# Internet of Things Platform to Encourage Recycling in a Smart City

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## Introduction

The value that information has received in recent years is incalculable. Until less than a decade ago, storing data seemed far from having a benefit, implying a high cost that in many cases could not be assumed. Advances in computing have made the analysis of information one of the main interests for scientists. These scientists, applying traditional techniques of artificial intelligence in a distributed way, manage to extract in many cases a valuable knowledge that was previously unthinkable (Sanchez *et al.*, 2014; Zygiaris, 2013).

One of the main sources of data generation that can lead to great benefits is the city. The beneficiaries are their citizens. According to numerous studies (Chamoso *et al.*, 2018b), cities can generate large amounts of daily data, spread across a wide range of sectors. The sectors of energy, traffic and public transport, services or public administration are just examples of sectors that can greatly benefit from the analysis of information generated in a city.

Over the last few years, different studies have been carried out to create distributed platforms adapted to recover that information, process it, and put it to the benefit of citizens through different applications. Some well-known examples are the platforms deployed in cities such as Barcelona (Bakıcı *et al.*, 2013), SmartSantander (Gaur *et al.*, 2015), or Málaga (Carillo-Aparicio *et al.*, 2013). However, there is still no standard that has been taken as a model to follow when deploying a platform that turns a city into a smart city; even within these vertical platforms there are many modules that can be developed from the layer applications such as applications that encourage citizens to carry out beneficial activities for the community.

One of these activities may be to encourage the users of a city to recycle waste. And it is necessary to implement solutions to the problem of what to do with garbage. The vast majority of European countries have adopted measures to recycle this waste (Candanedo *et al.*, 2018; Rivas *et al.*, 2018b).

One of these measures was the creation of urban waste treatment plants to manage the waste generated in the cities. However, for these plants to perform their recycling function it was necessary to develop a waste collection network. In the European Union (EU) there is no common method in waste management. Some countries have deployed a series of colored containers in which the user introduces the waste according to its type; in other countries it is in supermarkets where the consumer is allowed to deliver a series of waste and packaging for recycling. The use of these measures has allowed the recovery of numerous tons of garbage that were previously completely discarded in landfills, obtaining numerous benefits for both humans and the environment.

One of the main disadvantages of these systems is that the recycling of waste is often done altruistically, so it would be interesting to develop a mechanism that encourages this recycling to turn our cities into smart cities. This mechanism can be a module of a smart city platform with those mentioned above or a platform in itself, which can obtain its own data, process it, and make decisions. That is why this article proposes a platform based on agents that take care of all the processes that an Internet of Things (IoT) platform must incorporate to be incorporated in a smart city. The platform of agents thanks to the use of a gamification algorithm performs the task of encouraging users to recycle waste and communicates with the users' mobile application for bidirectional communication processes and that the user knows the state at all times of the achievement of the challenges.

The rest of the paper is organized as follows. The section "Related Work" contains all the works related to this article. The proposed system is shown in the section "Proposed System." The section "Simulation Results" presents the main results of our model and the Conclusion shows the conclusions of our findings.

## Related Work

This section reviews the three concepts on which the proposal is based (recycling methods, gamification, and IoT platforms). First, the current methods of recycling in the EU are presented, then the advantages of gamma techniques are shown, and finally the IoT platforms that allow the incorporation of gamma techniques for the encouragement of recycling and how these techniques will help us to increase citizen participation.

### Recycling Methods

To prevent large quantities of waste from being deposited in landfills and being converted back into useful materials, it was necessary to develop methods that would allow this waste to be collected separately and structurally so that it could be recycled.

In the EU each country developed different methods to deal with this problem of garbage collection. Spain was the first country to install glass collection containers in 1982. It was in that same year, when a model of cooperation between Autonomous Communities, local corporations, and manufacturers of glass containers was established for the management of the recycling of this element. In 1994, Directive 94/62/EC dictated the framework on which all the legislation of each of the countries of the European Community was to be developed.

At a general level, two predominant recycling models were developed in the EU within the European legislative framework, in which most of the countries that make up the EU are included. The first model consists of the deployment of colored containers according to the waste for which they are focused. Within this model there are small differences according to each country, such as the color of the container for each package, apart from the containers of urban waste and oil.

However, color identification is not identical in all countries that have adopted this model. For example, in Spain three containers are deployed: Blue (paper and cardboard), yellow (plastic waste), and green (glass). In France, there are three containers: Yellow (paper and cardboard), blue (plastic and aluminum), and green (glass). In Italy the colors also vary with respect to Spain and France. In addition, another variant is when the process of waste collection is carried out, which is governed by an annual planning that sets the days for throwing out the garbage (usually two days a week). The garbage must be deposited the day before the day set in the planning, and in some countries people can receive a fine if they do not recycle. There are even major differences; in Norway the system differs slightly, with one container for organic waste and another for paper and cardboard. The plastic is deposited in special bags, which are placed next to the paper and cardboard container. The glass is placed in special containers next to the supermarkets.

The second method widely adopted in Europe is the Deposit Refund System (DRS), which is being implemented in Germany, Sweden, and Denmark. In this model, in the purchase process the user pays a fee that includes this kind of waste, which is recovered once the container is deposited in perfect condition in the machines intended for collection; the user receives a ticket with which they can get this fee refunded. The DRS is complemented with the colored-container method, as in Germany.

Both methods have a good reputation and acceptance in the countries in which they are deployed, however, both methods have a number of points to review for improvement. The colored container recycling model has one disadvantage: It only allows the collection of some materials and the DRS model only serves to recover plastic or metal containers. Specifically, the DRS only allows the management of 8% of the packages, while, the model of colored containers takes care of 80% of the packages. The operation of the DRS model is linked to machines installed in supermarkets, so that citizens only deposit their packaging at the time when these establishments are open. In addition, in the DRS model the containers are engraved with a tax that the citizen has to pay when buying a product, in case the container presents a flaw or a dent and cannot be recovered.

Both models can therefore be improved, and even benefit from each other's advantages. Recycling by imposition (possibility of being fined) means that this process is carried out with reluctance and without paying attention to the correct recycling in the model of colored containers. The DRS system simply recovers the money that was paid for each container when they were purchased, and a very small percentage of containers are managed by this model.

### Gamification to Encourage the Recycling of Garbage

Gambling is a technique that has been developed for incorporation into certain daily activities for their incentive through the use of the mechanisms of play. Gamification arises within the educational sphere. The games are part of a set of activities that promote learning in a playful and interactive way. These games use the typical characteristics of entertainment games to tackle learning tasks, comprehension or social impact, tackling both cognitive and affective dimensions in such a way that they are very interesting for the objectives set out in this proposal. For this purpose, dynamism and gameplay concepts are used that make participation and interaction a stimulus in the learning process.

Gamification uses the characteristics of games with a purpose beyond entertainment and clearly focused on learning. Gaming in the recycling field allows for increased citizen participation in these tasks, allowing rewards to be given to users who perform correct actions according to fixed rules and receiving penalties in the opposite case.

The use of this technique can be focused on increasing the level of participation while maintaining the citizen's commitment to the environment. This technique has recently been used in fields such as home energy efficiency with very satisfactory results (García *et al.*, 2017a,b). However, it has been detected that it has not been used in the field of recycling so it is interesting to know if this technique produces satisfactory results in this field as well.

### Internet of Things Platforms

An IoT platform is the basis for devices to be interconnected and generate their own ecosystem. In other words, a web platform integrated to the IoT is the software that connects hardware, access points, and data networks to what is usually the application the user connects to. The market for IoT platforms is booming and continually expanding; in fact, there are surveys that say that more than 80% of companies believe that the field of the Internet of Things is the most interesting for their businesses. In addition, these platforms are necessary to solve middleware problems.

There is a wide variety of IoT platforms; however, to face the problems we are facing, it is necessary that this platform has a wide capacity to communicate, coordinate, interact and cooperate to carry out different actions. A methodology that combines these characteristics in the development of platforms is the multiagent system (MAS).

These characteristics have allowed this methodology to be applied in works with objectives as varied as the management of drones for livestock monitoring or as a legal control platform for drone flights (Rivas *et al.*, 2018a; Chamoso *et al.*, 2018a), aid in the systems of currency exchange in airports (Chamoso *et al.*, 2019), classification of facial images according to gender and age (González-Briones *et al.*, 2018f), optimization of energy consumption (González-Briones *et al.*, 2018e,b,c,a,d), being in all of them a methodology that has been adapted with high precision to the needs of the problem. It is for this reason that these systems have been widely accepted by the scientific community due to their intrinsic characteristics that allow them to be used in such diverse contexts. They are widely used to model behavior, simulate situations, or solve problems that are difficult or impossible to solve for a monolithic system.

The ability to interact between them without the need for any action on the part of the users gives them their own autonomy that empowers them with the capacity to perceive changes in the environment and react to them, being, therefore, a very propitious methodology for capturing data, learning behavior patterns, and making decisions in the face of changes. The multiagent systems as a basis for the development of an IoT platform allows modeling different architectures based on the above tasks for the development of activities within the field of recycling ranging from behavior simulation, learning behaviors associated with recycling, the efficient management of waste within supply chains, or learning behavioral actions of users.

The agents that make up the platform have their own autonomy that allows them to carry out the aforementioned tasks, making it a very suitable methodology for capturing data, learning behavior patterns, and making decisions in the face of changes. Multiagent systems have been used in different proposals within the field of recycling, from simulating behavior, learning behaviors associated with recycling, the efficient management of waste within supply chains, or learning behavioral actions of users.

For this reason, this methodology has been used in works that meet some of the subobjectives set out in this proposal. One of these works is carried out by Meng *et al.* (2018) in which a platform is presented to carry out simulations of domestic solid waste recycling actions together with the carrying out of social surveys. The agents of the platform simulate different domestic scenarios and based on various decisions simulations are made but does not encourage citizen participation in recycling tasks. In another work such as the one presented by Yang *et al.* (2011) a system is presented for the evaluation of the economic sustainability of a waste recovery system by means of simulation based on agents. To assess economic sustainability, process recycling rate, and economic efficiency, sustainability metrics are used to evaluate and compare two recovery processes.

Another work based on multiagent systems is that carried out by Mishra *et al.* (2012), in which agents coordinate effectively to execute different tasks such as waste categorization, transport, waste recycling, waste management, and assignment of reusable products. The agents allow to carry out a management of all the activities that take place in the supply chain; the management of these complex tasks is carried out in an effective way thanks to the cooperation and communication of the agents that model the supply chain.

These works are a clear demonstration that the agent-based system proposed for the development of an IoT platform to enable efficient management in waste collection chains and collection decision making while encouraging citizen participation in a smart city. The use of multiagent system has shown a number of advantages to simulate this type of problems and learn from the actions taken for decision making.

The development of a platform based on an architecture based on agents that adapts to the needs raised makes it possible to manage independent environments to make more optimized decisions, being able to take these decisions by quadrants, neighborhoods, or regions within a smart city. In addition, thanks to the use of gamma techniques, the platform will reward the neighbors with the greatest participation and will penalize those who do not participate. The platform will have communication with users thanks to the mobile application used by users to measure user participation. As a model for the development of the platform is the one presented by Rodríguez *et al.* (2011), whose contribution is the ability to make dynamic and adaptive plans to distribute tasks among agents (container status, transport management, gamification process, or user management among others). Context-Aware Framework for Collaborative Learning Applications is used for the development of the gamification system as a basis for its technical and social features implementation (García *et al.*, 2015, 2017c). The system learns from the actions taken by users to adapt to them and provide new solutions to increase the recycling rate and citizen participation.

## Proposed System

This section details the architecture that has enabled the technical development of the multi-agent system that implements the IoT platform that captures the data and the gamification system for the participation of users.

### Infrastructure

Agents of the IoT platform communicate with the mobile application to get information from users. The mobile application captures this information from the infrastructure that needs to be deployed for the case study. This infrastructure should not mean a change in recycling model currently deployed, but a small deployment of sensors that allow data capture. The information that is required by the platform and that must be sent by the mobile application is a structure that contains data related to the quantity, type of waste, the user who performs the action, as well as the state of filling of the containers and degree of occupation of the nearest waste treatment plant.

The infrastructure installed in each container consists of the following devices: (1) a QR code reader enabling the user to be identified. (2) GPS locator, which indicates the coordinates at which the container is located. (3) Weight sensor weighs the amount of waste introduced into the container. (4) Volumetric sensor, it allows to know the state of filling of the container. (5) NarrowBand IOT (NB-IoT) communication technology, for data transmission to the system. NB-IoT technology allows data transmission over long distances. (6) Solar panel, which feeds the different sensors deployed in the container so that the system is independent at the energy level.

The process of interaction between the user, the application, and the platform begins at the moment in which the citizen deposits the waste in a container, then the data structure is generated to be received by the mobile application and then sent to the IoT platform composed of the following fields: User id, type of waste, amount of waste, container id, location of the container, filling status of the container. The data structure is sent via the MQTT protocol using the NB-IoT network to a local station. The local station will act as MQTT broker sending the data in JSON format via REST services. There is a communication line between each container and the waste treatment plant that allows a collection truck to be sent to the containers that are complete (Dijkstra's shortest path algorithm is used to trace this route).

### Multiagent Architecture

The architecture is based on agents as this allows to adapt to possible changes such as the growth of the number of containers or change of the location of the containers in the region to be managed. This architecture is therefore dynamic and self-adaptable in real time to the characteristics of the context of the problem.

This process of self-adaptation is determined by the goals, desires, and tasks of each agent (amount of waste to be recycled, percentage of participation, etc.), while taking into account the objectives of the other agents, cooperating among them to achieve the common goal and specific goals. The core of the architecture is a group of deliberative agents who decide autonomously how to act and at what moment to intervene in the collective solution. The functionalities of the agents are not within their structure, but modeled as services. This methodology grants a wide capacity of adaptation to changes and in the recovery of errors. As it has been possible to extract from the review of the state of the art, a multiagent system allows us to adapt to a changing environment such as the increase or change of the location of the containers.

The architecture used is organized in four layers, with the manage layer being the layer in charge of managing the MAS and communicating with the mobile application (Figs. 1–6).

- *Manage Layer*. This layer, made up of at least one agent, is in charge of deploying the rest of the main agents in each layer. This agent also coordinates communication with users through the mobile application to update the progress of each user on the platform.
- *Smart City Layer*. The agents of this layer receive the information from the data structures that are received by manage layer. This layer checks the status of the containers to make decisions if necessary. Big data engine agents analyze the data received by complex event processing for pattern recognition. The architecture has an open data agent to acquire relevant data for analysis, such as meteorological data.
- *Data Layer*. The agents in this layer are in charge of capturing data from the infrastructure deployed in the smart city. IoT agents communicate with the agents deployed in the infrastructure layer to build the data structure that collects the data about the waste deposit in a container, which is sent in JSON format through REST services. The IoT broker performs the NGSI-to-NGSI (Next Generation Services Interface) conversion between IoT agents and the Context Broker agents, and the data is collected by data communication agents who transmit it for analysis to smart city intelligence layer.
- *Smart Government Layer*. This layer manages the results obtained by smart city layer for the collection of waste from containers or a larger deployment of containers in a certain area if the demand for waste collection or a larger shipment of trucks is not met. This layer is responsible for the process and gamification with the user, providing a bonus to or penalizing users with a decrease or increase in the rate of garbage imposed by the local government.
- *Infrastructure Layer*. The agents of this layer act as middleware between the users and the multiagent system. Each container has an associated agent that is responsible for generating a data structure (amount, type of waste deposited, user recycling, filling status of the container, occupancy rate of the nearest waste treatment plant). These agents, using LPWAN, send the information to the data layer agents.

The mobile application is a simple application developed in Android that manages the profile of users, updating the achievements of each user and showing the achievements or penalties achieved. The results shown are those that the application calculates through the smart government layer. This simple two-screen application also shows the economic benefit produced, the carbon footprint avoided by recycling, and other environmental information of general interest.

### Mock-Up Simulation

To simulate the decisions taken by the architecture and by the users, a model has been developed by the BISITE Research Group. This model is designed to connect with multiagent architectures to evaluate the efficiency of IoT platforms in problems of energy optimization (demand response) or sustainability cities.

In our case it has allowed us to simulate the results of the decisions of the algorithms of the architecture as to obtain the routes of waste collection by the shortest way using Dijkstra.

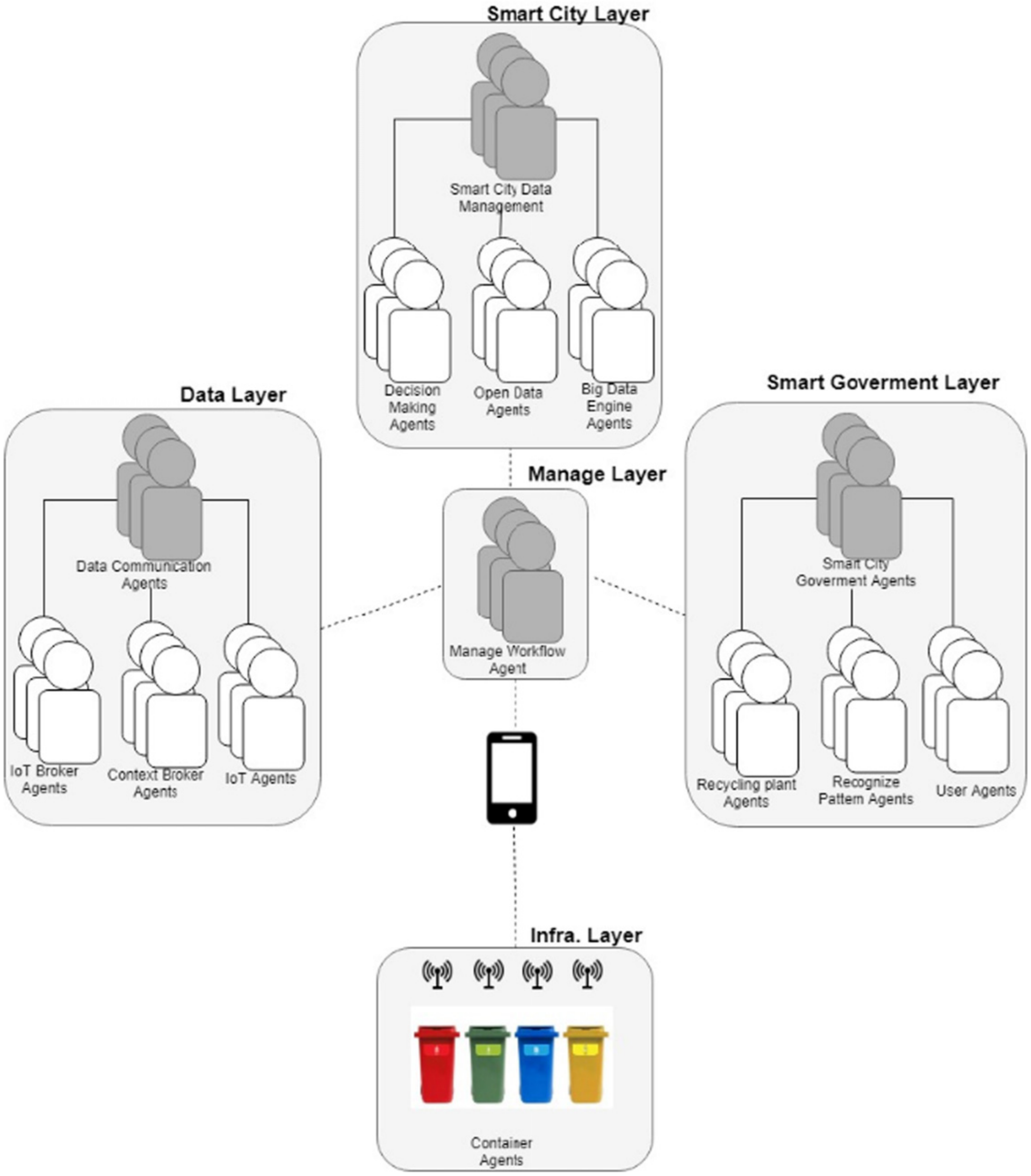


**Fig. 1** Agent based Internet of Things platform.

The model is designed in such a way that it can simulate from climatic conditions to electricity consumption by homes, neighborhoods, or regions defined by the user. In each of these neighborhoods is an electronic board, called cryptochip, which includes various sensors that can be referenced and integrated into different developments.

- The designed node has an accelerometer model LIS3DH with capacities to measure acceleration ranges from 0 to 16 g. This scale is dynamically adjusted according to the different needs of the moment.
- For temperature control, a TC1047A microchip sensor with ultra low power consumption of less than 35 $\mu$A is available.
- For the positioning of the data it has a system of last generation of the manufacturer Ublox, the model MAX-M8Q able to obtain the positioning through the four global standards of positioning by triangulation: GPS, Galileo, GLONASS, and BeiDou, in this way the time is reduced to find a “fixed” of position and with it the initial consumption, the highest in this type of devices.
- The device is equipped with an HTFS 800-P power consumption sensor capable of withstanding voltages of up to 2 KV and amperage peaks of up to 800 A.
- It uses a LoRaWAN communication network based on LoRa modulation, due to its high noise tolerance and indoor penetration if necessary.
- ATSHA204A encryption chip with SHA1 technology.

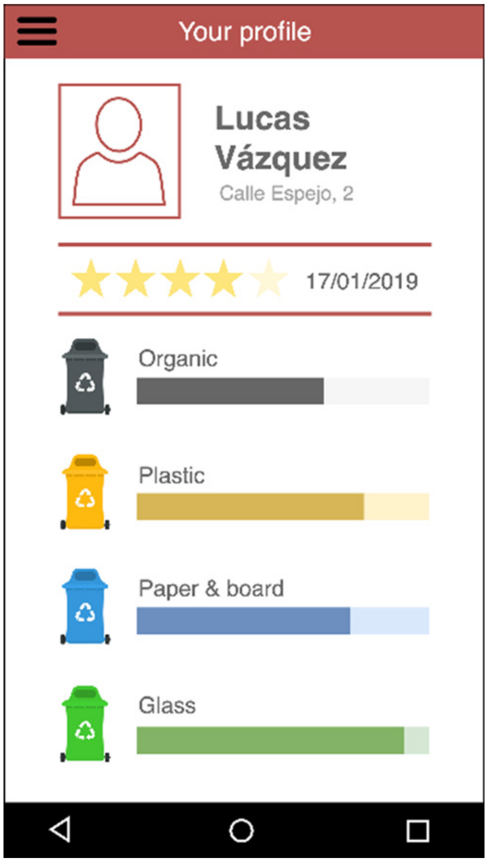


**Fig. 2** Android application for the visualization of the achievements obtained by each user.

**Fig. 3** BISITE Mock-up for the simulation of optimization problems, calculation of transport routes, sustainability problems in a smart city.

**Fig. 4** Calculation of the route to be carried out by the garbage truck to collect the waste in a more optimal way, using the Dijkstra algorithm.

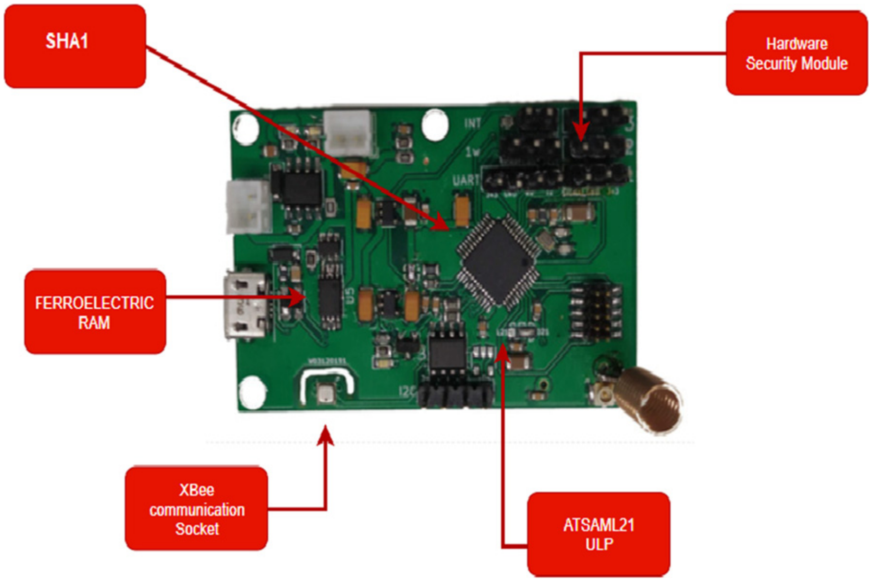


**Fig. 5** Cryptochip board that manages the simulation of conditions and the sending of safe data in the model.

This chip behaves like a generic gateway within the IoT paradigm. This implies that the strong points of the device are the security of the data it obtains from the environment, ensuring its reliability and in the same way transferring them safely to the upper layers of the developed architecture, being totally agnostic to them. Some of its functionalities are:

- *Data collection*, since it has the possibility of connecting multiple sensors in its pins allows to carry out a data collection depending on the type of project in which it is used.
- *Data encryption*, since it has a hardware encryption chip, it can apply an RSA signature to the data. This type of encryption algorithm is double key (public/private), therefore, the cryptochip can encrypt the information, send it, and in the destination application (or the blockchain itself) decrypt it to see the data.
- *Reading sensors*, thanks to its dedicated connectors, allows easy connection to several sensors simultaneously and have different methods of communication.
- *Reading and sending data in portable systems*, thanks to the possibility of being powered by a power bank and its low consumption, can be used in portable applications, in addition to carrying out the sending of data collected through the integrated communications modules thanks to the X-bee socket.
- *Integration in IoT systems*, thanks to the low consumption of the system, and the incorporation of wireless communication systems, allows the implementation of this board in IoT.
- *Traceability*, as the data collected and encrypted by the cryptochip that are sent to the blockchain have data from a GPS sensor, you can track precisely the path that has followed the cryptochip. For example, commercial transport containers, trucks, etc.
- *Internet of value*, has been built on open standards but its basis is blockchain technology. In this way we have a new tool (blockchain) to share and manage value of assets or goods without the need to depend on a trusted central entity that decentralizes the process.

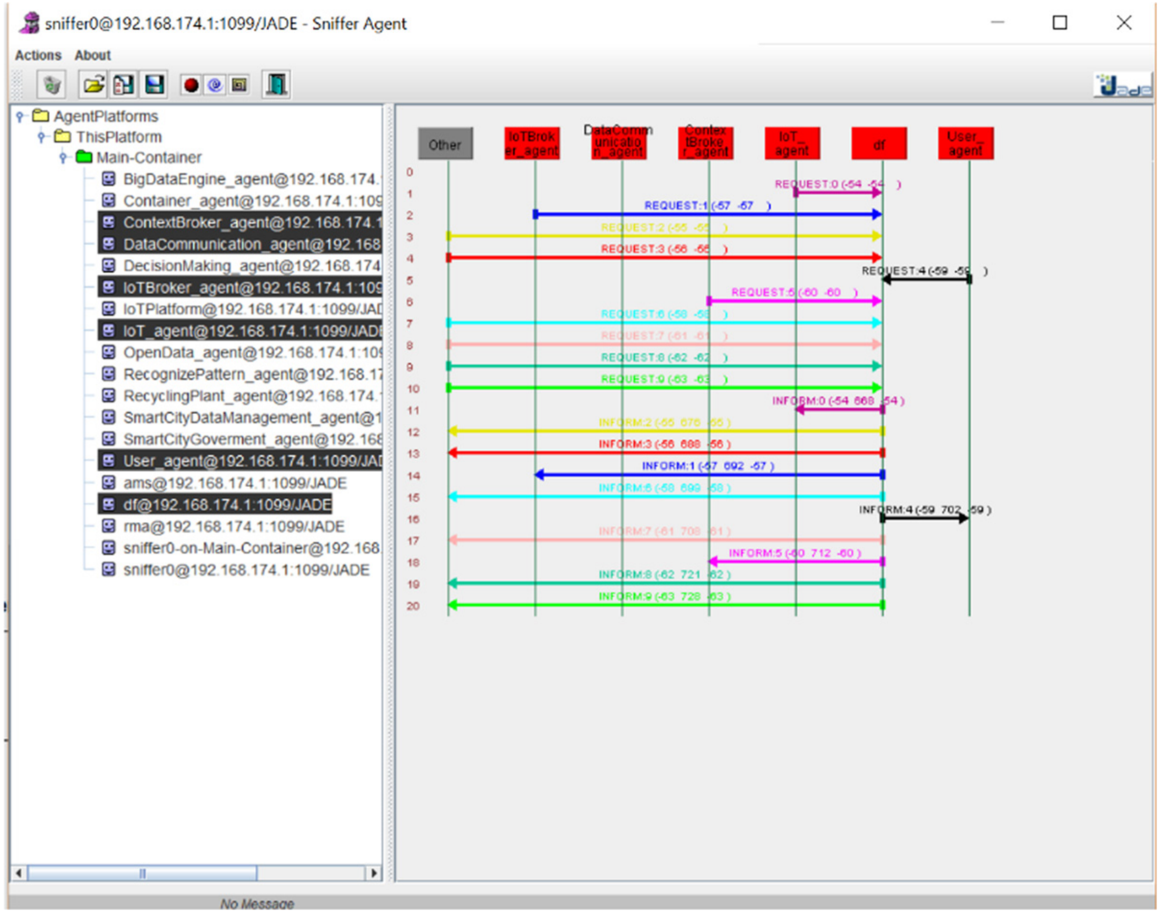


**Fig. 6** Communication between agents for capturing data from the environment and the user's mobile application.

## Simulation Results

This section details the characteristics of the case study in which the architecture has been tested and the results obtained, to assess whether the proposed IoT platform presents an advance in citizen participation in the recycling process and in the process of optimization of waste collection routes. The system has been evaluated in the mock-up previously presented, simulating a real context. It has been simulated the characteristics of an urbanization with a population of 2200 inhabitants with 30 containers with the required infrastructure (10 blue containers for paper and cardboard, 10 yellow plastic waste containers, 10 green containers for glass), and 10 red containers of urban waste (these containers without the infrastructure).

The experiment has been divided into two phases; in the first phase the number of people who recycle and the amount of waste collected in each container has been counted, and in the second phase simulations were produced using the proposed architecture using gamma algorithms. In this second stage, the interaction of the 2200 inhabitants has been simulated, deploying agents with different behaviors based on their belief, desire, and intentions.

The process consists of each agent simulating a user who is logged by reading the QR code that identifies the container and identifies the user so as to enable the opening of the container deposit and weighing of waste. Once the waste has been introduced, the container has the quantity of waste, sends the data structure generated (quantity of waste, type of waste deposited, user that recycles, filling status of the container, occupancy rate of the nearest waste treatment plant) through the local retransmission antenna deployed using LPWAN.

The information arrives at the IoT platform and it is the agents of the different layers who are in charge of making decisions such as sending a truck to collect waste from a specific container if it is full or updating the bonus or penalty in the user's profile. Each agent allows you to visualize the achievements that your user has accumulated during the current month (each month the profile is restarted, the achievements are not cumulative for the next month). If the user reaches the goals proposed by the municipality, the case study was proposed to increase the amount of waste by 18%. The users who obtained it obtained a reduction of 5€ on the monthly rate of rubbish (48€). At the end of the experiment, the amount of waste deposited was measured according to the simulated behavior to measure the efficiency of the system, as can be seen in Table 1, in which an increase of 17.2% is observed.

**Table 1** Quantity (kg) of waste collected from each container

| | *Before system* | *After system* |
|---|---|---|
| Blue container | 2214.15 | 2625.98 |
| Yellow container | 1731.24 | 2023.82 |
| Green container | 1595.07 | 1851.88 |
| Total | 5540.46 | 6501.68 |

## Conclusion

This article presents a novel model of an agent based IoT platform that allows through gamification mechanisms to encourage citizen participation in recycling tasks. The gamification is presented as a key aspect in this type of IoT platform because the acquisition of data from the citizens of a neighborhood can propose challenges with which to increase the amount of waste to recycle.

As with any IoT platform, it is necessary to deploy an infrastructure in each container to provide information about the user's interaction with the gamification model, e.g., information about which user has recycled, amount of garbage introduced, in which container garbage has been deposited, or the occupation status of the container, among others. This information provides the necessary knowledge to the platform for the execution of the gamification model, as well as for the definition of optimal routes of waste collection according to the state of occupation of the containers and the nearest waste treatment plant, allowing an optimal and efficient management of urban waste.

The behavior of users has been recreated based on data from their real interaction in the recycling process in their city. This case study has allowed us to know the validity of the proposed platform without developing the technical deployment of the necessary sensorization. The results of evaluating the proposed platform have satisfactorily concluded the usefulness of the proposal. On the one hand, citizen participation has increased by 32.2%, the amount of waste has increased by 17.2% and, on the other hand, the number of journeys for waste collection has been reduced by 53.4%. It is clear that the use of gamification and the problem of encouraging recycling in cities allows citizens to reward their good behavior due to the savings produced by reducing the number of trips for waste collection and the increase in the garbage tax for those who do not carry out this task, apart from the other social benefits that recycling produces.

Future lines of work include the deployment of the hardware part of the platform for evaluation in a completely real scenario. This real scenario will certify the good results obtained. This platform will also allow the system to be used to carry out social measurements that will make it possible to know the behavior patterns of the users (average amount of waste it deposits, frequency with which it goes to the containers, timetable, days of the week, etc.).

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