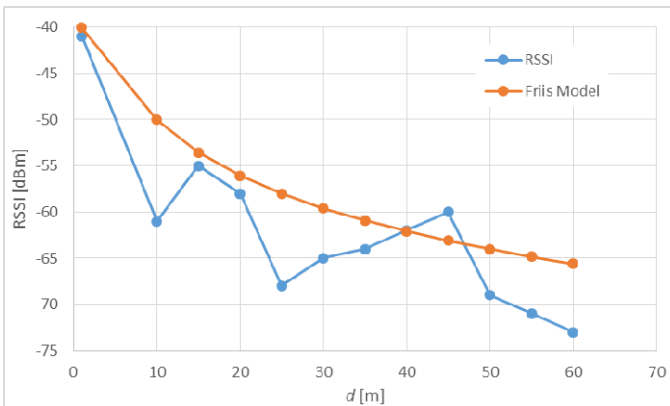


Fig. 3. Comparison of RSSI measurements and free space Friis model, as a function of the distance, for Tx(0) / 10 dBm transmitter power.

As the occupancy of intermedium nodes with given ongoing tasks can pose difficulties to routing of packets coming from other nodes, a supplementary test aimed at determining the effectiveness of DigiMesh protocol in multi-hop application either while the router (the intermedium node

between transmitter and receiver) either has no current activity or while it is busy and has some activities planned/ongoing. The goal was to determine the degree of packet loss.

V. CONCLUSION

The goal of swarms of surface autonomous vessels with multi-hop communication capabilities is to enable maritime tasks such as sea-border patrolling and environmental monitoring, while keeping the cost each drone low enough (few hundred Euros) to facilitate large-scale deployment. The exchange of information between the drones within the swarm is essential in several mission scenarios. Our current prototypes use a Raspberry Pi 2 as the on-board computer, and we are experimenting a multi-hop solution with XBee-PRO S1 hardware to allow for low-power, long-range communication.

The first test showed that LoS has critical importance at distances >100m. The maximum obtained distance for the maximum Tx power is 1400m. In fact, the maximum distance could be longer. However, it was not possible for us to keep LoS at distances above 1400m in the location used for our experiments. The higher is the value of RSSI, the shorter is the distance between transmitter and receiver. The registered reception power of RSSI at different distances was consistent with the Friis propagation model.

The second test of effectiveness of DigiMesh protocol in multi-hop topologies has also been successful. The maximum number of hops can be easily configured in DigiMesh protocol as well as broadcast hop and the number of trials of transmission.

The test conditions have been Tx(0) (10dBm) parameter, 50 packets transmitted. In our experiments, we did not detect any packet loss. Nevertheless, XBee DigiMesh protocol does not give the access to a routing table, and we therefore could not assess the path of a packet. This limitation needs to be overcome by the HANDCAD team in our ongoing work.

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