Advanced Research on Information Systems Security, an International Journal

# Secure Services Integration and Edge Computing for Effective Beekeeping

Luís Ferreira [a]*, Hugo Lopes [b], Carlos Abreu [c], Manuela Cruz-Cunha [d], Nuno Mateus-Coelho [e]

*[a] 2Ai – Applied Artificial Intelligence Laboratory, Polytechnic Institute of Cávado and Ave, 4750, Barcelos, Portugal*

*[b] LITEC – Innovation and Knowledge Engineering Lab, Optimizer, Oporto, 4000, Portugal*

*[c] Polytechnic Institute of Viana do Castelo, Viana do Castelo, 4900, Portugal*

*[d] 2Ai – Applied Artificial Intelligence Laboratory, Polytechnic Institute of Cávado and Ave, 4750, Barcelos, Portugal*

*[e] IPGT- Polytechnic Institute of Management and Technology, V.N. Gaia, 4400, Portugal*

*[a]Email: lufer@ipca.pt*

*[b]Email: hugo.lopes@optimizer.pt*

*[c]Email: cabreu@estg.ipvc.pt*

*[d]Email: mcunha@ipca.pt*

*[e]Email: nuno.coelho@islagaia.pt*

**Abstract**

Many of the issues that require resolution are not easy to mitigate just from the technology perspective. The ancestral learned logic of processes, the people traditions, and many other variants, define inner contexts that make the adhesion and efficient use of information technologies a delicate process. The enormous geographical dispersion of the beekeeping economic activity, the mostly amateur profile of beekeepers and the specificity in the traditional way as the activity is managed, compromises the applicability of integrative measures based on ICTE. An efficient and integrated management of a no-professionalized economic activity depends on two basic principles: i) the existence of effective tools capable of managing that activity and its synergies with other related activities, and ii) an infrastructure (technological, procedural, legal) that supports services properly profiled for any actor in that activity. This paper describes the work-in-process sBee - Smart Beekeeping, an applied research project that sought to integrate emerging technologies on the innovative management of critical issues that beekeeping needs to overcome. Electronic devices, Internet-of-things, advanced management algorithms and innovative visualization services were explored. The global system architecture, its supporting services and the communication infrastructure are here described. The integration of both internet-of-things and communications services, with the common beekeeping's management tasks, levered a proposal for improving this activity to become more effective. Furthermore, an advanced technological supporting platform was created and experimented, prepared for further developments, on mitigating emergent challenges that the digitization promotes, namely the security and traceability on food and related agriculture value-chains, as well as on the predictive and intelligent perception of current and future scenarios.

***Keywords:*** Business Integration; Effectiveness; Federated Social Network; Cloud Computing, LoRa, Internet of Things (IoT), Beekeeping, Beehive, Edge Computing.

---

* Corresponding author.

## 1. Introduction

The wave of digitalization represents the focus and base of many purposed solutions of computer engineering. Indeed, nowadays Information, Communications Technologies and Electronics (ICTE) shows, daily, new possibilities of its application and exploration [1]. The increasing: i) accuracy and sensing capacity of electronic devices and the capacity to retrieve and process the data they generate [2]; ii) possibility to integrate those devices with high capacity of data processing tools [3]; iii) capacity on those devices to implement edge computing models to reduce latency and improve efficiency [4]; iv) distance and quality for sending data with long range communication protocols [5]; v) availability of tools to analyse patterns on behaviours, towards the prediction of events, using artificial intelligence, and vi) the green energy offer and low consumption required [6], represents the current and emergent technological framework that information system architects and engineers can explore, in nowadays.

Nevertheless, each problem's domain has its own particularities and requirements that represent new challenges for matching specific and appropriate solutions [7]. Even more when some requirements are not at all tangible [8] since they are inherent to people, as human beings. Many times, the identified requirements do not fit, effectively, the practical needs.

Beekeepers face every day demands for efficient management of their activities: each intervention steps; what apiaries must be visited and what must be done there, in each hive; what material should be taken or to buy timely for each intervention; bee health treatments; honey harvest preparations [9], honey market fraud precautions [10], among many others requirements that could be here enumerated. Indeed, there are already a lot of technological solutions for distinct platforms (web, mobile, desktop, others) for hives monitoring, for the activity management, etc., aligned with the basic activities that a beekeeper support. However, not considering the usual high costs, most of it are quite distant for the real context of these activities, requiring from the beekeeper much more than he can give Many solutions have so many services that are sufficiently difficult or no relevant enough to be used. In some applications it is clear the gap between the developers and the persons that will use it, a common problem on Software Engineering.

The multi-sided platforms appeared as technologies, applications or services, that created value by enabling and facilitating direct interactions and/or transactions between affiliates [11], playing an intermediation role between all business process stakeholders. Maybe the existing beekeeping solutions started with that purpose, however, the feedback received from those who did try to use it, does not sustain that. For instance, many of the beekeepers that has more than one hundred of hives, did not even try to use it. Indeed, a very common strategy was followed by almost all applications, where new solutions arise, trying to add new features (or services), towards a differentiated offer. However, this approach can be a strategic failure since carries the risk of creating a complex solution (or service) with an inexplicit add-value to the end-user and, consequently, a poor user experience, compromising the expected favorable scenarios, as it is the announced by the Blue Ocean Strategy [12]. As has happened in many different domains, if solutions are getting in the way instead of helping, they're set aside. The beekeeping is a very practical and conservative activity that requires easy processes, and thus, easy used tools.

Considering the EU report [9] facts that: i) *"(...) whereas the beekeeping sector is crucial for the EU and makes a significant contribution to society, both economically with around EUR 14.2 billion per year and environmentally by maintaining ecological balance and biological diversity, since 84% of plant species and 76% of food production in Europe depend on pollination by wild and domestic bees (...)*"; ii) *"(...) more than 620 000 beekeepers in the EU ... in an activity widely practiced in leisure time or for personal consumption…(...)*"; and iii) *"(...) not all countries have a system for registering beekeepers and hives which facilitates the monitoring of developments in the sector, the market and the health of bees (...)*", it sustains the relevance, pertinence and opportunity to explore an efficient ICTE integration, and, knowing that *"(...) the beekeeping sector suffers from a particularly serious demographic and ageing problem, with only a small percentage of beekeepers under 50 years of age, which calls into question the future of the sector (...)*", will, for sure, difficult and compromises the applicability of integrated measures based on ICTE, which intend to guide, control and regulate the activity as a whole. Thus, the starting point is a serious challenge!

Considering the relevance of this economic activity for the national economy, and according to existing problems, the Portuguese national government decided to support research and development initiatives to mitigate problems and improve the beekeeping activity. Exploring the cloud infrastructures, the long-range communications potential, the Internet of Things emergent' s capabilities, the high-performance computing (HPC) processing and artificial intelligence (AI) application, allow the specification and prototyping of an integrated platform, technologically advanced, but sufficiently prepared to be used and valuable for most of the beekeepers.

The expected result of this applied research represents an integrated and distributed platform with a set of tools and services of real significance for all involved entities, namely: a) for those entities directly involved: i) a distributed and integrated ICT platform for the national beekeepers ii) a federated social network to support the interoperability of all beekeeping stakeholders (beekeepers, associations, authorities, insurance companies, suppliers, clients, others) [13]; iii) specialized electronic devices for remote monitoring and sensing, both the beehives ecosystems and apiaries surround areas [14]; iv) an active and transparent support for the on-site security service [15]; and, v) a set of innovative and effective services to support decision-making, predicting bee behaviour, anticipate corrective measures; facilitate the management of interventions; traceability of products; and b) for others entities, including academic environment and competences centres in innovation and research, will have data acquisition and processing services for monitoring and decisions control [16].

In this paper the authors describe the most relevant details on the development of sBee – Smart Beekeeping, the analysis and studies, the main achievements, and final contributions. The paper is structured as follows. Section two presents the essential background related the problem domain. Section three presents the engineering process that sustained the research and prototype development, flowed by the prototype exploration, and the obtained results exposition, on the section four. The paper finishes on section five, with the conclusions and further work perspectives.

## 2. Background

The current and emergent technological framework presents a significant set of potentialities that allow the projection and definition of an innovative system architecture for fitting the identified requirements. The main technological areas that sustain the proposed platform reside in the sensing capacity, communications possibilities, distributed processing, analysis, and multimodal utilization.

### *2.1. Information Technology and Beekeeping*

The information, communication and technology offer enormous challenges and opportunities [1]. The distributed capacity for processing huge amount of data, the easy communication support among distant and distinct devices and entities [17], the increasingly capacity and accuracy on getting data from local and remote sensors [18], the capacity to analyse high volume of data and predict incoming events [19], allied with the each more concern with green technologies and energy-efficient low power consumption, supported by the European Green Deal proposal [20], represent a great technological framework for sustaining an innovative solution for environment sensing and monitoring. The beekeeping can take advantages of that framework.

In beekeeping activity participate several distinct actors, some directly involved (beekeepers, associations) and others with a less evident participation, such as the authorities (health, security, etc.), civil-protection services (Firefighters, INEM), commercial agents (suppliers), insurance companies, municipalities.

According to the Portuguese study [21], *"(...) the beekeeping sector in Portugal, as in the rest of the European Union, is an activity traditionally linked to agriculture, normally seen as a complement to the income of holdings, (...)*". Being a socio-economic activity far from professionalization, it lacks principles, both in the explored business model and in the dynamics that regulate it, and tools for efficiently managing and controlling it.

An efficient and integrated management of a generally non-professionalized economic activity, is based on two basic principles: a) the existence of efficient tools for managing the activity and existing synergies with other [22], and b) an infrastructure (technological, procedural, legal) that offers effective services, i.e., supports pragmatic services for any stakeholder in the activity [23].

There is already a significant set of solutions for the apiculture sector, both national and international, that make use of ICTE. However, either by the report of the Portuguese National Beekeeping Plan (PAN) [21], or by the analysis of the results of the last global beekeeping meeting in Montreal [24], as well as from the feedback of the beekeeping associations and beekeepers, the following conclusions can be draw:

- Some solutions are relatively old and have never been able to "penetrate" the field of this activity in any obvious way.
- The most modern applications present a set of services developed without the active participation of the potential customers in its specification. They therefore become heavy and complex applications whose feasibility of use is reduced.
- Practically all applications represent isolated initiatives that have not been developed to integrate with other

ones. In a real scenario, a beekeeper needs to use more than one application, with redundant information among them.

- Many applications, although graphically and technologically well sustained, do not have services considered essential to make an effective IT platform.
- Practically all applications do not have the capacity for expansion or services adequacy, being dependent on the entities that developed them, under maintenance and support contracts.

### *2.2. Related work*

As applied research must be conducted based on problems that need to be solved, applications such as Mellarius - (http://www.mellarius.net/), BeeCloud - (http://beecloud.co/), HiveTracks - (https://hivetracks.com), are good references and give interesting guidance for the analysis and specification of new solutions. Sensing hives internals' ecosystem, anti-theft approaches, georeferencing of apiaries, data analysis reports and many others, can be services already supported, but are spread in different applications or not efficiently integrated, making them difficult to use or even useless. Assessing both existing applications as well as the opinion of the people who use or tried to use it, the requirements that need to be developed, corrected, improved or even avoided, were identified: i) the difficult registration of hives; ii) planning interventions and deciding what material to take; iii) the inability to use the application on site to record the intervention made in each hive; iv) the way in which intervention records are made; v) the inability of support at the site from the association's technician, are examples of difficulties to which existing solutions are unable to respond.

Similarly, platforms such as APISIG/FNAP (http://fnap.pt/projectos/projecto-apisig/), APIMAP (http://www.apimap.fr/uk/), SunCalc (http://suncalc.net/), among several others, that efficiently cross botanical, climatic, legal, and other issues, constitute important services that are available but are not integrated and not easily used. All these solutions have proven and recommended usefulness, so their use or, in some way, integration in new platforms, will certainly bring important added value. Georeferencing apiaries, support and monitoring of transhumance activities, orientation of apiary infrastructures, prevention against environmental problems (fires, weeds, favourable botanical conditions, etc.), control of legal areas, etc., will become tasks properly supported and monitored.

With the advent of Internet of Things (IoT), the sensing capacity increased a lot [25].The spectrum of use sensing devices has extended significantly, and several domains have solutions that explore it. The Agriculture is one that has benefited greatly [26]. In addition to wireless sensor networks (WSN), the IoT success comes from, on the one hand, the distributed increasing capacity of processing infrastructures, and on the other hand, the increasing communications possibilities and performance. The cloud infrastructure sustains the former [27] argument and the low power and long-range communications the second [28].

Having a large set of sources of data and the efficient capacity to transfer it from long distances and in an easier way, promotes the huge amount of data to be processed [29]. With data, getting useful information and better decision support, is a must. All these processes come possible with Data Science algorithms and tools, where great amount of related (or not) data can be analysed and existing relevant information retrieved, timely [30]. Big Data algorithms are suitable for such services [31] and effective dashboards are needed and possible to develop [32], since interesting and efficient data visualization libraries are emerging.

Nowadays mobile devices are quite spread and integrated as common tools, what makes them the perfect and preferred tools to be used anytime and anyplace [33]. So, the new applications must be prepared to fit any existing interaction equipment, allowing users to use the applications, transparently. For that, the responsiveness and multimodal behaviour of applications must be supported [34].

The capacity to handle occurrences, recording data and results, either using text, voice or video, exploring synchronous communication channels [35], allowing multi-side platforms for collaborative co-creation between beekeepers [36], are the main challenges to be achieved. The expected pragmatics services for a natural and active participation of beekeeper, will be possible.

## 3. sBee Platform

sBee represents a step forward for beekeeping activity, an innovative distributed and integrated platform developed following the more recommended techniques and processes of software engineering, but essentially simple to be used by beekeepers, usually very busy, conservative, and resilient persons to new technological solutions. Its development involves three main domain engineering areas, namely Computation, Electronics and Telecommunications, and Usability. It intends to be a disruptive solution, beekeeper-cantered, based on the cloud computing and the Internet of Things paradigms, prepared for continuous development and integration with third-party solutions. The platform allows the beekeeper having an active and effective participation on the platform.

### *3.1. Requirements and System Architecture*

Beekeeping is a very ancient activity with several cultural and regional and influences, as well as with very traditional ways of dealing with. Creating a new and revolutionary application can simply means no success at all. The direct involvement of beekeepers on the requirements analysis and identification, allowed the specification of a solution that helps the beekeeper on the, considered by them, essential services: (i) registering hives and apiaries; (ii) managing the diary agenda of “where and what to do each day”; (iii) managing “where and what have been done”; and (iv) be alerted and informed.

Figure 1 shows the global system architecture with the main logical components for the main requirements supported: remote management and local apiary/beehives interventions registration (A) – Beehive body, (B) – Beehive honey super).

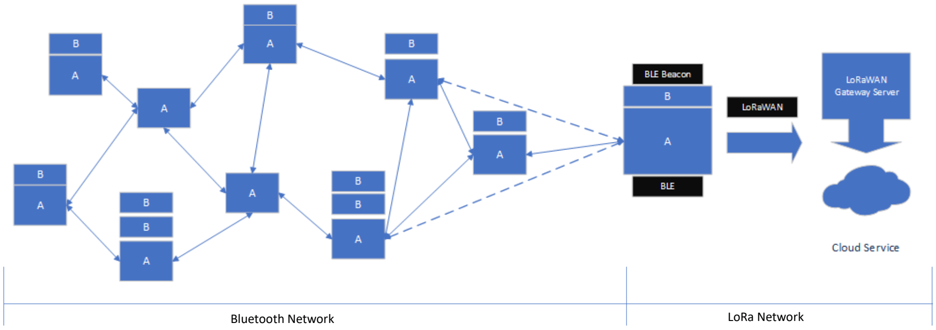


**Figure 1** - sBee System Architecture

One of the main features to be supported by sBee is the communicating capacity involving hives-apiaries-beekeepers. The need to have data for getting useful information, depends on such capacity. For this purpose, special devices were designed and prototyped: i) a hive IoT Infrastructure (node); ii) a communication network infrastructure in the apiary (Figure 1, Bluetooth Mesh Network) and iii) a communication network infrastructure for the interconnection between apiaries (Figure 1, LoRa Federated Network). The base for this architecture relies on the need to have almost real-time data sensing directly from all hives and apiaries, remotely. Being apiaries dispersed and distant, a long-range communications protocol was explored, and low energy consumption devices applied.

Considering the services, the solution was designed to support: i) communicational and integration services; ii) distributed and integrated information system and iii) recommendation and decision support systems. In the field of usability, sBee was projected to support responsible interfaces, simple user experience and effective services for local interventions.

### *3.2. Electronic sensing, processing, and communication*

The type of communication, the type of sensors and energy consumption were the most critical communicational features stated in the beginning. The distance between hive/hive and apiaries/apiaries can be in the order of tens of kilometres and the capacity to have feedback from those locals, remotely, was a must.

After some study and reflection on the existing communication technologies, two were chosen to be explored: i) LoRaWAN; and ii) Bluetooth® Low Energy (BLE). As both technologies were available for prototyping, we started the proof of concept to demonstrate hive/apiary identification and communications in a small apiculture domain. That system was characterized as follows: i) a LoRaWAN Gateway Server at a point with internet access to communicate via cloud services (this device is able to put all the apiary data to be later managed with specific API); ii) a Secondary Gateway, in a hive that will carry out the communication between the Gateway Server and the other hives in an apiary (this has a LoRaWAN chipset and another Bluetooth Low Energy as the Master function). This set foresees that the hive where this device will be installed is a few kilometres away from the Gateway Server and that the shortest distance between another hive is less than 100 meters. It will communicate directly with the Gateway Server through LoRaWAN and with the adjacent hives via Bluetooth Low Energy, being also able to recognize the placement of handles in the hive where it is installed. It will have also the capacity for sensory control (temperature, atmospheric pressure, CO2 levels, etc.); iii) The hives adjacent to the main hive will be equipped with a Bluetooth Low Energy chipset that allows the hive identification, sensory control and the identification of honey or shallow supers (if any). Communicate directly with the main hive or via network using a local Bluetooth mesh network; and iv) All handles have a device with a Bluetooth Low Energy chipset, implemented as beacon, which allows each handle identification. It may contain sensory information.

The implementation of a mesh network in BLE devices is relatively recent and, therefore, it becomes a challenge to create an API that adopts this model without complicating the whole system and consequently affecting other parts such as the energy autonomy or the addition of new equipment in the network itself.

It is imperative that devices have unique ID and consume as little energy as possible. In this sense, the approach of a final device adopted a strategy of a beacon model that is Ultra Low-Power. This beacon must be recognized by another device that can send messages to the LoRa Gateway directly or indirectly.

The protocol that supports the communication between all apiary nodes and remain parts (ex. the local weather station) of the system, handled a specific physical frame of data composed of the delimiting characters "!", "?" and "#". Next follows an example of such frame.

```
605367057C1054DD#node_WS#84#HALL:0#ROUT:0;0;0#WF:10.712#RIN:SE#NO:20.480#ETO:66.6
18#H2:101902.810#BAT:100-4-1+0
```

where:

605367057C1054DD: chip serial number

node_WS: chip name

84: number of readings

HALL: Anemometer in km/h

ROUT: Pluviometry in mm/h

WF: UV rays in m-2 s-1

RIN: Wind direction

NO: Temperature in °C

ETO: Humidity in %

H2: atmospheric pressure in Pa

BAT: 100-4-1+0: Battery information: is at 100 %, at 4 Volts, 1 means it is charging, 0 means it is not charging, 0 mA which is the current the panel is supplying.

Considering the dynamics of the apiary, where hives can be moved, inserted, or even removed, the algorithm that parses the frame considers:

When a new device "1" or "2" appears, it is communicated to the Gateway in the form "!XXXXXXXXXXXXXX" where XXXXXXXXXXXX is the MAC Address (ID) of the device that has entered the system. In the case where device "2" has already entered the system, but there has been a change in the temperature sensor, it is communicated in the format "#XXXXXXXXXXXXXXXXXAA" where XXXXXXXXXXXXXX is the MAC

Address (ID) of the device and AA is the new temperature value. When any of the devices per chance disappears, either by range or by loss, or even by lack of battery, it is communicated in the form of "?XXXXXXXXXXXXXX", where XXXXXXXXXXXXXX is the MAC Address of the device. This last part will be used also for the active system's security, so that the user is able to tell if there have been serious changes in the system.

According to the architecture defined a priori (Figure 1), fully functional prototypes were developed for the different types of devices that make up the same, proving the viability of the system (Figure 2). Although the equipment provided did not allow the construction of a model as detailed, due to the quantity as well as the quality, it is expected that, when expanding the network, system's behaviour will not change.

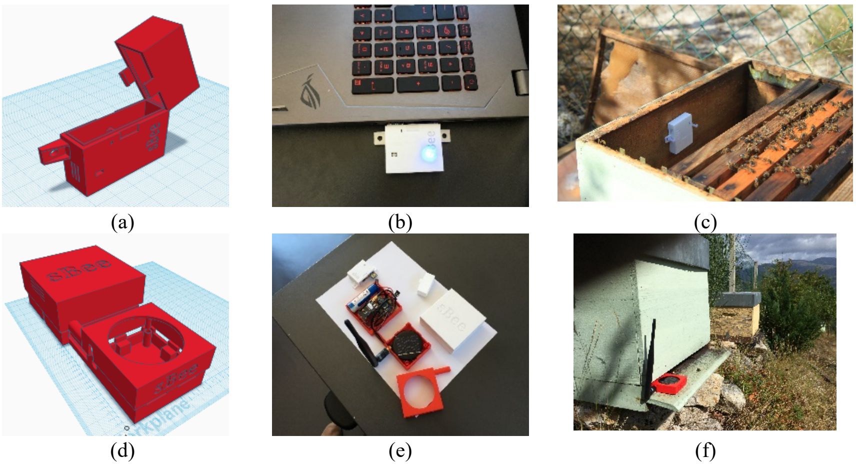


**Figure 2** - Models and prototyped devices

((a) – model for honey super device; (b) and (c) –honey's device; (d) – model for hive body device (e) and (f) - hive body device

Since the central device (Master Hive) must be able to communicate frequently the global apiary data, it will be the device with the least energy efficiency. Considering this, it was decided to place a rechargeable power supply using solar panels (Figure 2 e) f)). Once the entrance to the hive will normally have a lot of sun exposure and it is a more discreet place, this part of the box contains only the solar panel with the antenna and the connection is made through a fitting to the inside (Figure 2 f)). We could see that, in real context, the box fits perfectly inside the hive and only three frames of the beehive were temporarily removed to place it. This part contains all the apiary management hardware. After placing this device in the master hive, the other devices can be placed in the remain beehives of the apiary.

The small size one (Figure 2 b) c)) device is prepared to be used for both parts, in each beehive honey super or in the beehive-body (each hive can hold a hive body and up to 4 honey supers, which in turn can hold about 10 honey frames (Figure 3)). It has also the ability to collect sensory data, if desired.

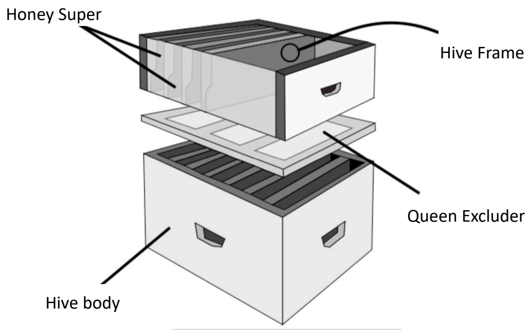


**Figure 3** - Beehive components

(Adapted from https://alexwallselt.com/2021/04/04/ielts-reading-diagram-labelling/)

This is very relevant to sustain the scalability costs. For instance, in the year 2015, in Portugal the average of hives per professional beekeeper/apiary was 59, according to the last national census [21]. Considering the minimum devices for each hive is 1 (b) in the hive body and 1 (c) by each honey super, a single beekeeper with 1 (a) apiary that holds 50 (b) hives, with no devices on hive frames (d), will require 1*50*2 = 100 devices (Equation 1), by apiary. Imagine the case where professional beekeepers deal with more than one hundred of hives!

$$TotalOfDevices = (a \times Apiary) \times ((b \times HiveBody) + ((c \times HoneySuper) + (d \times HiveFrame))) \quad (1)$$

### *3.3. Beekeepers Federated Social Network*

The sBee system represents a distributed solution whose participation must be duly authorized. Each participant will have a certain profile (beekeeper, association, authority, supplier, other). Once registered in the platform, it will have a set of services that allow him to interact with other registered members. The platform is prepared to integrate multiple synchronous communication channels such as video, audio, or chat, as well as asynchronous, like email and SMS. In the developed proof of concept, the communication via email and SMS was explored.

This component of the sBee represents the multimodal frontend of the platform. A Backoffice supports the set of its management services. Objectively it was instantiated in a web and mobile applications.

This Federated Social Network represents one of the innovative services of this platform. Any time, anyway, all beekeepers can be informed and, if necessary, checked by associations, authorities, and others. Remote help from health or veterinary authorities will be possible and in accident situations, the help from Civil Protection, can be easily required and the path to get the local, georeferenced. Customers and suppliers will beneficiate too for this network.

Summing up, all stakeholders, direct or indirectly involved, will have an integrated set of communicational services for helping beekeeping management and controlling, essential for its sustainability and support for the certified quality of bees related products.

### *3.4. Management Application*

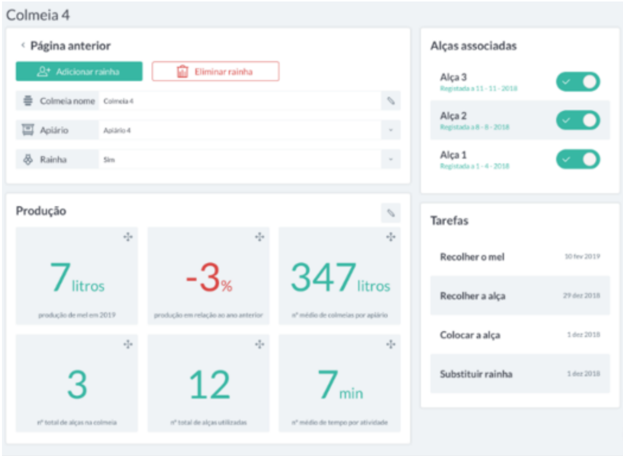


**Figure 4** - Hive dashboard with management services

The research allowed a concrete prototype that support all main objectives, namely sensing, communication and management: i) a set of prototyping electronic devices for hive and apiary management and for long distance data communication was completed (handles, hive box and apiary gateway); ii) a software solution to support the distributed platform is available (http://sbee.pt) (Figure 4) and, iii) a set of integration and expansion RESTful and Microservices (API) are there to enhance future developments or, to be explored by others application that intend to use or to integrate with sBee (Figure 5).


**Figure 5** - API for handling interoperability and future developments

## 4. Experimentations

Several experiments were prepared for the proof-of-concept validation. The external weather sensing (temperature, humidity, etc.), nodes communication and range, and activity management were the main explored domains.

### *4.1. Sensorial Data*

A minimalist weather station was created to get the external environment data, namely temperature, wind intensity and direction, as well as humidity. The communication was supported by LoRa (Figure 6). An example of the generated frames was presented earlier in this document.

**Figure 6** - Weather station and LoRa device

### *4.2. Communications*

Considering the communication, two experiments was conducted in real context. One focused the communication management between hives, and the other focused the communication range assessment.

In the first experiment, all three devices were placed in real hives (Figure 7 a)): i) device "1" (Figure 7 b)) containing only an ID and placed into a hive-body; ii) device “2” that contains an identification and a temperature sensor, placed in a hive box (Figure 7 b)), and iii) device “3” was insert in a master hive, which collects the data sent by the other devices “1” and “2”, and communicates the data to the gateway LoRa (Figure 7 c)).


(a) – three eletronic devices (b) – Honey super device (c) – Master Hive gateway

**Figure 7** - Experimental communication devices

In this experiment, a frame (string) is sent to the Gateway with the sensing data gathered from the devices. This frame allows to observe the system’s behaviour, namely when devices’ sensing data change. In the case the of any hive interior variants change (like temperature, humidity, etc.), the corresponding MAC Address of the device and the new variant value are sent to the gateway.

A publish-subscribe middleware using a MQTT broker was created to allow the dashboard display of the data gathered from all devices (weather station, beehives) (Figure 4). Next excerpt of code represents that broker configuration.

```
#!/usr/bin/env node
var mqtt = require('mqtt');
var Topic = 'application/+/node/+/rx'; //subscribe to all topics
var Broker_URL = 'mqtt://loraserver.digiheart.pt';
var Database_URL = 'localhost';
var options = {
    clientId: 'MyMQTT', port: 1883, username: 'estipca', password: '*******', keepalive: 60
};
```

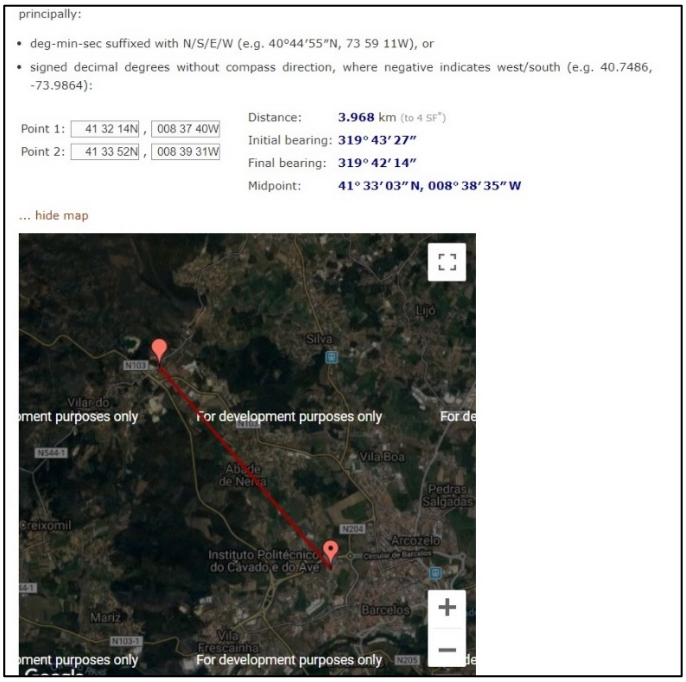


**Figure 8** – Communicating range tests

To explore the communication range, a Node-Red based logger was used to store all the messages received by the remote device. After moving the remote device, the "maximum" of the distance obtained was almost 4km (Figure 8).

### *4.3. Management*

The management of beehives in the apiary is one of the most important tasks for any beekeeper. The experiment fully demonstrates the capacity to automatically:

i. *register any new beehive*: when a new device was inserted in a new beehive, immediately was recognized as member of that apiary mesh.
ii. *notify for any existing beehive that "stop working"*: when working devices were disconnected, the

dashboard immediately shoes an alert on their beehives.

iii. *be actively secure*: when an existing beehive was moved for distances out of the range, the dashboard immediately alerts for “removed” beehive!

## 5. Conclusions and Further Work

The beekeeping is a very traditional economic activity that is superiorly recognized as essential, that receives considerable investments but, indeed, deals daily with critical problems. The effective use of ICTE

for contributing to overcome some of those problems, was the challenge and main goal of sBee – Smart Beekeeping, the project that this paper presents.

Besides the existence of several technical solutions, the prevalence of important services that were not supported, made relevant this project, and sustained the financial support of Portuguese government entities. An electronic platform for managing all beekeeping activity, including beekeepers, associations, authorities, and other participants; electronic devices for sensing and monitoring hives and apiaries; and a set of services for helping the beekeeper's daily life, getting information, and supporting decision taken, are the main contributions of sBee. The existence of an SDK API assures the required integration with third solutions. New services can be developed, or existing ones can be integrated in different solutions.

The solution must now be implemented on real scenarios for real efficiency and effectiveness, in a large-scale, tests. For that, many similar electronic devices need to be developed.

For better acceptance, awareness and training plans should be prepared and offered for all beekeeping community. Once deployed on the ground, a large set of data will be available and possible to be analysed. A new infrastructure is prepared to deal with the emergent concerns announced by APIMONDIA, that are related with fraud and all beekeeping supply chain control. Exportations and importations are difficult processes that require efficient mitigation mechanisms. ICTE represents important support for that too, where, for instance, new modules of services based on blockchain technologies are already being explored to integrate sBee, towards honey adulteration combat.

All electronic devices were designed to offer some edge computing capacity, i.e., capacity to pre-process locally the sensing data. Exploring it the most and data science models’ creation are the next steps that should be done. The artificial intelligence will contribute to relevant new set of services for smart decisions and anticipation of scenarios. Beekeeping will be improved a lot if it behaves according to future events.

The project fitted all defined requirements for the expected three years of development. The supporting government entities approved the on-going achieved results, that were presented in last APIMONDIA 2019, in Montreal-Canada [24].

**Acknowledgements**

This work was funded by national funds, through the FCT – Fundação para a Ciência e Tecnologia and FCT/MCTES in the scope of the project UIDB/05549/2020

**References**

[1] S. Buchholz and B. Briggs, "TechTrends 2020," 2020.

[2] E. Gambi, G. Temperini, R. Galassi, L. Senigagliesi, and A. De Santis, "ADL Recognition Through Machine Learning Algorithms on IoT Air Quality Sensor Dataset," IEEE Sens. J., vol. 20, pp. 13562–13570, 2020.

[3] M. Noura, M. Atiquzzaman, and M. Gaedke, "Interoperability in Internet of Things: Taxonomies and Open Challenges," Mobile Networks and Applications, vol. 24, no. 3. pp. 796–809, 2019, doi: 10.1007/s11036-018-1089-9.

[4] D. V. Gadasin, A. V. Shvedov, and A. V. Koltsova, "Cluster model for edge computing," 2020 Int. Conf. Eng. Manag. Commun. Technol. EMCTECH 2020 - Proc., Oct. 2020, doi: 10.1109/EMCTECH49634.2020.9261538.

[5] J. R. Rana and S. Naveed, "Low Power Long Range Wireless Protocols for IoT Applications for Pandemic Conditions," 2020.

[6] N. Hossein Motlagh, M. Mohammadrezaei, J. Hunt, and B. Zakeri, "Internet of Things (IoT) and the Energy Sector," Energies, vol. 13, no. 2, p. 494, Jan. 2020, doi: 10.3390/en13020494.

[7] C. Kowalkowski and D. Kindström, "Service innovation in product-centric firms: A multidimensional business model perspective," J. Bus. &amp Ind. Mark., vol. 29, pp. 96–111, 2014, doi: 10.1108/JBIM-08-2013-0165.

[8] O. Shaer and R. Jacob, "A specification paradigm for the design and implementation of tangible user interfaces," ACM Trans. Comput. Interact., vol. 16, 2009, doi: 10.1145/1614390.1614395.

[9] N. Erdős, "Relatório sobre as perspetivas e os desafios para o setor da apicultura na UE," 2018.

[10] APIMONDIA, "APIMONDIA statement on honey fraud," 2020.

[11] A. Hagiu and J. Wright, "Multi-Sided Platforms," SSRN Electron. J., Jun. 2017, doi: 10.2139/ssrn.2794582.

[12] A. N. H. Hong, G. N. K. Sing, and P. Y. Kien-hong, "Blue Ocean Strategy: A Preliminary Literature Review and Research Agenda," in British Academy of Management Conference, 2011.

[13] L. Ferreira, G. D. Putnik, N. Lopes, A. Lopes, and M. M. Cruz-Cunha, "A Cloud and Ubiquitous Architecture for Effective Environmental Sensing and Monitoring," Procedia Comput. Sci., vol. 64, pp. 1256–1262, 2015, doi: 10.1016/j.procs.2015.09.240.

[14] R. Tashakkori, A. S. Hamza, and M. B. Crawford, "Beemon: An IoT-based beehive monitoring system," Comput. Electron. Agric., vol. 190, p. 106427, Nov. 2021, doi: 10.1016/J.COMPAG.2021.106427.

[15] N. R. Mateus-Coelho, B. R. Fonseca, and A. V. Castro, "POSMASWEB: Paranoid Operating System Methodology for Anonymous and Secure Web Browsing," in Handbook of Research on Cyber Crime and Information Privacy, 2021, pp. 466–497.

[16] M. Townsend, T. Le Quoc, G. Kapoor, H. Hu, W. Zhou, and S. Piramuthu, "Real-Time business data acquisition: How frequent is frequent enough?," Inf. Manag., vol. 55, no. 4, pp. 422–429, Jun. 2018, doi: 10.1016/J.IM.2017.10.002.

[17] W. Lee, M. J. W. Schubert, B. Ooi, and S. J. Ho, "Multi-Source Energy Harvesting and Storage for Floating Wireless Sensor Network Nodes With Long Range Communication Capability," IEEE Trans. Ind. Appl., vol. 54, no. 3, pp. 2606–2615, 2018, doi: 10.1109/TIA.2018.2799158.

[18] L. Ahmedi, B. Sejdiu, E. Bytyçi, and F. Ahmedi, "An Integrated Web Portal for Water Quality Monitoring through Wireless Sensor Networks," Int. J. Web Portals (IJWP, vol. 7, no. 1, p. 19, 2015, doi: 10.4018/IJWP.2015010102.

[19] S. Chae, S. Kwon, and D. Lee, "Predicting Infectious Disease Using Deep Learning and Big Data," Int. J. Environ. Res. Public Health, vol. 15, no. 8, 2018, doi: 10.3390/ijerph15081596.

[20] S.-G. European Commission, "The European Green Deal," 2019.

[21] P. e A. G. (GPP) Gabinete de Planeamento, "Programa Apícola Nacional 2017-2019," 2016.

[22] L. Varela et al., "Decision support visualization approach in textile manufacturing a case study from operational control in textile industry," Int. J. Qual. Res., vol. 13, no. 4, 2019, doi: 10.24874/IJQR13.04-16.

[23] L. Ferreira, G. Putnik, N. Lopes, A. Lopes, and M. Cunha, "Big Data and Effective Environmental Sensing," in Scientific Conference on Enterprise System Engineering, 2015, pp. 1–7.

[24] L. Ferreira, M. Matias, A. Dias, and H. Lopes, "sBee – Towards an Effective Beekeeping," in 46th APIMONDIA - International Apicultural Congress, 2019, p. 343.

[25] P. J. Taylor, T. Dargahi, A. Dehghantanha, R. M. Parizi, and K. K. R. Choo, "A systematic literature review of blockchain cyber security," Digit. Commun. Networks, no. January, 2019, doi: 10.1016/j.dcan.2019.01.005.

[26] M. Lavanya and S. Srinivasan, “A survey on agriculture and greenhouse monitoring using IOT and WSN,” Int. J. Eng. Technol., vol. 7, p. 673, 2018, doi: 10.14419/ijet.v7i2.33.15473.

[27] A. Botta, W. [de Donato], V. Persico, and A. Pescapé, “Integration of Cloud computing and Internet of Things: A survey,” Futur. Gener. Comput. Syst., vol. 56, pp. 684–700, 2016, doi: https://doi.org/10.1016/j.future.2015.09.021.

[28] A. Lavric and V. Popa, “Internet of Things and LoRaTM low-power wide-area networks challenges,” in 2017 9th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), 2017, pp. 1–4, doi: 10.1109/ECAI.2017.8166405.

[29] A. M. S. Osman and B. Bergvall-kåreborn, “Big Data Analytics and Smart Cities : a Loose or Tight Couple ?,” 2015.

[30] I.-Y. Song and Y. Zhu, “Big Data and Data Science: Opportunities and Challenges of iSchools,” J. Data Inf. Sci., vol. 2, no. 3, pp. 1–18, 2017, doi: 10.1515/jdis-2017-0011.

[31] S. K. Sood, R. Sandhu, K. Singla, and V. Chang, “IoT, big data and HPC based smart flood management framework,” Sustain. Comput. Informatics Syst., vol. 20, pp. 102–117, 2018, doi: https://doi.org/10.1016/j.suscom.2017.12.001.

[32] L. Ferreira et al., “Dashboard services for pragmatics-based interoperability in cloud and ubiquitous manufacturing,” Int. J. Web Portals, vol. 6, no. 1, pp. 35–49, 2014, doi: 10.4018/ijwp.2014010103.

[33] A. Moura, D. F. Tomás, and L. Teixeira, “Mobile Applications in Data Acquisition for Production Planning and Control: Analysis, Implementation, and Evaluation,” Int. J. Web Portals, vol. 10, no. 2, pp. 1–14, 2018, doi: 10.4018/IJWP.2018070101.

[34] J. Hoebeke et al., “A Cloud-based Virtual Network Operator for Managing Multimodal LPWA Networks and Devices,” in 2018 3rd Cloudification of the Internet of Things (CIoT), 2018, pp. 1–8, doi: 10.1109/CIOT.2018.8627134.

[35] T. Eirinha, L. Ferreira, G. Putnik, M. C. Cunha, and N. Lopes, “Extending Federated Social Networks for effectiveness in health care,” in VinOrg’15 - Fourth International Conference on Virtual and Networked Organizations Emergent Technologies and Tools, 2015.

[36] G. Putnik and C. Alves, “Learning material co-creation infrastructure in Social Network-based Education: An implementation model,” in Procedia CIRP, 2019, vol. 84, pp. 215–218, doi: 10.1016/j.procir.2019.07.003.

[37] N. M. Coelho, M. Peixoto e M. M. Cruz-Cunha, “Prototype of a paranoid mobile operating system distribution,” in 2019 7th International Symposium on Digital Forensics and Security (ISDFS), Barcelos, Portugal, 2019.