Communication between Drones and Citizens in Emergency Situations: The Future of Info-mobility

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Abstract
This paper refers to the preparation phases of real-world test-use cases regarding communication between drones and citizens conducted as part of the EU's AURORA H2020 project. A description is made of both the stakeholders involved in the co-development and selection of the tests, as well as the main research findings to develop the hardware side and software platform involved in the chosen final field-test solutions.

Keywords: UAM, drones, cooperative-ITS, urgent logistics, emergency communication, info-mobility

1. Introduction - The Project Aurora

The Aurora Project is one of three European 'sister' research projects regarding air mobility. Sibling projects include the Airmour and FF2020 projects. Aurora involves eight partners located in the south EU area: Seal Aero (leader) (Spain), Siemens and Thales (France), the European Passengers Federation-EPF and Ghent University (Belgium), Robodrone (Czech Republic) and the Universities of Pisa and Florence (Italy).

The Aurora project is focused on developing a transition framework within a multi-modal urban mobility and smart city context to support cities and regions on their path towards UAM (Un-crewed Aerial Vehicles) integration and develop and distribute to relevant stakeholders the AURORA legacy and decision support recommendations that cover wide range of (social, regulatory, technological and operational) UAM aspects.

Aurora develops a UAM Concept of Operations (CONOPS) inter-operable with evolutionary development of U-Space architecture and services, taking into account a multi-modal urban mobility context, smart city context (including medical emergency and logistics services within), and air traffic services provision and Aurora benchmark sustainable urban air mobility indicators with regard to the overall environmental footprint, that will extend the well know Sustainable mobility indicators set by the World business council for sustainable development.

Moreover, the project actively involves citizens and relevant stakeholders in a co-creation process regarding new UAM services and actively contribute to public acceptance activities regarding these services, and UAM in general, trough dedicated dissemination and communication activities and involvement of stakeholders.

Finally, following the previous co-creation phase, Aurora integrates the autonomous flight UAM solution into the smart city context, including emergency and urgent logistics services. In the following section we describe real world use cases for the individuation and preparation process (for which the University of Pisa in responsible).

2. The Transport of Good by Drones

E-commerce has seen exponential growth in recent years [1]. For the use case of the transport of goods, UAVs bring various advantages, including: reducing delivery times, avoiding congestion, lowering operating costs, and lowering environmental impact/reducing carbon emissions when using electric aircraft.

Customer loyalty strongly depends on delivery times, especially in the so-called "last-mile deliveries", i.e. deliveries over very short distances, and the evolution of UAVs will increasingly be able to satisfy these greater requests.

Furthermore, it is precisely the last-mile deliveries that represent the majority of shipping costs (about 53%, source: businessinsider.com), and therefore UAVs could potentially contribute where cost reduction is critical. To date, making forecasts on this market is rather difficult, given that regulatory and technological barriers are high.

Trivially, it is clear that an operation in which a drone must transport a load above humans, even more so if it moves autonomously and beyond visual line of sight, must meet higher safety requirements than a simple inspection operation, where the danger to humans is much reduced. With regards to the definition of a regulatory framework, progress is starting to be made. For example, in Europe beginning in January 2021 drone operators became allowed to use their fleets in populated areas, after having published a framework that allows operations in urban environments classified as medium risk (e.g. parcel deliveries, line inspection railways and electricity supplies, supplies of emergency products such as medical equipment and vaccines).

In China, also beginning on January 1, 2021, the government formulated standards for express delivery services by UAVs with a maximum load weight of 150 kg and a speed not exceeding 100 km/h, specifying conditions, procedures, risk assessment, etc. Secondly, currently there is still a technological limitation regarding the carrying capacity of the vehicle, which does not allow drones to transport goods above a certain size and weight. A further factor to consider concerns the infrastructure, i.e. having to find landing spots every time a delivery needs to be made, which is a nontrivial aspect especially in urban and city environments.

The combined effect of these aspects is multiplied in the passenger transport sector, where the required safety, technological and infrastructural requirements are even more stringent. From an economic point of view, this segment may represent lower potential than others for the reasons just mentioned. Estimates assume a 4-billion-dollar market by 2035 (current size of 0.3 billion dollars), according to Porsche Consulting, with revenues divided between: 60% deliveries, 15% cultivation and fertilization, 10% emergency transport, 10% heavy load transport, and 5% maintenance and air treatment.

Other estimates assume a market of 27.4 billion dollars already by 2030 (source: marketsandmarkets.com).

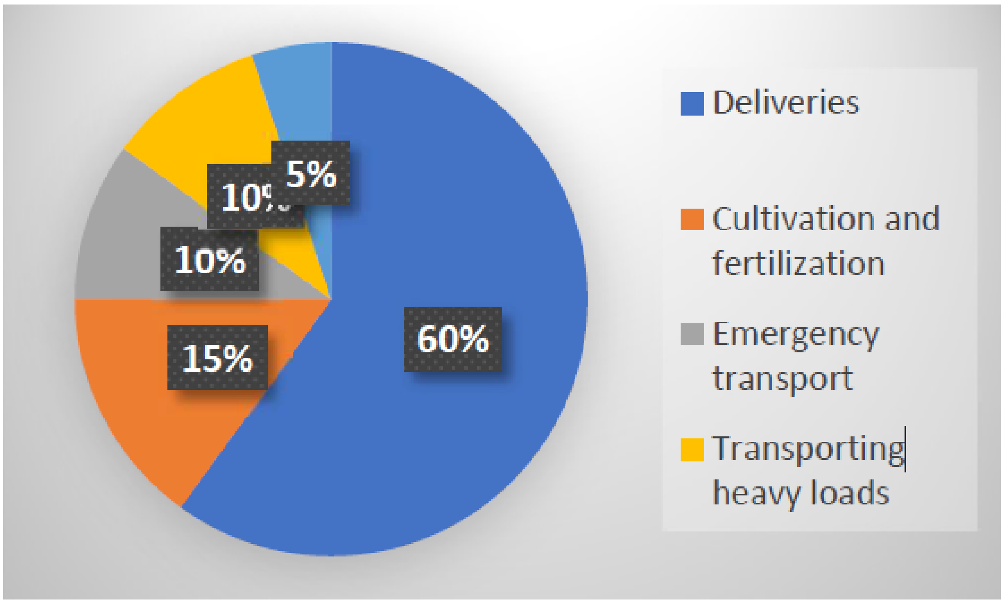

Figure 1: Breakdown of the freight/goods segment to 2035 (source: Porsche Consulting)

It is reasonable to expect an intermediate result. The goods market represents a fundamental training ground for the testing phase and expansion of know-how and experience for companies regarding drones for the transport of heavy loads (cargo drones), with the aim then to pass on this knowledge for the development of drones for the transport of passengers, effectively air taxis. According to Morgan Stanley, a first massive application of VTOL vehicles will concern the B2B (Business to business) or B2C (Business to client) delivery of loads weighing less than 25 kg on average. Initially there will be a phase where their use will be limited to medical supplies and disaster relief, and examples of this are already happening today. Zipline, a US drone operator specializing in the delivery of medical cargo, has flown its fleet over 1 million kilometres making over 13,000 deliveries in Rwanda, 35% of which carrying blood for transfusion. It has also started supplying coronavirus test kits in Ghana. In the UK, Skyports, a British start-up, began delivering personal protective equipment between hospitals in Scotland to fight COVID-19 in 2020, also establishing itself as the country's first BVLOS operation [2].

Figure 2: Zipline drone carrying medical cargo

Polaris Market Research, a US research and consultancy company, hypothesizes that the global market for medical drones should reach almost one billion dollars by 2027 (the value in 2019 stood at 110.9 million dollars), with a CAGR in the period 2020-2027 of 31.6%. Subsequently, we will see the first mass application of these aircraft for the delivery of parcels in rural areas, which we are already seeing in small doses.

The current last-mile delivery system is strongly influenced by the density of the delivery network, and in extra-urban areas the density is not such as to often allow prices similar to those in urban areas. Delivery via VTOL could be the most practical and efficient solution. However the current regulation on BVLOS operations to date limits the application of drones for long distance deliveries, and therefore progress needs to be made on this issue.

3. Use Case Individuation

The initial phase of the project has been to start the individuation of involved and interested stakeholders. The following table summarizes the different stakeholders involved in the co-creation and Use-Case individuation phase.

The stakeholders are subdivided on the basis of target audience type, introducing three main interest areas:

- Aviation safety;
- Integration;
- Environment.

Regarding the Aviation Safety we involved:

- Air Section Finance Police – Pisa;
- 36° Brigata Aerea- Italian Air Force;
- AlaToscana-Elba Island Airport Company;
- Management and coordination Helipad Elba;
- National Coast Guard;

- ENAC (Italian National Civil Aviation Company);
- Pitom (local Drons Company).

Regarding the Integration we involved:
- Piombino and Portoferraio Municipalities;
- Fire Fighters- Portoferraio District;
- Prefecture Elba Island (Vice);
- IDNova srl (RFID-BLE company);
- Aedit srl (Software development Company);
- Director of the Health Services and Citizen Support Area - Company USL Toscana Nord Ovest;
- Port System Authority of the Northern Tyrrhenian Sea;
- Italian Transport Minister;
- Tuscany Freight Village - A.Vespucci;
- Civil Protection Portoferraio;
- Université de Nice Sophia Antipolis - Centre National de la Recherche Scientifique;
- University of Kentucky (USA).

Individual meetings have been held for each stakeholder and a general meeting was held on Elba Island in the summer of 2021. The initial implemented Use Cases list is reported in Table 1 with an indication of the relative main stakeholder requesting them.

Table 1: Table Type Styles

Case Studies Requested	Main Stakeholders
(1) Drug transport (2) Test tubes transport (3) Organ harvesting (with the prior consent of AOUP) (4) IMA employee time networks (hearth attack) (5) Blood transport	USLNORDOVEST-Tuscany, Portoferraio Municipality
(6) UAM urgent landing (7) Fly paths planning and conflicts avoiding	Technical case studies
(8) Beach monitoring during the turtle nesting period (9) Waste monitoring (10) Monitoring of illegal actions within the Park	Archipelago National Park
(11) Drugs transport from central warehouse to hospitals (feasibility) (12) Surveillance and parks vehicles driving	Vespucci Tuscany Freight Village
Communication with citizens by means of: (13) Direct communication drone-citizens (14) Emergence communication between road infrastructure and citizens	Civil Protection

An analysis of the feasibility from legal and operational perspectives led to the inclusion of only eight of the use cases, including the transport of emergency goods (first six use cases) and the communication with citizens (the last two use cases). For the first five use cases, with the help of Siemens, we developed a simulation for the transport of goods between Piombino Hospital and Portoferraio, using a Tri dimensional path connecting the two helipads and minimizing possible interactions with ship routes (see the density of ships in 2021 and 2022 of Figure 3).

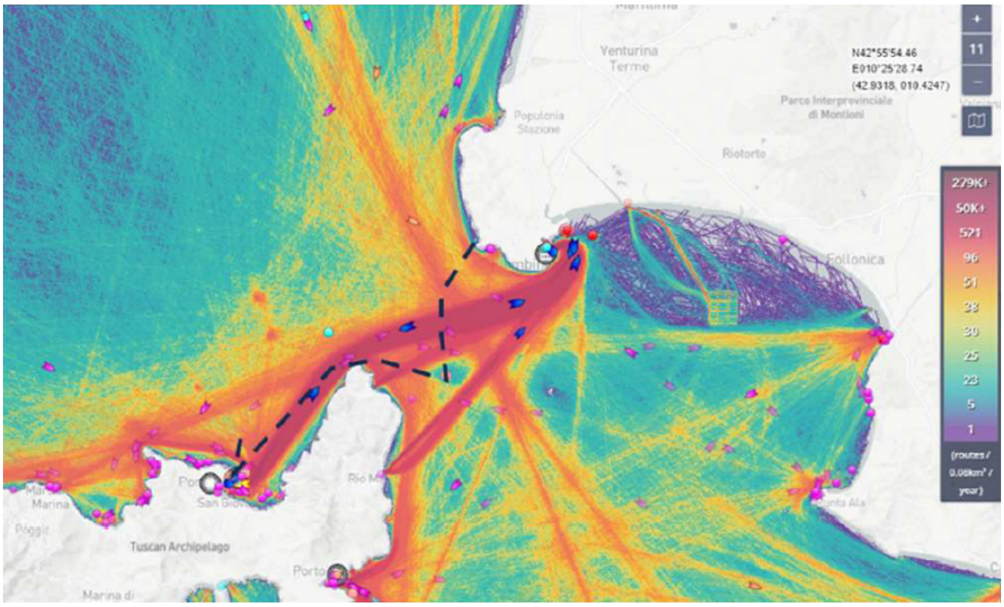

Figure 3: Vessel density in 2021 and 2022 (source: https://www.marinetraffic.com)

For the emergency landing use-case during the drone fly from Piombino to Portoferraio it was decided to not use the small helipad located in the Palmaiola Island (see Figure 4) because this deviation from the direct path intersects the path with the biggest density of vessels.

Instead, we simulated a sea emergency landing system with a system to avoid ships by installing a GPS system to allow the recovery of the drone and a flotation system that prevents the drone from sinking and is activated upon contact with water.

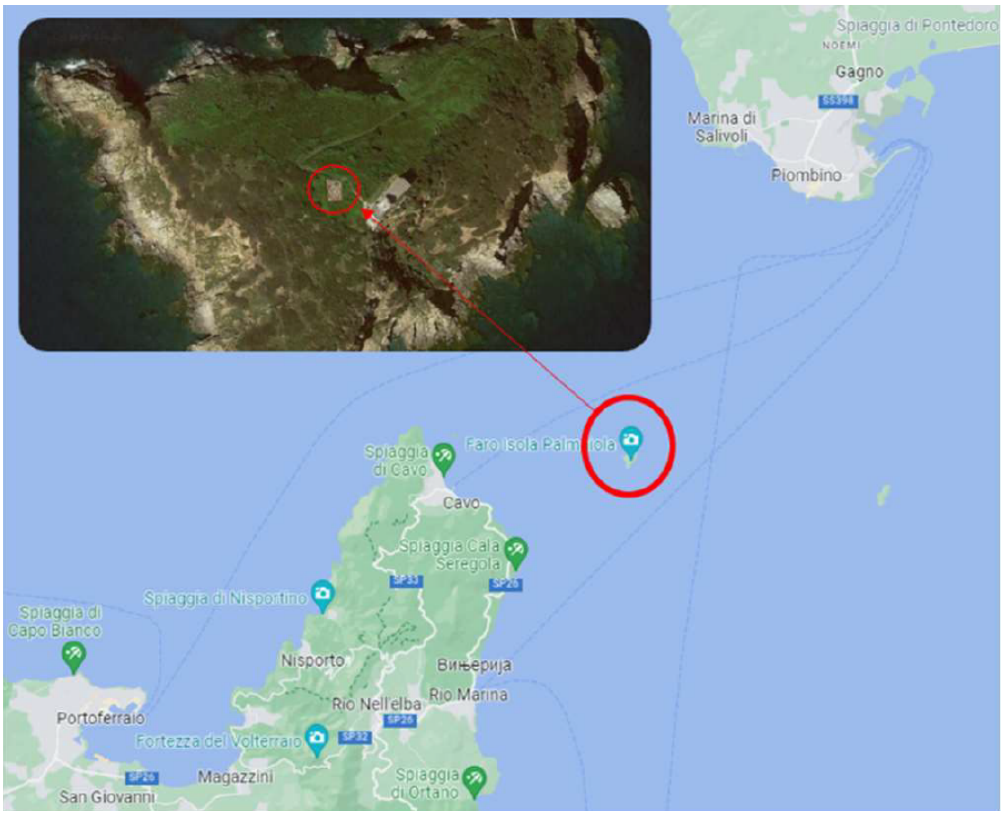

Figure 4: Location of the Palmaiola Island and its helipad

4. Real-world Use Cases Preparation

To describe in more detail areal-world scenario, an abandoned building area in Campiglia Marittima municipality with no legal restrictions to drone flights was identified (see Figure 5).

Figure 5: The Testing location

In this area we planned the communication testing use cases for which we developed both the hardware and software systems.

4.1. Hardware System Testing

Experimentation with the related project, research & development and testing activities has the purpose of allowing the identification of the best hardware and software technological architecture, and the best operation and usability of information and alerts.

The fixed or mobile field hardware consists of RFID tags with radio frequency information transmission and from battery-powered drones for patrolling the identified prototype areas; the software component resides in the cloud with usability from any fixed or mobile device with Internet connectivity. The choice of sensor technology for testing field information retrieval and alerting systems automatically falls within the scope of automatic radio frequency identification, i.e. RFID technology (Radio Frequency Identification).

RFID is a wireless communication system created between readers and transponders with which it is possible to exchange wireless information. However, RFID technology encompasses a very broad spectrum of frequencies and standards, each of which with different operational and functional characteristics. The goal was to identify the most RFID technology suitable for the purpose of the project.

Some characteristics under consideration of RFID transponders:
- Be able to be read from a distance even if not in view;
- Have a “read & write” memory to modify data;
- Have a unique identification code;
- Reading of several transponders at the same time;
- Static or moving readings.

Firstly, we differentiate passive tags from active ones. Passive RFID systems use tags without internal power. The power required for sending of the RF ID comes from the electromagnetic energy transmitted by the RFID reader. Passive RFID in the absence of a signal from an RFID reader is completely inert. Passive tags work from low frequencies (LF-125 KHz) up to very high frequencies (UHF -900 MHz) and are commonly used for logistics, control accesses, production tracking, anti-counterfeiting. On the other hand, active RFID systems use battery powered RFID tags that transmit the signal at defined cadences. Unlike passive RFID, active RFID works at a higher frequency and mainly at 2.45 GHz. The advantages introduced by the use of an active technology are mainly two, i.e. a clear detection distance greater and the integration of sensors on board the tag. These tags are mainly used in real time projects location system (RTLS), vehicle identification, service enabling, monitoring, pick by light or general applications where it is necessary to identify at large distances. The communication frequencies between Reader and Transponder depend both on the nature of the TAG and on the intended applications and are regulated (to control power emissions and prevent interference) by the usual international bodies e national. In the UHF band, in the upper area, the sub-band cantered on 2.4 GHz allows for further miniaturization of the TAG. It deals with, of a bandwidth very crowded by other technologies (Wi-Fi, Bluetooth, ZigBee), with which it is necessary to live. However, all outside Europe, both passive and active TAGs are used on this band, according to the ISO 18000-4 standard. In the context of active technology RFID TAGs with a frequency of 2.45 GHz (or higher), an analysis of in-depth analysis to identify the most performing and suitable one for the project; comparing the main ones low-power wireless options by comparing key operating characteristics, such as frequency band, support of network topology, throughput, range and coexistence. Among the potentially indicated low-power wireless technologies we can list:
- Bluetooth Low Energy;
- ZigBee;
- Wi-Fi;
- Active tags;
- UWB.

This wide range makes selection more difficult. Every technology compromise between energy consumption, bandwidth, and range. Some are based on open standards while others remain proprietary. To complicate further things, new wireless interfaces and protocols keep emerging to meet the needs of IoT. In the project in question (alerting system in real time in an urban context linked to the usability of information from citizens or competent bodies) the main parameters in the choice of sensors can be:
- Low consummation for a long autonomy;
- Response speed;
- Low cost;
- Small size;
- Worldwide standards;
- Usability with consumer tools (e.g. smartphones, tablets, etc.).

The tests led to the choice of Bluetooth Low Energy for multiple reasons. First, It is commonly believed that the range of a wireless technology is proportional to the power of the transmitter combined with a receiver's RF sensitivity measured in decibels (the "link balance"). More transmission power and higher sensitivity increase the range by effectively improving the signal-to-noise ratio (SNR). SNR depends on a receiver's ability to properly extract and decode a signal from the noise environmental. At a threshold SNR value, the BER (Bit-Error-Rate) exceeds the radio specification and communication fails. A Bluetooth Low Energy receiver, for example, is designed to tolerate a maximum BER of only about 0.1%.

The latency of a wireless system can be defined as the time between transmitting and receiving a signal. Also, while it is typically a few milliseconds, for wireless applications it is an important figure. For example, a low latency isn't that important for an application that automatically polls a sensor for data maybe one once per second but could become critical for a consumer application like a remote control where a user is expect an imperceptible delay between pressing a button and the next action. The latency for BLE technology (consider also in this case that the values depend on the configuration and operating conditions) is minimal and equal to 2.5 m/s.

The element that allows to uniquely distinguish a Tag or a BLE device from another is represented by Bluetooth Device Address: similar to the MAC Address of Ethernet devices and made up of 48 bits (6 bytes). Typically, the unique code of each BLE sensor cannot be modified by the user. Moreover, the BLE technology allows automatic monitoring of the tags present in the radio coverage area of the device monitoring (e.g., smartphone); it can work in the background with the receiving APP which can notify the tags entering or they leave the area. This function appears to be particularly suitable for the purpose of the project as it allows citizens or bodies competent to receive notifications in real time.

The main operating systems natively support BLE technology and to date 95% of mobile devices (smartphones, tablet, etc) are enabled for communication with this standard. The security functions are performed by the Security Manager, a set of protocols and algorithms designed to provide the Bluetooth Protocol Stack the ability to create and exchange security keys; it is these keys that allow two devices to communicate securely through an encrypted link (AES), verify the identity of the remote device and, if required, they obscure the Bluetooth Device Address to prevent devices with malicious intent from track/locate a particular device.

Finally, the use of sensors in BLE technology allows many advantages, including:

- Simple and quick installation due to the small size of the tag;
- Easy set up installation;
- Minimal maintenance (apart from periodic battery replacement);
- Firmware updates via OTA (on models that support this feature);
- Low costs for installation and maintenance activities.

Having individuate the technology BLE as the one to apply, we tested many sensors BLE:

- BleBulbe beacon is a Bluetooth Low Energy proximity beacon, based on new-generation BLE chip NRF52;
- Smart Beacon designed for indoor/outdoor IoT applications;
- RFID BLE Active-Tag at 2.45 GHz.

The last one has better features for our Use-Cases (see Figure 6) with a reading range of more than 100 meters, a good battery life (3-5 years), a good robustness and limited cost and weight (65gr).

Figure 6: The active RFID selected (source: Idnova srl)

4.2. The Software Platform

At the software level, a Database schema was created and a framework for managing user authorizations was defined.

The system is made up of two parts, an app for smartphone and a web back end/dashboard from which the individual sensors are inserted, their location is specified and the messages to be sent are set, as well as their type of alert (success, warning, danger and other info) and duration (permanent or temporary) (see Figure 7).

In the case of a temporary message, the period of validity of the message is indicated. All the APIs developed for the Project have been documented through the Swagger framework. So, one is able to insert the communication functions also in existing smartphone applications (examples are the Apps especially developed by a port Authority for its customers, or by a City for the citizens), so as not to weigh down the 'app fleet' of each single user (see Figure 8).

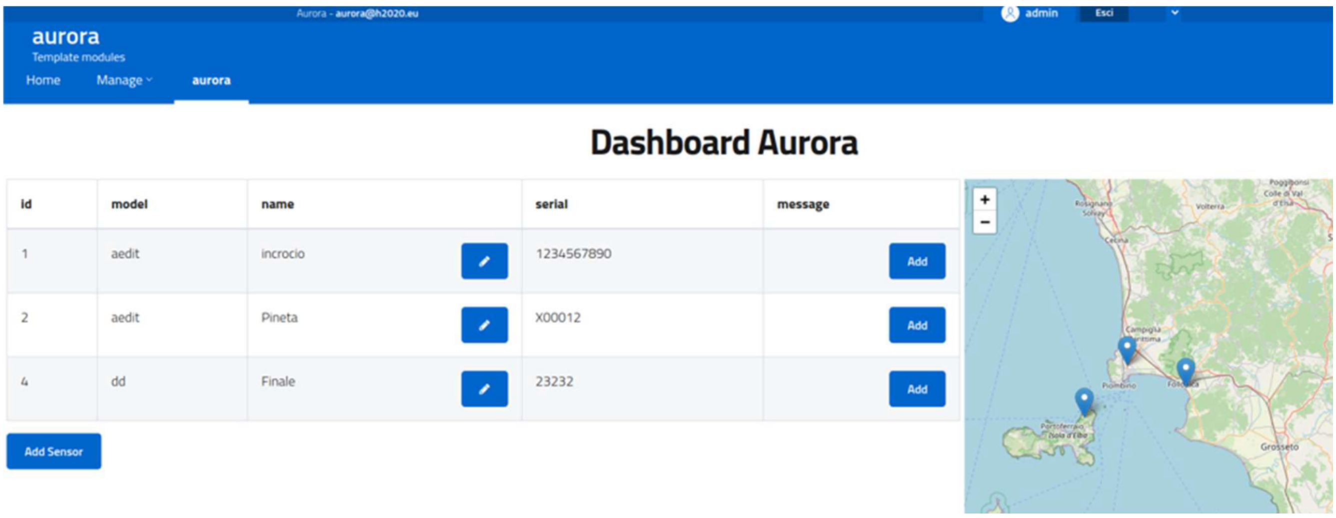

Figure 7: The back-end to organize messages and sensors locations

A first prototype of a very simple APP has also been developed which scans all the Bluetooth in the vicinity. Once scanned, if it finds a "known" Bluetooth, the system shows the message contained. Figure 8 shows a screenshot of the App with the message (the same message arrives with a simple notification in the smartphone).

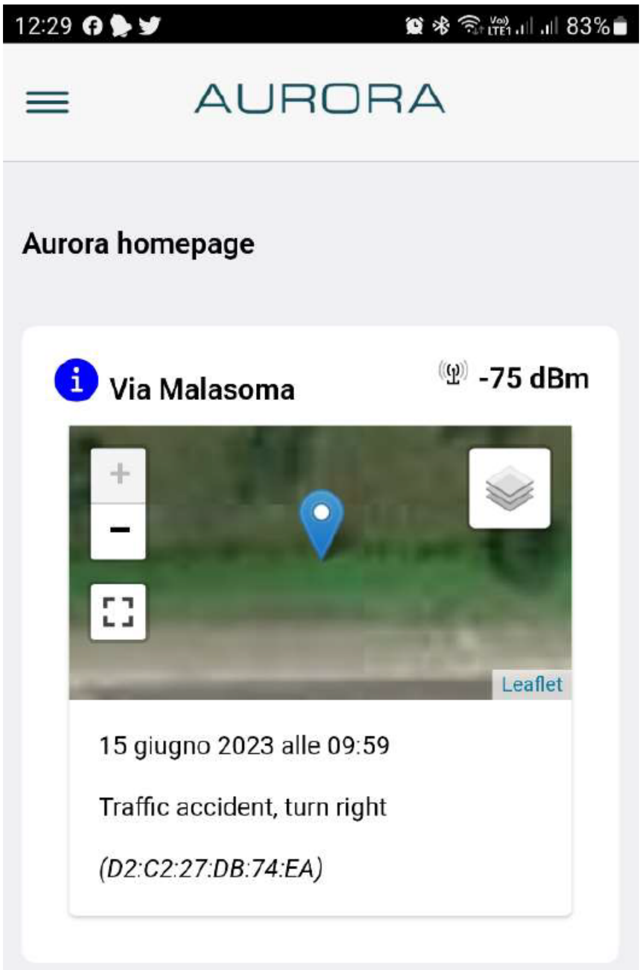

Figure 8: An example of the message received by any single user

5. Conclusions

The use of drones to communicate with citizens in emergency situations seems to be one of the most interesting applications in the future [3]. The growth of the internet and smart hone technologies will bring quick development of this application to find missing people in mountain areas or in case of environmental disasters [4]. The application involves several fields where there are risks due to dangerous goods movements [5], to citizen crowds [6] or other. A related application is the provision of monitoring system to study citizen behaviour in case of disaster or other emergency situations [7], even extending to an indoor environment [8], [9]. The developed platform can be a first step towards further services.

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Authors' Biography

Antonio Pratelli is a professor of Transportation Planning and Traffic Studies at the Faculty of Engineering of the University of Pisa (Italy). As a visiting professor of transportation network analysis, roundabout intersections design and highway safety, he has given lectures at Iowa State University and the University of Kentucky (USA), the University of Bahrain (BH) and the University of Zagreb (HR). In June 2011, *"for his outstanding contribution to transportation engineering"*, he was awarded the prestigious WIT Eminent Scientist Medal by the Wessex Institute of Technology (United Kingdom).

Lorenzo Brocchini is a postdoctoral researcher specializing in Civil Engineering, with a focus on Traffic and Transportation Engineering. He has significant experience in traffic dynamic simulations, urban network analysis and sustainable logistics planning. Today, he is a member of research teams at the University of Pisa (Italy) and the University of Avignon (France), where collaborates on important strategic research projects funded by the European Union requiring knowledge and practice of advanced methodologies based on GIS modeling tools and dynamic software applications.

Reginald Roy Souleyrette is the Commonwealth Chair Professor of Transportation Engineering at the University of Kentucky (USA), where he is also the program manager for planning and decision analysis at the Kentucky Transportation Center. To date, he has successfully completed several sponsored projects for USDOT, State DOT, local transportation agencies, foundations, and private transportation companies, with a focus on traffic data, highway safety, and rail engineering. He is also a fellow of the Association of Traffic Safety Information Systems Professionals and a fellow of both the American Society of Engineers (ASCE) and the National Academies' Transportation Research Board (TRB).

Teng Wang is a leading research professional with a PhD and a Professional Engineer (PE) license from the State of Kentucky (USA) focused on civil engineering - transportation. He is a member of the Transportation Research Board (TRB) and an experienced research engineer with a proven track record in civil engineering and his main fields of interest are focused on statistical analysis of traffic data, highway planning and road safety, traffic remote sensing applications, and railway engineering. Currently, he also serves as a reviewer for several internationally renowned scientific journals in civil and transportation engineering.

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