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Enabling Customizable Services for Multimodal Smart Mobility With City-Platforms

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ABSTRACT In the last decades, the cities' capacity for generating digital information has grown exponentially. In this context, the successful implementation of smart cities' concept depends on the current possibility of handling the significant volumes of sensed data. This is particularly notorious in the case of urban mobility. Researchers in the field of urban planning have shown a great interest in urban mobility problems, proposing different route recommendation services towards making it easier and safer to move around the city. This paper addresses the development of an urban data platform and how to obtain and integrate information from sensors and other data sources to provide aggregated and intelligent views of raw data to support urban mobility. With the aim of evaluating the efficiency of the developed platform, we present an intelligent urban mobility solution, where the context-awareness, user preferences, and environmental factors play a significant role in the process of route planning. Finally, our work provides an experiment to assess different long-range wireless communication technologies to enable its implementation within an urban environment.

INDEX TERMS Smart city platform, Internet of Things, urban mobility, multimodal transportation, smart mobility.

I. INTRODUCTION

The EU (European Union) cities face several challenges to ensure secure, affordable, and clean energy, smart electromobility, and intelligent services. In order to overcome these challenges, the European Commission launched the Smart Cities (SCs) and Communities lighthouse projects, under the Horizon 2020 research and innovation program [1], [2]. This project's main idea is to support the implementation of smart urban technologies and bring together cities, industries, and citizens to demonstrate solutions and business models that can be scaled up and replicated, leading to transforming their ecosystems into smarter and more sustainable environments.

The SCs is a terminology given to urban areas that use information and communications technologies (ICTs), to support various domains and municipal services, e.g., in governance to create a collaborative process for city management, in mobility to provide personalized and on-demand mobility services, and an environment to solve pollution issues [3]–[6]. The SCs, built on top of large-scale Internet of Things (IoT) systems that are overgrowing worldwide, provide an excellent opportunity across many cross domain sectors [7]. IoT refers to the interconnection of heterogeneous objects or things on the Internet, capable of collecting and exchanging data [4]. It is an abstraction of the physical world,

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enabling physical as well as virtual interaction between devices and users [8]. In particular, as the IoT brings all the networked physical and virtual machines to the Internet, it is foreseen as a core enabler for smart cities [9]–[11].

However, the challenge facing the SCs is how to exploit the advanced technologies gathered under the umbrella of IoT, to support synchronization between the three elements of SCs, namely, ''objects'' that represent the inclusion of IoT with virtual systems, ''data'' that is massive and heterogeneous from multiple sources and, ''services'' providing customizable value propositions [12]–[14]. The objects, which include devices embedded with sensors, actuators, cameras, etc., are distributed all over the city. These objects produce a huge amount of data. This data represents different types of measurements in diverse formats, which are afterward stored at the data lake. The use of this information to improve efficiency in decision making and also in the development of reliable estimates and forecasts, as may be the case for route optimization and mobility, is valuable but not without complications. Advanced data processing is required to associate (linked data) and normalize (data model) these large volumes of unrelated data to discover patterns, dependencies between them and semantic relationships, and obtain useful knowledge for municipal managers.

In order to overcome the challenge and promote the development of SCs, the primary focus should be on the accessibility of objects and services. A further objective is to build an architecture that enables multiple information sources to be integrated into a single framework by reusing infrastructure, data, and services [15]–[18]. In this sense, overcoming the fragmentation of the market and achieving interoperability between established smart city silos via global standards and interworking mechanisms are critical items towards the successful adoption of smart cities [4], [19], [20].

SC platforms are unified frameworks for city operation and services that allow sensing, data fusion and integration, communication, customizable service providing, and intelligent decision-making, among others. The SC platforms provide a set of different real-time data visualization and control panels that help manage the city effectively and make it easier for residents to access and understand the information available. This allows citizens to feel an integral part of the city and actively participate in its sustainability and energy efficiency, since citizens can see for themselves the impact of their behavior on the city as a whole. For example, it will be more helpful to the residents with respiratory diseases if they know which parts of the city have the highest air pollution to avoid these areas during their mobility. In addition, information related to electric vehicles (EV) charging stations such as location, charging speed, connector type, and availability contribute to saving time, avoiding traffic congestion and reducing pollution.

Different issues must be addressed by smart city platforms in relation with:

- Scalable and standardized data model, working with heterogeneous data sources.
- Information management with different levels of security and protection.
- Capability of providing useful and innovative services and mechanisms for interaction with third parties.
- Analyze information, extract knowledge and optimize process flows
- Promotion of energy sustainability (mobility and self-consumption),
- Technological independence of organizations,
- Use and support of smart contracts, ensuring transparency with citizens.

Currently, few municipalities have platforms or systems for real time monitoring and subsequent inference of urban process parameters. The commonly employed strategy is data collection, offline analysis, and action, followed by system adjustments and repetition of the whole process. Based on that, we designed and developed our platform to demonstrate the benefits of open data and open platforms for smart city adoption. One of the main motivations of this work is to present an integrated solution for sensor systems and environmental sensing, which enables smart services using open data.

In this sense, the contribution of this work focuses on developing a comprehensive Smart City ecosystem platform, where all of its components interact and collaborate to provide a set of customizable services based on a customizable and parameterizable ontology, as illustrated in the case of multimodal smart mobility. Specifically, the contributions of the proposal here described are:

- **Data standardization** and **context information management.**
- **Interoperability:**easy integration of any system/data into the platform, no matter the data format.
- Provide a unique **Smart City ecosystem framework**, where people, processes, policies, technology, and other enablers work together to deliver a set of outcomes.
- **Automate the processes** between entities, citizens, and administrations (smart contracts).
- Provide a **comprehensive smart mobility solution** to users, where the information that is related to mobility is provided by the platform.
- **Context-awareness.**
- **Co-responsibility** between citizens and administrations.

A schematic description of the elements analyzed within this work is depicted in Fig. 1.

The rest of the paper is organized as follows: Section II, presents the related work. Section III presents the use of city platforms as service enablers. Section IV discusses multimodal smart mobility. Section V describes the implementation of the city platform, the customizable smart mobility service proposed, the interaction of third-party systems with

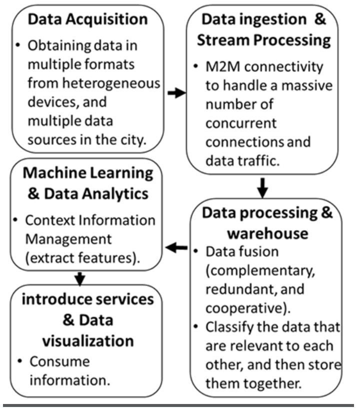


FIGURE 1. **Schematic description of the smart city platform.**

the mobility service through a REST API and a case study. Finally, Section VI presents the conclusions of the paper.

II. RELATED WORK

Although many proposals have been made in the field of Smart City platforms, we will now analyze some of the most relevant contributions in this field.

Zanella *et al.* introduced in [4] the need for these platforms to include a large number of diverse end systems, providing open access to different digital services. The provision of services and backing to third parties require proactive and relevant support to citizens with services capable of creating and managing digital identities [21]. The reuse of the functionalities of legacy systems and applications by adapting them to new architectures has been described in [22]. The provision of multiple data sources related to smart city services consumers and the impact of data simplification is described in [23], whereas providing distributed frameworks for service discovery is described in [24].

Common and interoperable data model definition, as well as interoperability are addressed in [40], where a modular approach to achieve interoperability is presented. Cross-platform interoperability for sensors is addressed in [41], whereas in the case of [9], the interaction is performed by means of adaptive semantic adapters. The standardization issue is addressed in [42], where the ISO 37120 standard for city services and quality of life is suggested as unified framework for smart city dashboards; and [43], where a summary of smart city standardization is presented.

Efficient and effective urban mobility and public transportation can significantly contribute to achieving economic, ecological, and sustainable objectives. Current efforts focus on considering mobility as a service [44]–[46], since smart mobility allows energy saving policies, relevant reductions of polluting emissions and a better quality of life for citizens. Table 1 summarizes some relevant contributions on the field of customizable travel support and multi-modal routing planner.

Smart cities sustainability is addressed in [47], where system architectures, control strategies and multi-vector energy systems modelling are depicted, as well as the integration of computational intelligence and machine learning for smart cities. The relevance of fog computing for sustainable smart cities is addressed in [48], which discusses the challenges an issues of fog-based IoT environments, highlights main applications of fog computing and discusses various caching techniques in the IoT era, even considering UAVs and AI/ML techniques and technologies.

Smart contracts are currently an interesting object of study, as they make possible interesting interrelations among smart cities, and between these and their citizens. Ekiden [29] leverages a novel architecture that separates consensus from execution, enabling efficient Trusted Execution Environments (backed confidentiality) preserving smart contracts and high scalability, while [30] analyzes the need of a distributed network formed among cities, allowing the integration of distributed electric energy into the power grid.

Security and personal data management, preserving policies and regulations related with personal data protection, are addressed in [49]–[52]. Privacy as well as security aspects have to be considered [49] granting an end-to-end secure solutions and environments where personal data, in transit or/and storage, remains under the full control of the users. The efforts to standardize security solutions for the IoT ecosystem initially introduced in [52] focused on communication security solutions for IoT, and their standardization, but it also applications, data custody and services. Protecting information is crucial and specific security mechanisms must be designed and implemented [51]. Blockchain techniques have also been considered to build secure and reliable data sharing platform among multiple data providers, where IoT data is encrypted and then recorded on a distributed ledger [52].

III. CITY PLATFORMS AS SERVICE ENABLERS

Smart city platforms (SCPs) can be described as systems that: 1) ingest heterogeneous data harvested from different sources (open data, IoT devices, citizen's information...), 2) a tool to provide city data (energy, transport, crowdsourced data...) sharing and integration, 3) an efficient tool to map, store and provide useful management dashboards. SCPs must also enable data coordination, provide customizable integral services, favor the creation of business activity, develop innovative applications and services, and enable urban planning and the evaluation of new policies (such as smart urban mobility, healthy habits, citizen awareness, among others). SCPs must focus on citizens and be the catalyst that allows the flow of information and service to and for the citizen. Ultimately, SCPs should emerge as an infrastructure that will conform the citizen-administration relationship, allowing not only the efficient conclusion of administrative procedures or the provision of services adapted to the needs of users. It will also offer an efficient and effective mechanism for auditing and granting transparency of administrations. The platforms should allow citizens to see how their behavior affects the welfare of the city, as a vehicle to raise awareness among

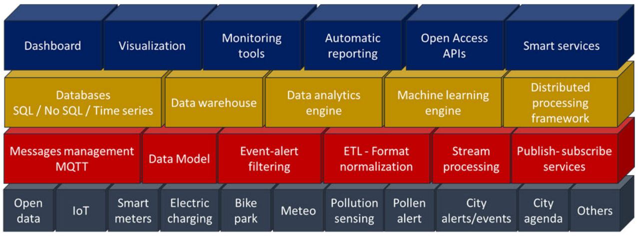


FIGURE 2. **Schematic description of the city platform layer architecture.**

them that municipal management begins with the citizens themselves.

The definition of the architecture of a SCP must be as generic as possible, achieving the maximum possible interoperability, scalability, efficiency, and simplicity. Fig. 2 depicts the different layers and components that a SCP must include. The lower level is referred to data acquisition. The next higher level refers to the flow of the data acquired at the lower level (data adaptation, information standardization, information source and destination flows...). The third level refers to the storage, analysis and processing of this data; and finally, the upper level refers to the provision of services to third parties, system monitoring, the presentation of control panels, etc.

To ensure the proper operation of this architecture, it is compulsory to have a suitable data model that guarantees the semantic integrity of the system and allows the transformation of data into information, and later into knowledge. Obtaining the data model is a complex task in administrations, which have multiple systems and information sources that have been implemented at different times and for different purposes, but which coexist in an unstable balance. It is far from frequent that SCPs share the same data model. In fact, the lack of standardization at this level is one of the main causes of the difficulties observed when exchanging information between cities, institutions or even companies or organizations providing services. The European Union (EU) is making a major effort to make FIWARE [53] the tool to support global interoperability. FIWARE is a vast ecosystem providing standardized application programming interfaces (APIs) used in open-source implementations of generic enablers (GEs) based on open specifications. FIWARE has now turned into a foundation focused on the high-level data interoperation of IoT and other systems using a Context Information model extended from the Open Mobile Alliance next-generation service interface (NGSI) 9/10 standard [54]–[56]. Probably one of FIWARE's most useful contributions is its data modeling given by the Context Information Management API NGSI-LD, which supports linked data, property graphs, and semantics (JSON-LD).

In addition, it is necessary to have an adequate mechanism for data ingestion, transformation, and storage. Data ingestion can occur synchronously or asynchronously, from very heterogeneous sources and in large volumes. For this reason, it is mandatory to standardize the data model as much as possible and to transform data before its storage. In this sense, an extraction, transformation and loading (ETL) process is used to store the obtained information following the corresponding data model. Although there are different possibilities for this, the tools most commonly used are the set of applications provided by Apache (Kafka, Nifi, Hadoop, Cassandra…), the use of the Fiware platform (with the broker Orion and the generic enablers –Ges-), or the use of cloud-based solutions such as those provided by Google, Azure or Amazon. Fig. 3 describes some of the components that provide data ingestion and stream processing, data storage and processing, data analytics and machine learning and data visualization and management (dashboards) in our city platform implementation proposal. Stream-processing tools such as Apache Kafka allow handling and transforming real-time data feeds minimizing latency and maximizing data throughput.

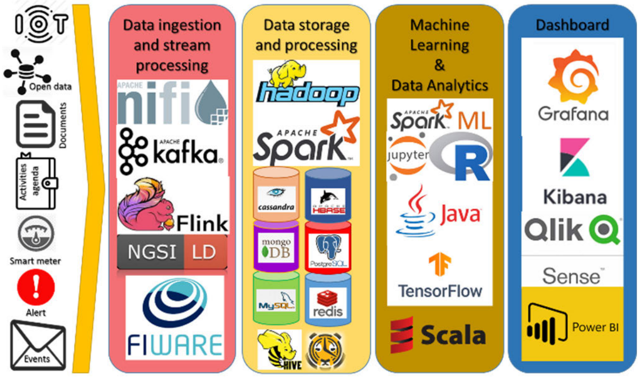


FIGURE 3. **Smart city platform implementation.**

The development of a real city platform poses many challenges when integrating some legacy information systems and their associated services, into the service catalog. Many of the services provided use information delivered in non-standardized formats, require specific communication protocols, or even use third-party proprietary formats. This implies the need to have a layered architecture that allows the introduction of adapters and parsers that guarantee the necessary standardization and easy maintenance of the platform. The viability of the platform is therefore directly conditioned by its scalability, ease of maintenance, standardization, the semantic efficiency of its data model and its accessibility.

The use of cloud computing makes the platform easily scalable to meet changing demand for the IT resources, covering two main types of scalability: horizontal and vertical scaling, which gives highly customizable infrastructure according to necessity. Leading cloud service providers or an on-premise infrastructure offer auto-scaling service, which monitors the performance of applications and automatically adjusts the capacity to maintain steady and predictable performance. Furthermore, CloudHealth technologies provide the ability to manage many elements of scalability across one cloud or multiple clouds.

On the other hand, the data standardization and context information management provide the ability to integrate existing services, different technologies, and protocols,

TABLE 1. Related work concerning urban mobility, public transportation and customizable multi-modal routing planner.

Ref	Contribution	Comments
[25]	• Enhancement of travel planners and micro navigators with the aid traveler context. • Provides a high-level analysis of how and in which situations context information can be useful. • Addresses different types of context information and possible risks.	• Appropriate only for the Swedish context. • The system may not be applicable in other countries if the Swedish PTS (public transport systems) and travel support are not similar to them. • The study focuses only on context-aware travel support during unplanned public transport disturbances, whilst other kind of situations have not been considered.
[26]	• An IoT enabled navigation system for urban bus riders. • Interconnects the commuters with the real-world of public bus infrastructure. • It has the capability to recognize and predict crowds inside the bus.	• Focuses on micro-navigation and crowd-aware route recommendation. • User Preferences are not taken nor external factors.
[27]	• Identified significant types of context such as, location, identity, time, and activity.	• Provide useful knowledge regarding context-awareness.
[28] [29] [30]	• A mobile recommender system for personalized multi-modal routes based on collaborative filtering and knowledge-based recommendations. • Developed for route recommendation, primarily targeted for private cabs and taxis.	• Did not yet take contextual information such as the weather into account. This is an important part of a route RS as a user might want to avoid walking or bicycling in case of bad weather and prefer a less popular route instead if this route provides protection from rain, wind or snow.
[31]	• A based personalized end-to-end mobile App for bus route recommender system, based on commuters' individual comfort preferences.	• Did not take into account, contextual information and environmental factors.
[32]	• Provides multimodal trip information obtained from variant journey planners. • Realizing a comprehensive information service.	• Suitable for International trip. • User context-awareness are not taken, even external factors.
[33]	• A context-aware recommender system for multi-modal route planning, considering the user's personal preferences and contextual information such as the weather and others' opinions.	• The mobile App prototype uses a text-based interface only and is not yet available for download.
[34]	• An Algorithm for itinerary prediction based on personal preference and real-time network congestion conditions. Prediction based on personal preference.	• Did not take contextual information such as the weather and location into account.
[35]	• An information gathering system for sharing the information related to the bus location relies on a collaborative mechanism with a Bluetooth board and smartphones.	• The system requires installing an App on the user's phone, which may not be suitable for some users. • No Context-awareness factors are taken or external factors.
[36]	• A framework for the navigation system to recognize the context of commuters in public transportation.	• User Preferences are not taken as well as external factors. • It requires the stability of the Internet connection.
[37]	• An Android App to evaluate the commuter's satisfaction and identify the necessity for personalized route recommendations in public transit based on commuters' feedback.	• The recommendation is only based on convenience without taking into account user context-awareness and environmental factors.
[38]	• A big data analysis of different datasets related to public transit network to identify user's perception-related problems.	• User preferences, user context-awareness, and external factors are not considered.
[39]	• Mathematical model for preference aware transport matching.	• User context-awareness are not taken nor external factors.
This work	• Comprehensive multimodal trip information, taking user preferences, user context-awareness, and other external factors into consideration.	• It deals with different sources of real-time data within the smart city, which makes the recommended route more comprehensive, dynamic, and able to change depending on the surrounding conditions.

introduce new third-party services or applications, and extend applications' interoperability. Services like Nifi are used to automate the data flow among different information systems and components. Furthermore, context information management provides the exchange of cross-cutting context information, to be used in SC use cases, particularly scalability and extensibility.

In the design and implementation of context aware applications and environments, communication systems play a key role in order to provide adequate levels of interactivity, among users as well as between devices. In this sense, HetNet communication paradigms provide optimized performance in terms of bandwidth, coverage, energy consumption, delay and quality of experience metrics, by dynamically allocating traffic resources as a function of user/device demands. In terms of sensor/actuators within a smart city framework, wired communication systems such as PLC, Ethernet or FTTH can be employed in order to provide connectivity with different elements of the urban infrastructure (i.e., lampposts, video surveillance infrastructure, traffic lights, charging points, etc.).

Wireless communications are employed when high levels of user mobility, ubiquity and very large sensor node deployments are considered. In this case, different wireless communication systems can be employed, depending on coverage/capacity requirements, bandwidth needs, energy consumption and form factor restrictions, among others. Wireless communication systems can be classified as a function of their coverage range, spanning from wide area connectivity (mainly public land mobile networks), short range communications (wireless body area networks and personal area networks), high capacity local area networks (given by WLAN) and mid to long range low capacity and low energy wireless sensor networks. The election of the specific systems is given mainly by coverage/capacity relations (i.e., transceiver distance range as a function of receiver sensitivity, which is at the same time dependent on transmission bit rate and overall interference levels), as well by inherent form factor, cost and reduced energy capabilities. The surrounding environment determines wireless channel performance, given by line of sight/non line of sight propagation conditions, the existence of strong multipath components and channel dynamic effects, such as Doppler shift, particularly in vehicular communications.

In the case of IoT applications, wireless communication systems in principle need to provide service to a large number of devices, with low/moderate transmission rates, low cost and low energy consumption. Within the array of different wireless communication systems, several of them are candidates in order to support IoT, such as NB-IoT/LTE Cat M (in the case of PLMN), Bluetooth Low Energy (BLE) in the case of Wireless Body Area Network (WBAN) and Low Power Area Network (LPWAN) standards in the case of wireless sensor networks (WSN), such as ZigBee or LoRa/LoRaWAN, among others. The specification and characteristics for these system are described in Table 2 [57]–[65].

IV. MULTIMODAL SMART MOBILITY

We conceive multimodal smart mobility as a customized and on-demand service provided to users to solve their mobility needs effectively and efficiently. In addition to meeting the individual criteria of each user, the mobility service will seek to promote sustainable mobility and minimize the impact of the carbon footprint.

In this work, we present one of the applications linked to our urban data platform for the smart city. We introduce intelligent urban mobility, which is one of the many benefits of open data and urban data platform for smart city development. The work is an integrated solution for several sensor systems, which enables experimentation with applications and services in order to enhance their operation, being one of them smart urban mobility, as shown in Fig. 4.

The idea is to use the data produced from IoT systems as well as from other sectors to create urban mobility solutions that are more comfortable, efficient, and take into account environmental and societal constraints. The challenge is given by the fact that the IoT systems collect increasingly significant amounts of data. Without a context, the data is meaningless and rarely effectively leveraged because of the difficulties in interpreting data models and efficient linking of data across distributed systems.

Therefore, the platform deals with most of the available information that comes from the different sector applications and IoT systems in the city – in our example, the city of Pamplona, Spain [66]. This information contains, for example, the schedule for bus and trains, the availability of public parking among the town, the warnings that come from the municipal government, and the traffic jam information that comes from provincial traffic offices, among others. After subsequent data processing and handling, interoperable context information is generated according to relevant contexts for smart applications in proper formal definitions. Finally, the extracted knowledge is used to build the decision-making process and, at the same time, to provide information to the end-user, as shown in Fig. 5.

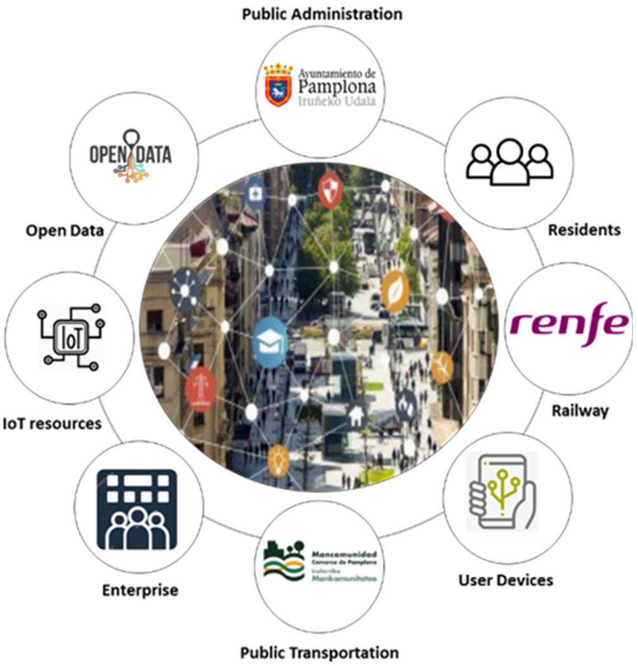


FIGURE 4. Interoperability between several service domains in a smart city.

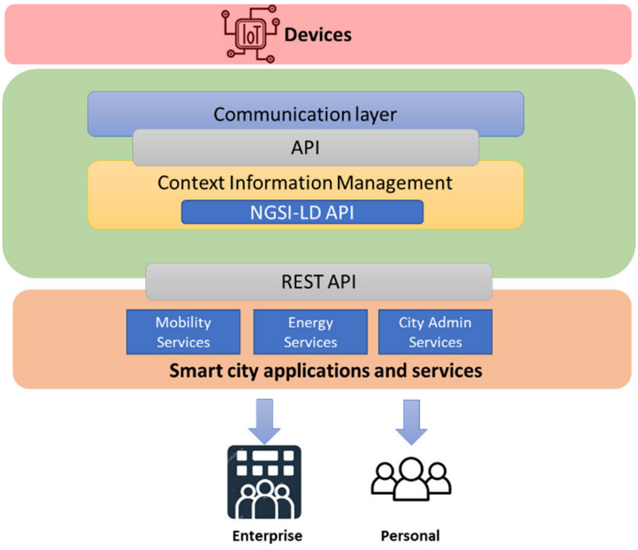
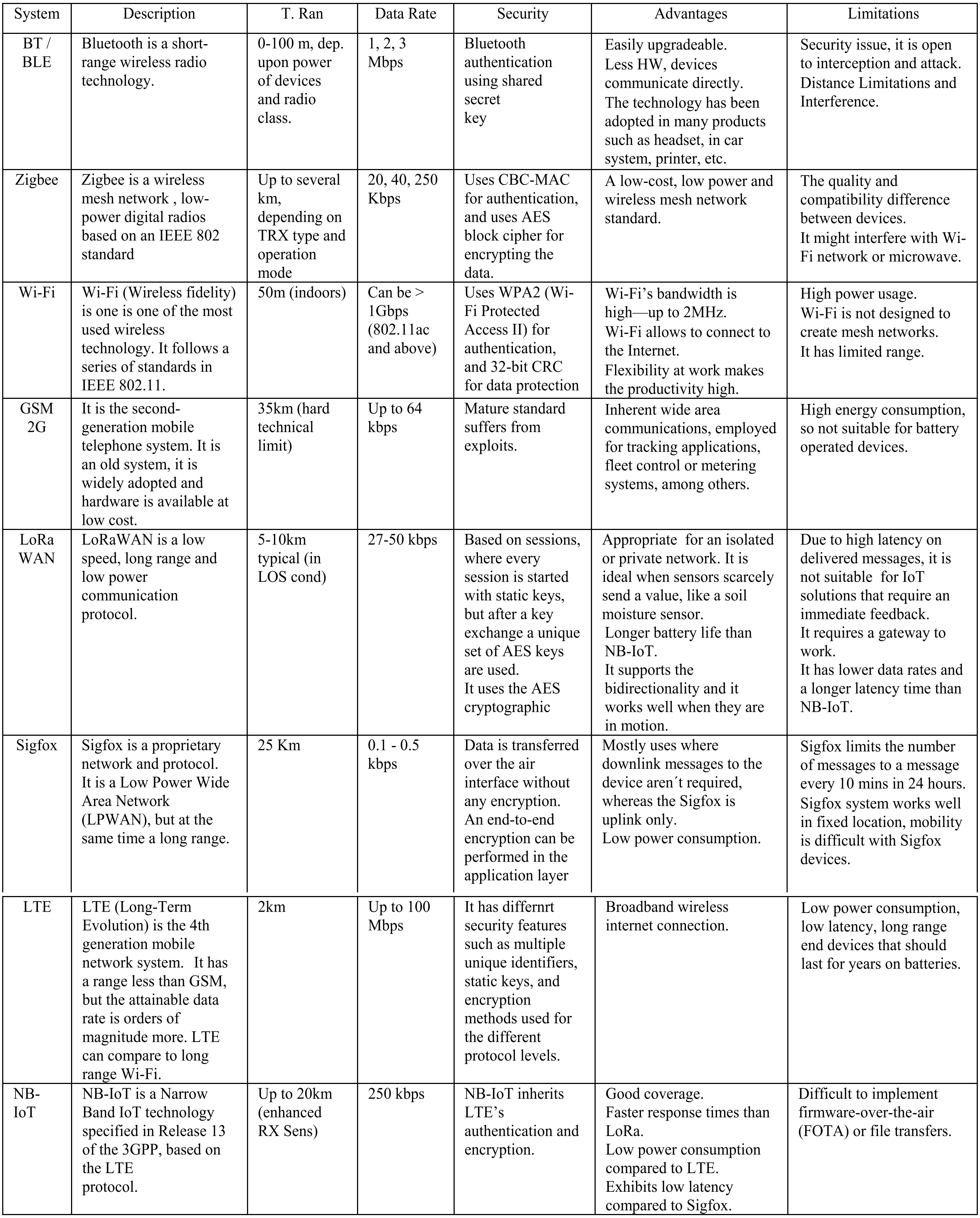


FIGURE 5. Schematic representation of the smart city platform.

The platform bases its functionality on using the NGSI-LD (LD stands for linked data) API. The NGSI-LD is designed to allow cross-domain sharing while preserving the need to enable restrictions based on privacy (GDPR), security, or licensing concerns. The NGSI-LD defines a simple way to send or request data using a serialization format (JSON-LD), which is already well-known to many software developers, enabling its rapid adoption. Therefore, the platform provides a set of APIs to software developers and third-party

TABLE 2. Wireless communication standards IOT/C-IOT.



System	Description	T. Ran	Data Rate	Security	Advantages	Limitations
BT / BLE	Bluetooth is a short-range wireless radio technology.	0-100 m, dep. upon power of devices and radio class.	1, 2, 3 Mbps	Bluetooth authentication using shared secret key	Easily upgradeable. Less HW, devices communicate directly. The technology has been adopted in many products such as headset, in car system, printer, etc.	Security issue, it is open to interception and attack. Distance Limitations and Interference.
Zigbee	Zigbee is a wireless mesh network , low-power digital radios based on an IEEE 802 standard	Up to several km, depending on TRX type and operation mode	20, 40, 250 Kbps	Uses CBC-MAC for authentication, and uses AES block cipher for encrypting the data.	A low-cost, low power and wireless mesh network standard.	The quality and compatibility difference between devices. It might interfere with Wi-Fi network or microwave.
Wi-Fi	Wi-Fi (Wireless fidelity) is one is one of the most used wireless technology. It follows a series of standards in IEEE 802.11.	50m (indoors)	Can be > 1Gbps (802.11ac and above)	Uses WPA2 (Wi-Fi Protected Access II) for authentication, and 32-bit CRC for data protection	Wi-Fi's bandwidth is high—up to 2MHz. Wi-Fi allows to connect to the Internet. Flexibility at work makes the productivity high.	High power usage. Wi-Fi is not designed to create mesh networks. It has limited range.
GSM 2G	It is the second-generation mobile telephone system. It is an old system, it is widely adopted and hardware is available at low cost.	35km (hard technical limit)	Up to 64 kbps	Mature standard suffers from exploits.	Inherent wide area communications, employed for tracking applications, fleet control or metering systems, among others.	High energy consumption, so not suitable for battery operated devices.
LoRa WAN	LoRaWAN is a low speed, long range and low power communication protocol.	5-10km typical (in LOS cond)	27-50 kbps	Based on sessions, where every session is started with static keys, but after a key exchange a unique set of AES keys are used. It uses the AES cryptographic	Appropriate for an isolated or private network. It is ideal when sensors scarcely send a value, like a soil moisture sensor. Longer battery life than NB-IoT. It supports the bidirectionality and it works well when they are in motion.	Due to high latency on delivered messages, it is not suitable for IoT solutions that require an immediate feedback. It requires a gateway to work. It has lower data rates and a longer latency time than NB-IoT.
Sigfox	Sigfox is a proprietary network and protocol. It is a Low Power Wide Area Network (LPWAN), but at the same time a long range.	25 Km	0.1 - 0.5 kbps	Data is transferred over the air interface without any encryption. An end-to-end encryption can be performed in the application layer	Mostly uses where downlink messages to the device aren´t required, whereas the Sigfox is uplink only. Low power consumption.	Sigfox limits the number of messages to a message every 10 mins in 24 hours. Sigfox system works well in fixed location, mobility is difficult with Sigfox devices.
LTE	LTE (Long-Term Evolution) is the 4th generation mobile network system. It has a range less than GSM, but the attainable data rate is orders of magnitude more. LTE can compare to long range Wi-Fi.	2km	Up to 100 Mbps	It has differnrt security features such as multiple unique identifiers, static keys, and encryption methods used for the different protocol levels.	Broadband wireless internet connection.	Low power consumption, low latency, long range end devices that should last for years on batteries.
NB-IoT	NB-IoT is a Narrow Band IoT technology specified in Release 13 of the 3GPP, based on the LTE protocol.	Up to 20km (enhanced RX Sens)	250 kbps	NB-IoT inherits LTE's authentication and encryption.	Good coverage. Faster response times than LoRa. Low power consumption compared to LTE. Exhibits low latency compared to Sigfox.	Difficult to implement firmware-over-the-air (FOTA) or file transfers.

TABLE 2. ***(Continued)*** **Wireless communication standards IOT/C-IOT.**

LTE-M	LTE-M (Long Term Evolution, category M1) is a low power wide area (LPWA) technology standard published by 3GPP in the Releases 13-15 specification.	Up to 20km (enhanced RX Sens)	1024 kbps	Benefits from PLMN security and privacy features.	supports IoT through lower device complexity and transmits small amounts of data over long periods of time, with low power consumption.	LTE-M has higher throughput with lower latency and battery use is optimized accordingly.
5G	5th generation mobile network system. deployed on the concept of WISDOM (Wireless Innovative System for Dynamic Operating Mega communications concept).	Depending on coverage/capacity relations	50 Mbps-2 Gbps	IMSI encryption	It supports significantly faster mobile broadband speeds and heavier data usage than previous generations as well as to enable the full potential of the Internet of Things.	Initially, less widespread coverage comparing to 3G and 4G. Initial higher cost

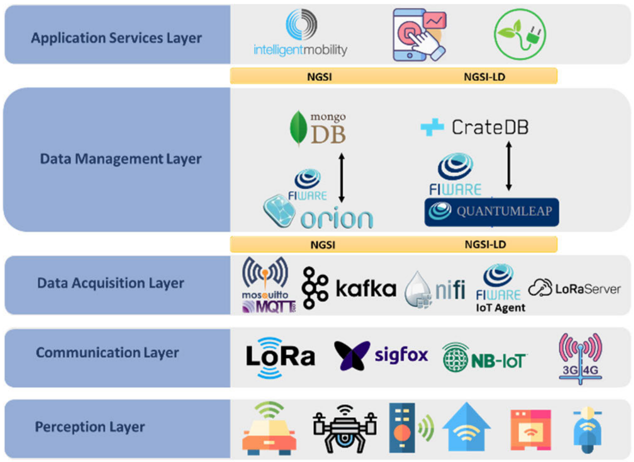


FIGURE 6. The platform layered architecture.

applications to accelerate the development of smart mobility solutions.

The system is structured in five main layers, namely, perception layer, communication layer, data acquisition layer, data management layer and application layer, as shown in Fig. 6. This architecture offers adequate scalability, since it allows the municipal managers to define the platform's service catalog (either incorporation or cancelation of services) as required. In this sense, scalability is achieved in three dimensions. The first is the possibility of defining and offering new services and functionalities, or the possibility of cancelling them, as the situation requires. The second dimension is the use of mechanisms for publishing services and access to the platform through a REST API and JSON files, which allow adequate accessibility to the platform while maintaining adequate distributed performance. Finally, the implementation of the platform in a virtualized system, which allows to adapt the operative instances of each component to the needs of each moment.

The perception layer consists of physical objects, which are monitored by sensor and actuator devices, having as main objective the collection of sensor data and command actuation. The Data Acquisition layer is composed of several communication technologies such as LoRaWAN [69], Sigfox [69], broadband cellular network technology, etc. To transmit sensory data and commands between the upper layers and the perception layer. The Data Management layer includes protocols and software components for data acquisition (e.g., MQTT [70], Kafka [71], and LoRa Server [72]) are the key characteristic of this layer, in addition to security and device management functions. The FIWARE IoT Agent GE also belongs to this layer as it translates the internal FIWARE data representation in JSON from/to devices. The Data Management layer includes software components responsible for data storage, processing and distribution based on one of FIWARE GEs (Orion). The Application Services Layer is in charge of information presentation, exchange and use.

V. SYSTEM IMPLEMENTATION

In this section, we describe the implementation of the city platform, the customizable smart mobility service proposed and the interaction of third-party systems with the mobility service through a REST API. We also include a case of study referred to a traffic restricted access zone which involves all the elements described in this section.

The smart mobility service considers the available information, which is provided on-demand by the city platform, and, according to the requisites provided by the citizen, offers the information that complies the given requisites. Urban mobility includes mobility by public transport (bus and taxi), including bus lines, frequencies and bus stops. But it also includes private vehicles, whether by car, motorbike or bicycle. This implies taking into account all the events that occur in the city (traffic, accidents, weather, works, levels of pollination, cultural agenda...), knowing in real-time the occupation of car parking or managing the access to traffic-restricted areas.

A. CITY PLATFORM IMPLEMENTATION

We have developed a city platform in order to provide customizable services for multimodal smart mobility.

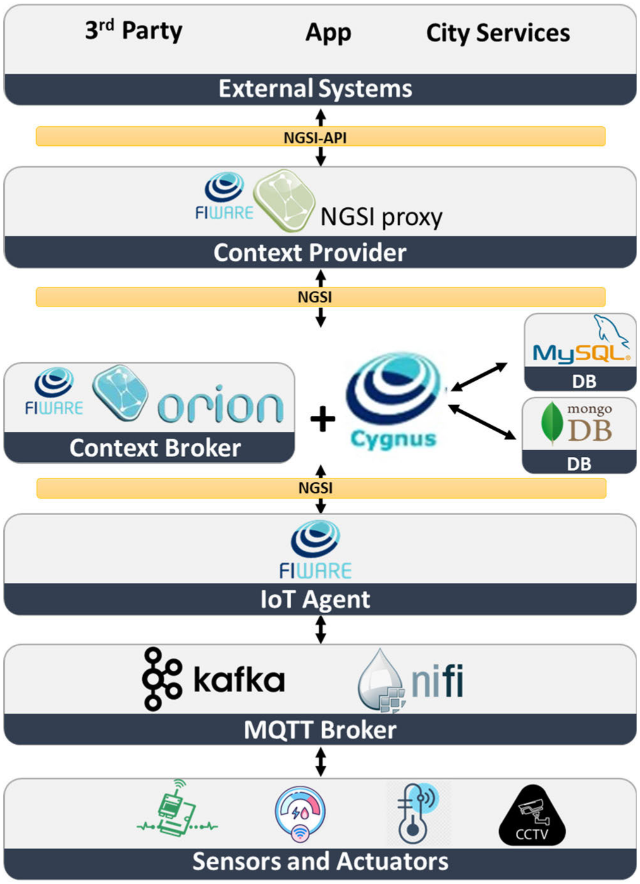


FIGURE 7. The Platform design and implementation.

```xml
    <nota_legal>http://www.aemet.es/es/nota_legal</nota_legal>
</origen>
<elaborado>2018-10-09T12:44:01</elaborado>
<nombre>Pamplona/Iru�a</nombre>
<provincia>Navarra</provincia>
<prediccion>
    <dia fecha="2018-10-09">
        <prob_precipitacion periodo="00-24"></prob_precipitacion>
        <prob_precipitacion periodo="00-12"></prob_precipitacion>
        <prob_precipitacion periodo="12-24">55</prob_precipitacion>
        <prob_precipitacion periodo="00-06"></prob_precipitacion>
        <prob_precipitacion periodo="06-12">5</prob_precipitacion>
        <prob_precipitacion periodo="12-18">20</prob_precipitacion>
        <prob_precipitacion periodo="18-24">40</prob_precipitacion>
        <cota_nieve_prov periodo="00-24"></cota_nieve_prov>
        <cota_nieve_prov periodo="00-12"></cota_nieve_prov>
        <cota_nieve_prov periodo="12-24">2300</cota_nieve_prov>
        <cota_nieve_prov periodo="00-06"></cota_nieve_prov>
        <cota_nieve_prov periodo="06-12"></cota_nieve_prov>
        <cota_nieve_prov periodo="12-18">2300</cota_nieve_prov>
        <cota_nieve_prov periodo="18-24">2300</cota_nieve_prov>
        <estado_cielo periodo="00-24" descripcion=""></estado_cielo>
        <estado_cielo periodo="00-12" descripcion=""></estado_cielo>
        <estado_cielo periodo="12-24" descripcion="Intervalos nubosos con lluvia escasa">43</estado_cielo>
        <estado_cielo periodo="00-06" descripcion=""></estado_cielo>
        <estado_cielo periodo="06-12" descripcion="Poco nuboso">12</estado_cielo>
        <estado_cielo periodo="12-18" descripcion="Intervalos nubosos">13</estado_cielo>
        <estado_cielo periodo="18-24" descripcion="Intervalos nubosos con lluvia escasa">43</estado_cielo>
```

FIGURE 8. A snapshot of meteorological information in XML format.

```
▼ object {4}
    type : FeatureCollection
    totalFeatures : 40
  ▼ features [40]
    ▼ 0  {5}
        type : Feature
        id   : TRAURB_Sym_TUCTaxis.1
      ▼ geometry {2}
          type : Point
        ▼ coordinates [2]
            0  : 613463.076398
            1  : 4740560.97749678
        geometry_name : the_geom
      ▼ properties {5}
          FEATURE : 10200059
          CPARADA : 940
          PARADA : Mendillorri - c/ Palacio (c/ Concejo de Olaz)
          LONGITUD : 18
          BEGINLIFE : 05/09/2017
    ▶ 1  {5}
    ▶ 2  {5}
    ▶ 3  {5}
    ▶ 4  {5}
```

```
▼ object {4}
    type : FeatureCollection
    totalFeatures : 117
  ▼ features [117]
    ▼ 0  {5}
        type : Feature
        id   : PAMPLO_Pol_JuegosInf.1
      ▼ geometry {2}
          type : MultiPolygon
        ▼ coordinates [1]
          ▼ 0  [1]
            ▼ 0  [5]
              ▼ 0  [2]
                  0  : 608822.177
                  1  : 4742323.242
              ▶ 1  [2]
              ▶ 2  [2]
              ▶ 3  [2]
              ▶ 4  [2]
        geometry_name : the_geom
      ▼ properties {11}
          FEATURE : 60100006
          CJUEGOINF : 60
          JUEGOINF : Paseo de Santa lucía
          BARRIO : Buztintxuri
          FECHAJUEGO : 2005
```

FIGURE 9. A snapshot of territorial information in JSON format.

As Fig. 7 shows, the system collects data from sensors, actuators and other sources with the aid of a MQTT broker. With the aid of the Apache Kafka and Nifi components, data collected is normalized and properly transmitted to the Fiware IoT agent, where the Orion context broker performs the data storage with the support of the Cygnus component. Data storage follows the NGGSI data model and can be performed either into relational and non-relational databases. If requires, distributed file systems as HDPS can also be used. Finally, the API REST allows third party interaction with data. The system uses message queueing, ETLs and data flow management to ensure data garbage, while the Fiware's components provide consistent and persistent data storage, all through standardized and interoperable NGSI data models.

In the perception layer, we deal with several types of sensors and actuators. The public administration and other sectors already deployed them partially, and the rest were distributed along the city. The sensors and actuators include air quality sensors (NO_2, O_3, CO), noise monitoring sensors, available parking slot sensor, and smart streetlights sensors [73]. All the data collected is transmitted using wireless communication technologies to Internet.

Data garbage and import from logical sources is performed automatically by a set of specific bots that update the information automatically with the programmed frequency to the platform. As the municipal services schedule any cultural, institutional, sport, social, educational, environmental or safety (pollution, traffic…) activity or event, the information is automatically uploaded to the platform so that it can be available for the mobility services to offer an adequate service.

We acquired the environmental factors from four major sources. The first one is AEMET (Agencia Estatal de Meteorología, Spain's meteorological agency) [67]. It provides open data about meteorological and climatological information. This information includes weather forecasting, warnings, announcements, and public attention. Fig. 8 illustrates a snapshot of the XML file that we imported from the AEMET's web service to acquire meteorological information.

The second source is SITNA (Sistema de Información Territorial de Navarra) [68]. SITNA provides information including various topics: orthophotos, cartography, facilities, hydrography, culture, environment, infrastructures, and so on. Fig. 9 shows a part of two JSON files form SITNA that have information regarding taxi stands and municipal parks which including (ID, type, coordination, etc.). We used this information to provide a set of mobility options depending on the user preferences.

The third source is the information provided by the Government of Navarre concerning air quality control [69] and meteorology [70].

With respect to crowd counting, we used a Wi-Fi RSSI (Received Signal Strength Indicator) - based crowd counting system implemented in-house to estimate the number of people in a crowd at a certain area. So, depending on estimates, the system avoids the routes of these overcrowded locations, which contributes to reducing traffic congestion and shortening the trip time. The working principle of Wi-Fi RSSI- based crowd counting system is based on reading the strength of the Wi-Fi signal from the user's mobile. In this way, the system does not need any kind of registration or pairing to work, ensuring that the privacy of the user is not violated. Fig. 10 illustrates the heat map of the number of Wi-Fi access points and the RSSI values received during a journey in the city of Pamplona.

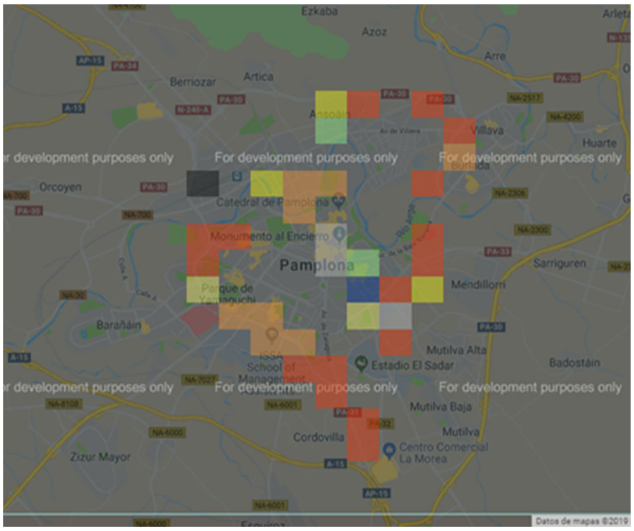


FIGURE 10. Heat map of RSSI values crowdsensing estimations.

For the case of physical sensor data collection, we use a Zigbee wireless sensor network, based on an adequate balance in terms of coverage/capacity performance, meshing capability and low energy consumption [58]. The proposed use case presents moderate coverage requirements (with expected communication links in the range of 1-50m) and transmission bit rates that are below the maximum achievable rate of 250 Kbps. The adopted solution consists of an IoT cloud which provides cloud storage to store the sensors measurements (bases in "ThingSpeak" [71]), a gateway to connect networks of Digi XBee to wide area network (WAN), a coordinator as sensors measurements collector, and end-devices which provide sensor readings over Xbee communication links as shown in Fig. 11.

As seen in Fig. 11, a coordinator placed, for example in the bike station, collects the measures acquired by sensors (end devices) acting as the gateway of the WSN. Coordinators and end-devices consist of a Bluno Nano, which is an Arduino Nano with Bluetooth 4.0, Xbee Shield, and Xbee pro s2c modules. End-devices also include a battery, a GPS (Global Positioning System) module, and some sensors (temperature, humidity…). The main function of the end-device is to provide the coordinator with the measurements of all sensors. The end-device has an on-demand operation mode (pool from the coordinator) and a periodical autonomous acquisition mode. The use of a Digi XBee Gateway is due to be a low-cost programmable solution to connect networks of Digi XBee-enabled devices to WAN. XBee Gateway receives serial data from an XBee node of the network and stores it in the DRM (Digi Remote Manager) automatically. DRM is a secure management application to monitor and control distributed IoT devices, which offers advanced compatibility with many cloud analytic platforms, making deployment and management of IoT networks and devices faster and easier. Both Gateway and Coordinator are expected to be powered directly from the mains, ruling out the possibility of battery operation.

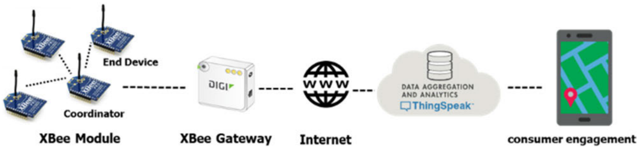


FIGURE 11. Zigbee wireless sensor network.

Data from both sensors and logical sources arrive to the Data Acquisition Layer, at whose MQTT broker the data ingestion occurs. Fig. 12 illustrates an example of data management and translation to JSON format.

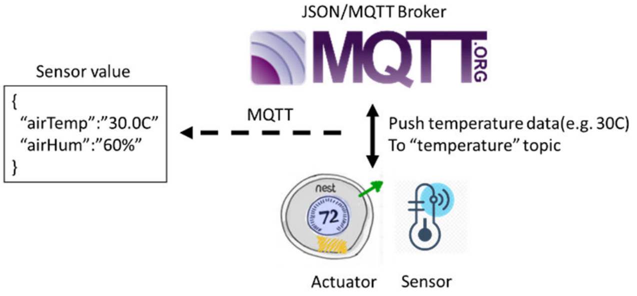


FIGURE 12. Translation of sensor data into JSON format.

Subsequently, data received by the MQTT Broker is sent by means of publish/subscribe schemas to the FIWARE IoT Agent. The FIWARE IoT Agent works with NGSI-formatted data, which is provided to the FIWARE Orion Context Broker. The FIWARE Orion Context Broker hold context data information such as data entities, subscriptions and registrations into relational and no relational databases, as MySQL and MongoDB in our case. In case of requesting a context data from external sources, the Context Provider NGSI proxy (which is in our platform is Express.Js, a minimal and flexible Node.js) offers an NGSI interface for context providers. It receives requests using NGSI, makes requests to publicly available data sources using their own APIs in a proprietary format, and returns context data back to the Orion Context Broker in NGSI format.

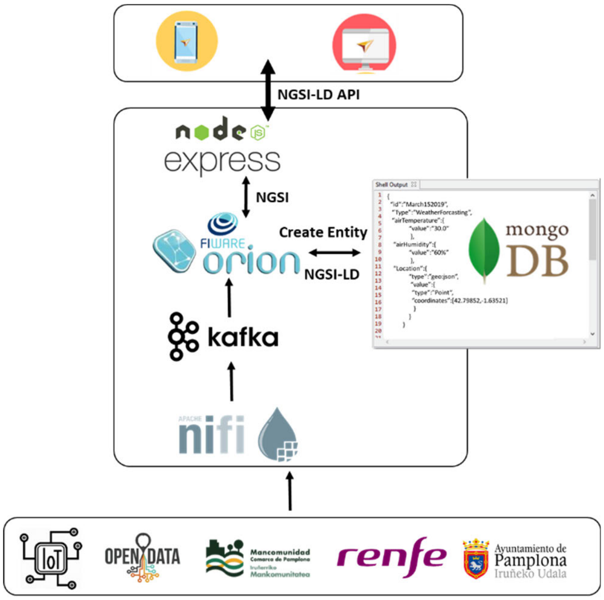
B. CUSTOMIZABLE SMART MOBILITY SERVICE

Once we have obtained, through the integration of external sources, information such as pollution levels, weather conditions, city traffic, pollination level, etc. we can proceed to propose intelligent mobility solutions to users. To do so, users can define their preferences and interests, which can be specific to a particular moment or of long duration. For example, let' s suppose that a citizen allergic to grass pollen, who rides a bicycle around the city, wants to visit a photo exhibition at a civic center in the old town. Furthermore, the user first wants to visit a pharmacy, wishes to avoid rush hour traffic congestion and finally wants to park her/his bike in a guarded bicycle parking lot. Our system takes into account, with the help of an ontology and a semantic reasoner, all these issues and suggests different mobility options to the user, and guides her/him on the journey by updating all those aspects that may change in his environment during the journey (for example, traffic conditions, parking occupation, rain forecast…). The aim is to offer an effective, efficient and real-time mobility service so that the user can adapt her/his mobility plan to her/his real needs as the state of the city changes.

The smart urban mobility service provides a customizable mobility through semantic interpretations through a web app. To provide the service, it operates in two modes: (1) user profile registration mode; and (2) service request mode. The user profile registration mode is used to register user profiles, such as an ID, password, information around individuals and characteristics (age, profession, gender), location of home and workplace or other significant places (location of school or grocery shop…). The service request mode allows to request an urban mobility service based on the registered user profile and the requisites indicated in the query. The service consists of a web service, the ontology, the reasoner, and the REST API. Fig. 13, shows the data flow of the information. Data acquired form different sources is normalized and properly stored into the platform, which allows data query by the reasoner and its publication by the web service according to user's preferences.

1) DATA MODEL

This subsection presents the data model of the intelligent urban mobility service. Fig. 14 illustrates the implemented semantic model (ontology). The idea is to make use of the huge amount of data, obtained from the different sectors within the smart city system, to provide a new urban mobility service to the user. The challenge lies on the fact that this amount of data comes with different data types and formats, so there is a need to build a knowledge base as a semantic representation to convert and formalize it from unintelligible format to a textual and meaningful format. This can be achieved by building semantic reasoning and representation that facilitates the perception of multiple data sources as meaningful. Therefore, building an ontology is to enhance the system performance by describing the different formats and data types more knowledgeably and better representing the data context.



```
{
 "id":"March152019",
  "Type":"WeatherForcasting",
  "airTemperature":{
          "value":"30.0"
          },
  "airHumidity":{
          "value":"60%"
          },
  "Location":{
          "type":"geo:json",
           "value":{
           "type":"Point",
           "coordinates":[42.79852,-1.63521]
            }
          }
      }
```

FIGURE 13. Service flow diagram for intelligent urban mobility.

However, to provide customizable multimodal service to residents, the platform offers a REST API to allow third-party applications, which will be described later. Fig. 15 describes the behavior and data flow of the smart mobility service. The query engine manages the interaction between data and knowledge and provides, with the aid of the REST API, the information required to the third-party apps.

The REST API allows third-party Apps to interact with the smart mobility service. The engine receives the requests (JSON format), builds the appropriate SPARQL queries and executes them against the knowledge base obtaining a set of RDF (Resource Description Framework) triplets, which describe the conceptual model. The engine takes into account both the customized parameters included into the request and the triplets recovered, and provides a JSON file with the results, which is submitted to the App. Finally, the third-party App receives the response in JSON format (also available in XML format if required) and then displays the information.

However, aspects such as user preferences, crowd estimation, and environmental factors played a significant role in the process of journey planning in addition to other elements such as the General Bikeshare Feed Specification (GBFS) and the real-time General Transit Feed Specification (GTFS) depicted in Fig. 14). Thereby, users can plan their routes based on what they prefer rather than what regular journey planners do, which in most cases disregard personal preferences and the actual situation. Both aspects are of particular relevance in the preference setting in a multimodal of some transportation modes, such as biking, which depend on personal characteristics and exogenous factors, such as the weather.

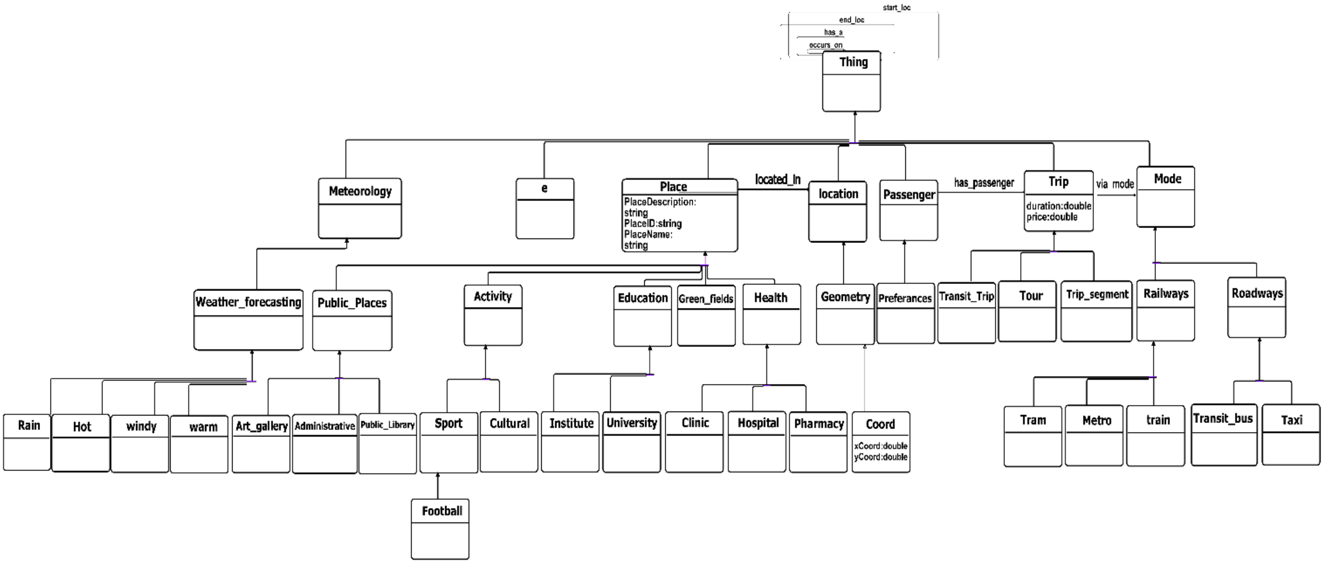


FIGURE 14. Semantic model of the intelligent urban mobility.

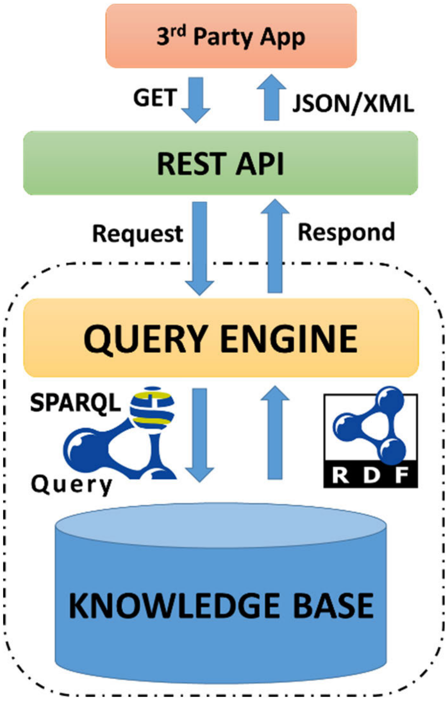


FIGURE 15. Smart mobility service schema.

As seen in Fig. 16, the environmental factors include several elements, such as natural environment (weather, air quality, and others), land use mix, accessibility to points-of-interest (schools, shops, parks, and gyms), etc. The environmental factors offer various options that helped commuters make their decisions about which one of the two modes of transport (public bus and bicycle sharing) they would ride. Alternatively, in the case of mixed mode, with which mode they will they start their trip, and with which one they will end it. Previous studies reveal that the cycling behavior of BSS cyclists tends to be influenced by environmental factors, including land use mix, green space, cycling facilities, and safety [72]–[77]. The importance of external factors is given by the fact that they influence the individual's election of the means of transport they would use and when.

2) DATA VISUALIZATION

Fig. 17 shows several recommended routes based on user request. The route in red color represents the bicycle route, whereas the one in blue color is for the urban bus route. The mobility proposal can include intermodality if desired. In this case, the system considers the possibility of booking a guarded parking slot or that the folded bicycle can be transported in the bus. Fig. 18 depicts part of the data harvested from sensors located on a bicycle moving across the city as the real-time location and the air temperature.

C. INTERACTION WITH THIRD-PARTY SYSTEMS

Interaction with third-party systems is provided by means of Swagger [78], an Interface Description Language (IDL) for describing RESTful APIs expressed using JSON. The REST API follows the OpenAPI 3.0 specification [79] and uses the JWT (JSON Web Token), based on the RFC 7519 standard, to define a compact and self-contained way of securely transmitting information between parties as a JSON object. This information can be verified and trusted because it is digitally signed. One of the main features of JWT is that it does not need to store the tokens into a database on the server or support an authentication service. An example of query may be:

$$GET$$

$$https : //XXX.XXX.XXX/events?id\_types = 8, 12, 14$$

$$\&idZone = SouthEast\&includeTraffic = true\&dateFrom$$

$$= 2020 - 11 - 12\&dateTo = 2020 - 12 - 31$$

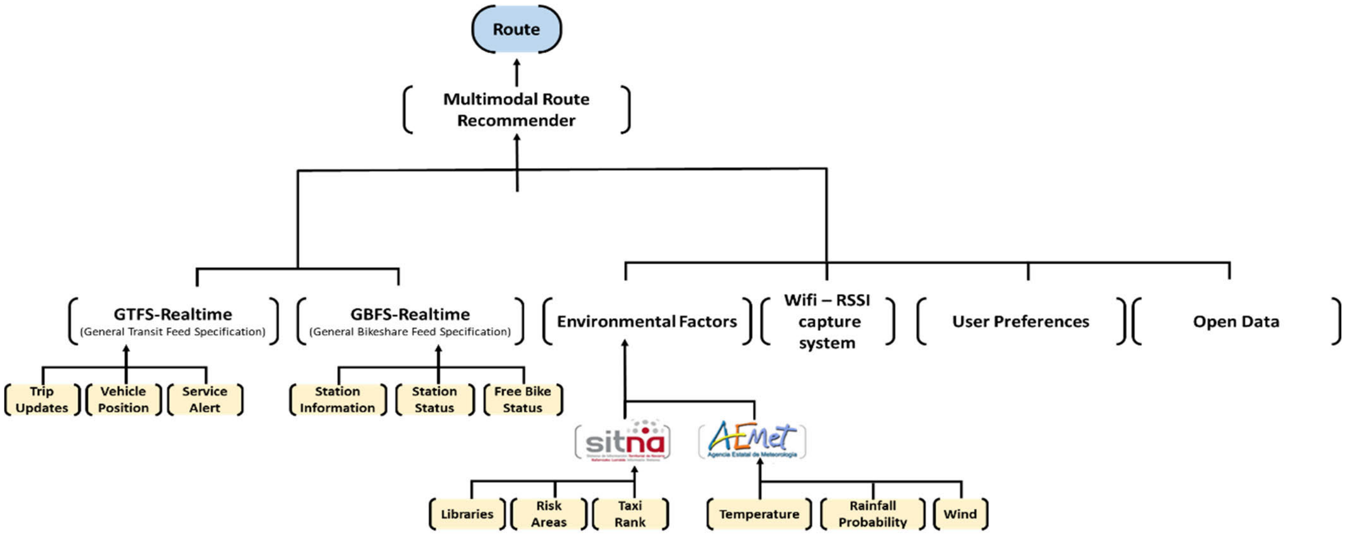


FIGURE 16. Some of the data sources of the intelligent urban mobility system proposed.

FIGURE 17. Data visualization of several recommended routes.

Obtaining as result a JSON file including all the information available that satisfies the conditions of the query. Swagger provides the needed transparency in order to interact with the remote service with a minimal amount of implementation logic. This makes it relatively easy to develop and deploy new services and applications based on the mobility service above described and the support of the city platform.

D. CASE STUDY: ZAC SYSTEM

In order to provide insight in relation with the system developed, a specific case study is presented in this section. The

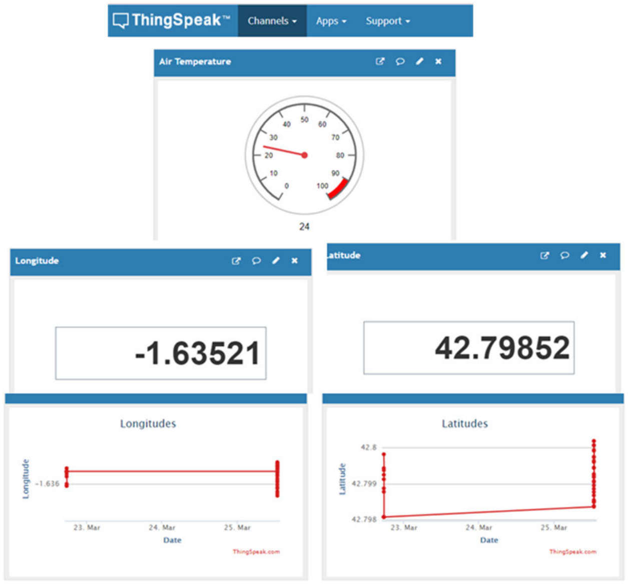
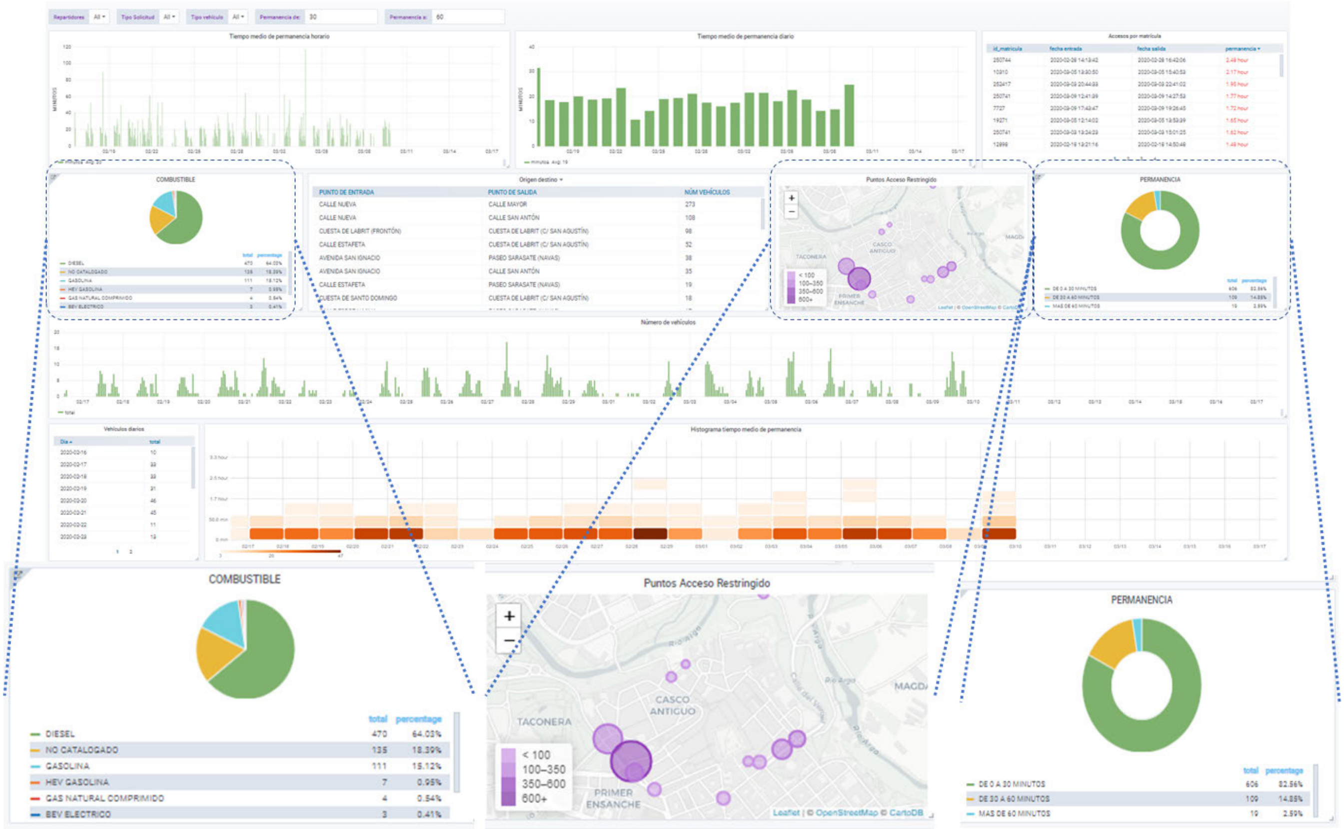


FIGURE 18. Data visualization of sensory data in the ThingSpaeak cloud.

ZAC (Restricted Access Zone - Zona de ACceso restringido) is a traffic-restricted area located in the middle of the city of Pamplona, in the so-called Old Town. The streets which are part of the restricted traffic zone are mainly pedestrian, with the goal of preserving freedom of transit and safety of pedestrians and cyclists. The aim of ZAC is to reduce the volume of motor vehicles on the streets of the Old Town, guaranteeing greater urban quality in the area by improving the aesthetics and reducing the noise and smoke generated by motor vehicles. This area is monitored and controlled by cameras distributed across the entrances to the ZAC, in order to enforce access to authorized users. The authorized users are those who can only enter by their private cars, whereas



PUNTO DE ENTRADA	PUNTO DE SALIDA	NÚM VEHÍCULOS
CALLE NUEVA	CALLE MAYOR	273
CALLE NUEVA	CALLE SAN ANTÓN	108
CUESTA DE LABRIT (FRONTÓN)	CUESTA DE LABRIT (C/ SAN AGUSTÍN)	98
CALLE ESTAFETA	CUESTA DE LABRIT (C/ SAN AGUSTÍN)	52
AVENIDA SAN IGNACIO	PASEO SARASATE (NAVAS)	38
AVENIDA SAN IGNACIO	CALLE SAN ANTÓN	35
CALLE ESTAFETA	PASEO SARASATE (NAVAS)	19
CUESTA DE SANTO DOMINGO	CUESTA DE LABRIT (C/ SAN AGUSTÍN)	18

COMBUSTIBLE	total	percentage
DIESEL	470	64.03%
NO CATALOGADO	135	18.39%
GASOLINA	111	15.12%
HEV GASOLINA	7	0.95%
GAS NATURAL COMPRIMIDO	4	0.54%
BEV ELECTRICO	3	0.41%

PERMANENCIA	total	percentage
DE 0 A 30 MINUTOS	606	82.56%
DE 30 A 60 MINUTOS	109	14.85%
MAS DE 60 MINUTOS	19	2.59%

FIGURE 19. View of the implemented ZAC control dashboard. [Source: Ayuntamiento de Pamplona and SICE].

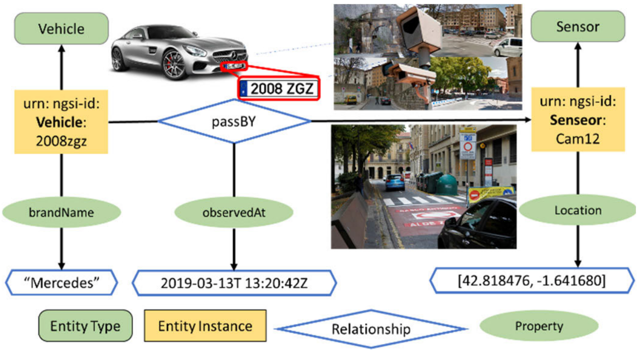


FIGURE 20. Combined data Exchange – ZAC system.

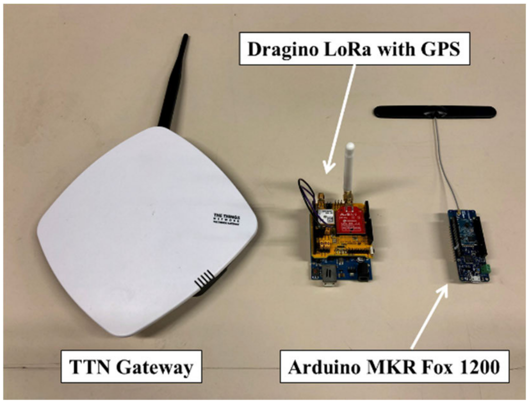


FIGURE 21. Employed LoRaWAN and SigFox hardware for measurements.

the bicycles are exempt from requesting authorization. Therefore, we used the data that come from the ZAC system in our intelligent mobility application to avoid passing into this area in the absence of a permit for that or to recommend the use of bicycles in case the location of the destination is inside this area.

Fig. 19 illustrates the dashboard of the ZAC system used by the city council of Pamplona. Built from the data provided by the city platform using the interactive visualization tool Grafana, the dashboard presents information about the restricted zone such as the number of vehicles that entered, the average of daily stay time, vehicle registration plates, presence/absence of transit permit, the level of air pollution, vehicle entry/departure time, the stay time for each vehicle, and many other details.

Fig. 20 depicts the ontology implemented in linked-data and NGSI-LD standard in the ZAC system to control the entrance of vehicles to the restricted zones in the Old Town.

The ZAC use case presents coverage/capacity requirements given by communication links that can span up to 1 km, with very low communication transmission rates. In this sense, LWPAN communication protocols provide adequate service in terms of scalability, power consumption, coverage and bit rate requirements.

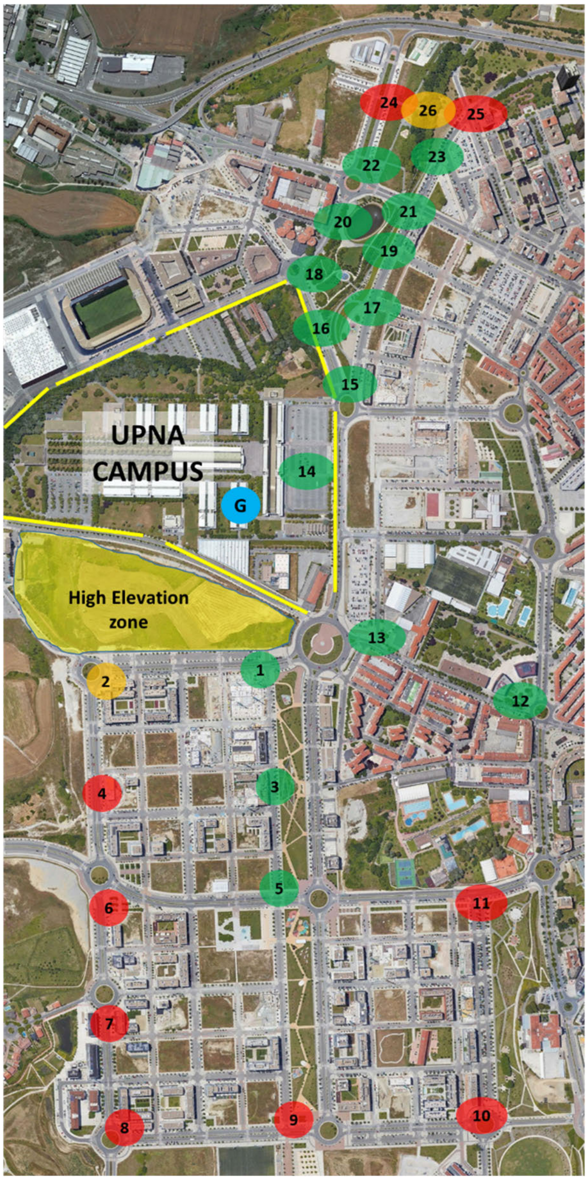


FIGURE 22. LoRaWAN measurements results. Green: No packet losses. Yellow: some packet losses. Red: All packets lost.

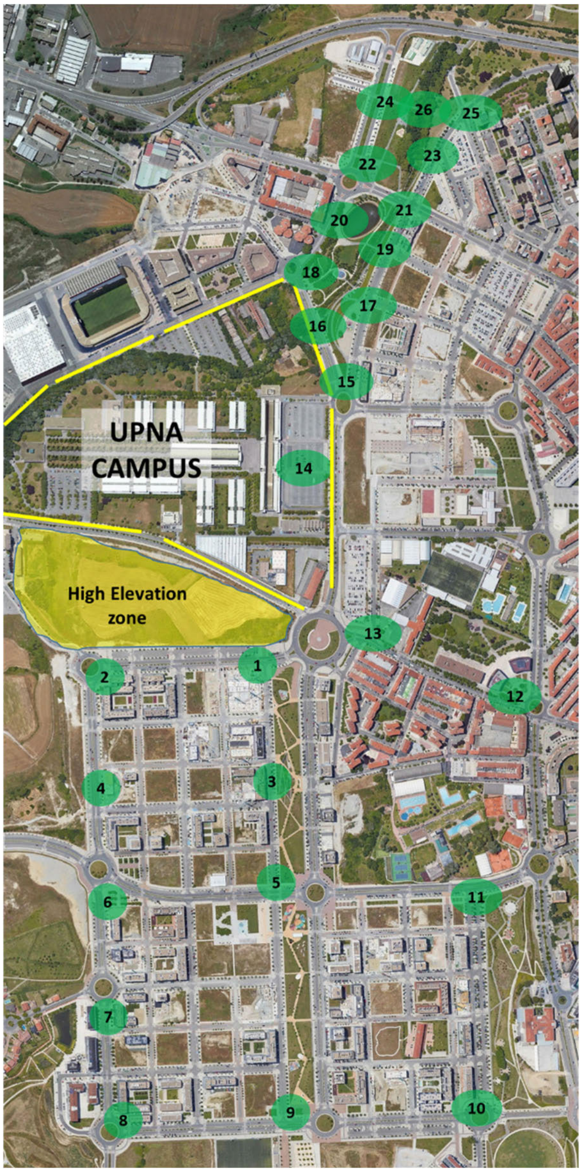


FIGURE 23. SigFox measurements results. Green: No packet losses. Yellow: some packet losses. Red: All packets lost.

In order to assess different long-range wireless communication technologies for their implementation in urban environments, a measurement campaign has been carried out within an urban test scenario in the city of Pamplona. For that purpose, SigFox and LoRaWAN technologies have been chosen, both operating at 868 MHz frequency band. Fig. 21 shows the employed hardware.

On the one hand, the TTN LoRaWAN Gateway from The Things Networks and the Dragino LoRa shield with GPS mounted on an Arduino UNO board have been employed to assess LoRaWAN technology. The TTN Gateway has been deployed within the Electric, Electronic and Communications Engineering Department building of the Public University of Navarre (UPNA), and it is represented by a blue circle named "G" in Fig. 22. The gateway has been located on the second floor, near a window, in order to increase link visibility. On the other hand, the Arduino MKR FOX 1200 device has been used for SigFox technology assessment. In this case, no gateway deployment is needed since SigFox alliance provides the network infrastructure and coverage, so unlike LoRaWAN, there is no need to establish and maintain the wireless communication network infrastructure.

Fig. 22 shows a map where the UPNA campus is delimited by yellow lines. The LoRaWAN Gateway location is represented by the blue circle, and the 26 measurement points where the mote based on Dragino LoRa shield has been deployed are shown with different colors. Green color represents that no packet has been lost in the communication; yellow color means that some packets have been lost; and red color that all packets have been lost. For each measurement point, 4 packets have been transmitted from the mote to the

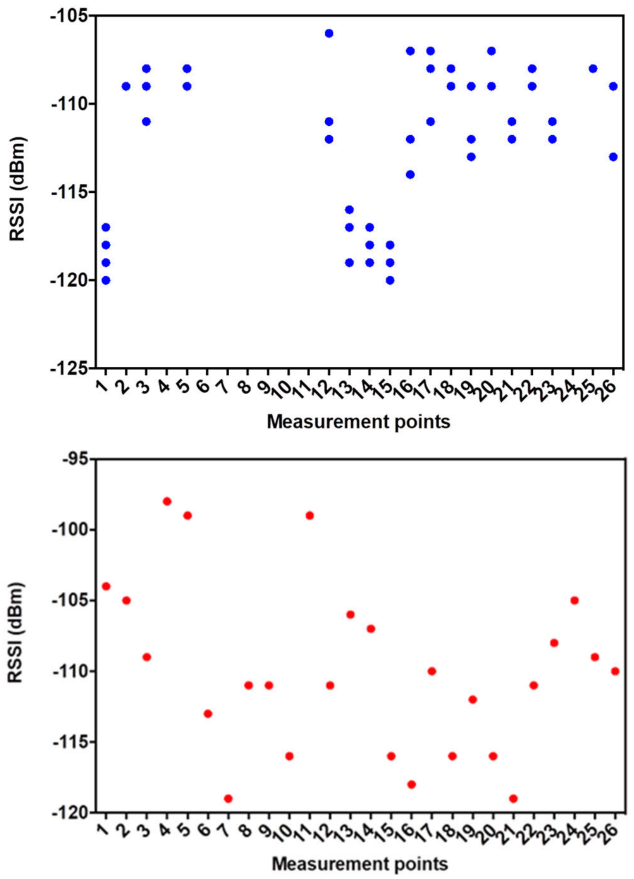


FIGURE 24. **RSSI values for LoRaWAN measurements (top) and SigFox measurements (bottom).**

TTN Gateway. The packets have been sent every 30s, which is the shortest interval between packets allowed by LoRaWAN. The equivalent measurement set for the case of SigFox setup is depicted in Fig. 23.

Fig. 24 presents the RSSI of the packets received by the Gateway and stored in the cloud. Note that in some 'Green' cases (e.g. 14), less than 4 points are seen in the graph, but 4 packets were received: different packets with the same RSSI value are represented by the same point in the graph. As it can be seen, the Gateway covers a wide are of the surrounding of the UPNA campus, but the high elevation zone (marked in yellow in Fig. 19, which is higher than the tallest building of the University) causes great losses in the communication with the nodes deployed across the hill, even for short distances from the Gateway (e.g. measurement points 2 and 4). It is worth noting that the coverage would be expected to be better if the Gateway could be deployed in higher levels. All these results and facts show that even the LoRaWAN technology is an interesting one in order to cover wide urban zones, the deployment of the Gateway and the overall radio planning tasks have a great impact in the performance of the network.

The same measurements have been taken for the case of SigFox technology. As mentioned, in this case, no network infrastructure is needed to be deployed. Therefore, only the Arduino MKR FOX 1200 mote has been deployed in the same 26 measurement points. Again, 4 packets have sent in every point, with 30s interval time. In this case, all the packets have been successfully received and stored in the cloud. SigFox shows better performance within this urban environment in terms of coverage, with no infrastructure deployment requirements. However, control on wireless communication network by the user isn't enabled and per node costs arise in the use and operation of the system. In relation with system scalability as related to wireless network capabilities, in the case of LoRaWan, the limitation in the number of connected devices is given mainly by the handling capability of each one of the gateways provided within the service area under analysis, as well as by interference thresholds (in the case of simultaneous transmissions). In this way, several thousands of transceivers can be handled by each gateway in the case of non-simultaneous transmissions, providing feasible wireless connectivity in different urban/city related applications [85], [86].

VI. CONCLUSION

In this work we have discussed the development of an urban data platform as a supportive infrastructure in the development of a smart city is presented. A range of functionalities are addressed, obtaining information from the environment through sensors or open data sources or other alternative sources fulfilling security and privacy requirements. In order to fulfill interoperability requirements, the obtained data are normalized to the NGSI format, translating from the formats, and different protocols of the data source to the platform data models. The normalized data in then distribute to the various vertical services linked to the platform, in our case the urban mobility. In order to evaluate the performance of the platform, we introduce an intelligent urban mobility solution that utilizing the data obtained by the platform from multiple sources and networks, along with the preferences of commuters to dynamically respond to demands and operate more efficiently. A platform architecture is implemented, following a five-layer model, considering elements from perception and sensing to data management and processing. Two different use cases are described, which have been implemented in the city of Pamplona: intelligent urban mobility-bike handling and restricted vehicle access zone control system. System description implementation and evaluation have been presented. The proposed system provides a scalable and adaptive solution in order to implement a Smart City handling platform.

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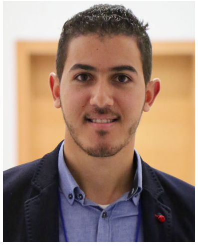

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