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COOPERATING SMART OBJECTS IN IOT INFRASTRUCTURES FOR CONTEXT-AWARE APPLICATIONS

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Il tempo scorre, gli obiettivi si raggiungono e passano. Ma la cosa piu' importante rimane non trascurare cio' per cui ci troviamo al mondo: gli Affetti.

Grazie alla mia famiglia, mio padre Alfio e mia madre Adelaide. Tutto cio' che sono e' il risultato dei vostri insegnamenti e sacrifici.

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La dedico a voi.

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ABSTRACT

Over the last years, researchers have shown a great interest for Internet of Things (IoT). The evolution of this new paradigm, provides a new "object" concept, in which new relevant technologies enrich ordinary objects with new interesting features which aim to make them Smart. Each object becomes a device able to gather information and react in the surrounding environment.

In accordance with the raise of IoT paradigm, many researchers and companies have developed systems and applications that exploit the new smart objects' technologies to provide customized information and services. In fact, the spread of smart objects in areas/spaces frequented during activities of daily life promote the usage of these services, but, often, is not clear for users which services are available in a specific place at a specific moment.

In order to provide personalized services, IoT applications gather personal data such as preferences, habits, and information about users' positioning which are part of "User Context", a relevant concept that has been studied several years ago, and that is treated in the next chapters of this Thesis with the introduction of the Context-Aware Applications.

In particular, the users' positioning is considered a very relevant concept for the Context-Aware Applications, with several Indoor and Outdoor local-

ization technologies developed during the last years, such as GPS or Bluetooth Low Energy(BLE) which allow to collect users' information within constrained and unconstrained environments (cities, buildings, offices and houses).

The work done during the Ph.D. years focuses on cooperating smart objects in IoT infrastructures that exploit the aforementioned indoor and outdoor localization technologies to provides Context-Aware Applications.

In particular, this Thesis is going to introduce IoT concepts with the works developed during these years which apply IoT Context-Aware concepts in several fields, including smart cities and smart environments.

The first chapter of this thesis introduces the Internet of Things as a new paradigm and as an enhancement for the quality of ordinary peoples' lives. It aims to highlight the IoT origins and its development through new communication technologies.

Initially, the introduction chapter shows the increase of ordinary objects' capabilities through the exploitation of IoT concepts, and introduces the application domains in which these new devices are placed.

The first chapter also introduces the relevant Context concept, the development of Context-Aware applications to provide customized services within smart environments, the establishment of new IoT networks which have many common points with the traditional networks, and a set of relevant open issues as challenges for the research communities.

The other chapters report a set of works developed during my Ph.D. years which aims to provide customized services in several IoT domains to increase the users' experiences within a smart environment.

In particular, these works aim to provide solutions for several issues in smart cities (Chapters 2, 5), smart homes and offices (Chapter 3), and smart museums (Chapter 4). The main common objective is to show how the IoT could represent a value added to the people's lives.

Peoples have a great interest towards the technologies, and a relevant number of persons is already equipped with smart devices (i.e. smartphones). For this reason, i think that could be a useful to exploit these devices and their sensors for the creation of customized services without the using of expansive infrastructures or additional annoying equipment if their are not necessary.

The Thesis also introduces a more complex and expansive IoT solution i.e. an Air Quality Monitoring System which aims to report the air pollution information through a web application, and gather user's context information through a mobile application in order to suggest the appropriate places or the appropriate routes (in term of pollution) to reach a destination.

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SOMMARIO

Nel corso degli ultimi anni, i ricercatori hanno mostrato un grande interesse nei confronti dell' Internet of Things (IoT). L'evoluzione di questo nuovo paradigma porta alla nascita di un nuovo concetto di Oggetto (Object), che grazie alle moderne tecnologie viene arricchito da nuove e interessanti caratteristiche e funzionalita' che lo rendono Intelligente (Smart). Da qui il termine Smart Object. Ciascun oggetto diventa un dispositivo capace di raccogliere informazioni e reagire all'ambiente che lo circonda.

Con l'ascesa del paradigma IoT, molti ricercatori e aziende hanno sviluppato sistemi e applicazioni che sfruttano l'utilizzo dei nuovi Smart Object per fornire servizi personalizzati e informazioni utili.

Infatti, la diffusione di Smart Object all'interno di aree frequentate, promuove l'utilizzo di questi servizi, anche se spesso non e' chiara la loro disponibilita', dipendente dal tempo e dallo spazio.

Le applicatizioni IoT mirano alla raccolta di informazioni personali, quali preferenze, abitudini, ed informazioni relative alla propria posizione, definendo il Contesto (Context) dell'utente, un concetto molto importante, studiato diversi anni fa e trattato nei prossimi capitoli mediante l'introduzione delle applicationi Context-Aware.

In particolare, la posizione degli utenti e' considerata un concetto molto importante per le applicazioni Context-Aware, con diverse tecnologie di localizzazione Indoor e Outdoor realizzate negli ultimi anni, quali GPS o Bluetooth Low Energy (BLE), permettendo di raccogliere informazioni all'interno di ampi o ristretti ambienti (citta', edifici, uffici e abitazioni).

Il lavoro svolto durante il mio Dottorato di Ricerca si e' focalizzato su Smart Object cooperanti all'interno di infrastrutture IoT, sfruttanti le tecnologie indoor e outdoor appena mensionate per la realizzazione di applicazioni Context-Aware.

Questa tesi presentera' i concetti dell'Internet of Things e diverse questioni ancora irrisolte, o parzialmente risolte, insieme ai lavori sviluppati durante questi anni, nei quali ho cercato di applicare i concetti dell'IoT in diversi ambiti quali Citta' Intelligenti (Smart Cities) ed Ambienti Intelligenti (Smart Environment).

Il primo capitolo di questa tesi introdurra' l'Internet of Things come nuovo paradigma ed miglioramento della qualita' della vita. Verranno messe in evidenza le origini dell'IoT e il suo sviluppo attraverso l'introduzione di nuove tecnologie.

Questo capitolo introduttivo mostrera' l'incremento delle capacita' degli oggetti ordinari attraverso l'utilizzo dei concetti dell'IoT, e presentera' diversi domini applicativi in cui questi dispositivi vengono posti.

Inoltre, il primo capitolo introdurra' l'importante concetto di Context, lo sviluppo delle applicazioni Context-Aware per la realizzazione di servizi personalizzati all'interno degli ambienti smart, la realizzazione di reti IoT che presentano molti punti in comune con le reti informatiche tradizionali, ed un insieme di problematiche ancora aperte che rappresentano sfide per la comunita' di ricerca.

Gli altri capitoli riporteranno una serie di lavori sviluppati durante l'attivita' di Dottorato di Ricerca, e che hanno come obiettivo la copertura di diversi domini IoT fornendo servizi in grado di aumentare l'esperienza utente all'interno degli ambienti smart.

Questi lavori hanno l'obiettivo di fornire soluzioni per citta' (Capitolo 2, 5), abitazioni e uffici (Capitolo 3), e musei (Chapter 4). L'obiettivo comune e' mostrare come l'IoT possa rappresentare un valore aggiunto nella vita delle persone.

Le persone hanno mostrato un grande interesse nei confronti della tacnologia, ed un numero non indifferente di utenti sono gia' forniti da una serie di dispositivi smart (come gli smartphone). Per questo motivo, penso sia molto utile sfruttare questi dispositi ed i loro sensori per la realizzazione e la personalizzazione di servizi, senza la necessita' di utilizzare ulteriori costose infrastrutture, o fastidiosi sensori addizionali.

Infine, questa Tesi introdurra' un sistema maggiormente complesso e costoso, ovvero un sistema per il monitoraggio della qualita' dell'aria, che ha come obiettivo quello di realizzare un report dell'inquinamento attraverso un applicazione web, raccogliendo informazioni di contesto dell'utente per fornire dei consigli su quali strade utilizzare o quali posti raggiungere evitando l'inquinamento.

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CHAPTER

ONE

INTRODUCTION TO THE INTERNET OF THINGS PARADIGM

1.1 The Internet of Things

The development of computer networks, Internet Protocol and communication technologies brings to a new mobile-oriented connected world. These technologies, with others, are widely exploited for the implementations of concepts concerning to a new paradigm called Internet of Things (IoT) [1–3]. This term was first documented by British visionary Kevin Ashton in 1999. In particular, he used IoT term to describe a system where the Internet connects to the “real world” via a ubiquitous network of data sensors. The origin of IoT has been attributed to members of the Auto-ID Center at MIT, the development community of the Radio-Frequency Identification (RFID), around 2000.

The RFID is a technology that allows ordinary objects to be uniquely identified by “smart tags” [4] which are able to store small quantities of data. In line with the RFID technology, the members of the Auto-ID Center aimed to discover information about a tagged object through an internet address or a database entry related to a particular RFID. In this way, each physical object can be identified through the recognition of a universal identify (like a URI).

Today, the concept of Thing is more general and is not limited to RFID only, but it is widely exploited into the research world, and it is subjected to novel interpretations in which different aspects and technologies are combined: Internet Protocol, Sensing and Communication Technologies, Ubiquitous computing, Pervasive computing, and embedded devices. Thus, the IoT brings to a new vision for data exchange and computation that is opposite to the traditional paradigms for data acquisition, that include the ordinary computer networks.

Then, the union of the Internet and new emerging technologies lets us transform everyday objects into smart objects able to obtain knowledge and react in their environments [5]. These “Smart Objects”(SOs) are the building blocks of IoT paradigm: everyday objects turn into smart objects through the addition of intelligence in order to collect environment information, and interact with physical world or with other smart objects to share or exchange data information. In addition to these features, each smart object could be able to provide computational capability, collaborate with other smart object to reach specific objectives, and change their positions in order to create a mobile network able to cover a large operation area.

The smart objects acquire a relevant importance into the people’s life, in which, the IoT play an active role with a huge number of interconnected devices that provide useful services which aim to elaborate a significant amount of available data.

The literature introduces various design alternatives for smart objects. The key differences in smart objects designs can be found along the following three design dimensions [5]:

- *Awareness*, which is the smart object's ability to understand (sense, interpret, and react to) events and human activities occurring in the physical world.
- *Representation*, refers to a smart object's application and programming model (programming abstractions).
- *Interaction*, which denotes the object's ability to converse with the user in terms of input, output, control, and feedback.

Thus, smart devices are extremely heterogeneous in terms of resource capabilities and communication technologies. For example, the modern smartphones and tablets are a particular smart devices equipped with a significant computation capability and a set of sensors able to interact with the surrounding environment. In particular, smartphones and other smart objects are equipped with several electronic modules for internet connectivity. In fact, Internet is the core of IoT, and it allows to introduce new computations ways rather than traditional computation systems. In line with these concepts, the Cloud provides the abstraction of a set of computers, offering computation and storage services.

Although the smart objects are very heterogeneous, the most useful designs involves three main object types:

- **Activity-Aware Smart Objects**: An activity-aware object can record information about work activities and its own use. In particular, these objects are able to understand the world in terms of event and activity streams that are directly related to the use of them self. Furthermore, activity-aware objects already support relevant applications. Technically, an activity-aware smart object should analyze the data gathered from its sensors, and applies several recognition algorithms in order to detect activities and events.

- **Policy-Aware Smart Objects**: A policy-aware object is an particular activity-aware object which is able to interpret events and activities with respect to predefined organizational policies. Furthermore, these objects provide context-sensitive information to raise warnings and alerts if the policies are infringed.

- **Process-Aware Smart Objects**: These smart objects have a relevant role in industrial work management and operation. A process-aware object provides workers with context-aware guidance about tasks, deadlines, and decisions.

Despite the benefits described above, relevant open issues affect the new IoT systems and architectures.

In particular, security and privacy represent the main challenges: the dynamic nature of networks, and the capabilities of devices to collect personal information and share data among their could produce high risks for confidential data leaks. Furthermore, smart devices could be subjected to direct attacks aimed to retrieve users' information, or to alter important data that could cause inappropriate operation modes.

The following sections aim to describe the main IoT application domains and open issues that need solutions.

1.2 IoT Application Domains

During the last years, the IoT has rapidly covered many application heterogeneous domains:

- **Building automation, Smart home and Smart environment**, which aim to automate many systems like Heating, Ventilating, Air Conditioning, Lighting to improve the comfort with a particular attention for the energy consumption.

- **Smart cities**, that represents a large sector that involves the use of digital technologies to improve the provided services within the cities. In particular, smart cities aim to provide smart services within transport, energy, health care, water, waste management, and air pollution monitoring fields.

- **Smart agriculture**, which includes smart irrigation applications.

- **Health IoT applications** that include devices able to monitor personal activities (*e.g.*calories burned, number of steps for a day etc.) to promote a regular lifestyle, or to give indications about the health conditions of people. In general, these devices are "wearable" and they are equipped with a set of sensors and a moderate computation capability which allows to send information to external services in order to store and manage them-self. Furthermore, these stored information could be consulted and analyzed whenever possible.

- **Remote monitoring** for patient monitoring, smart grid, pipeline sensors, and desktop/server monitoring.

- **Industrial automation** which involves the use of various control systems aimed to reduce human intervention.
- **Transportation and logistics domain** in which cars, trains, buses, and bicycles are becoming more instrumented with sensors, actuators, and processing power [1]. Furthermore, roads are also equipped with tags and sensors which aim to send information about the traffic and transportation vehicles. Then, vehicles includes various systems to enhance the security, promote the exchange of relevant information, and automate the guide.
- **Smart museum** which includes various systems to improve the museum experience.

1.2.1 Smart Cities

The smart city is considered a relevant domain and a concrete implementation of IoT paradigm, which allows to create an ecosystem of persons, smart objects, and resources. The increasing of population, vehicles, and resources consumed (e.g., light, water, clear air) produces a deterioration of quality, sustainability and security of the cities. In order to improve the sustainability and the security of cities, and then of citizens, the IoT provides solutions that guarantee to optimize the use of the available resources, the reduction of pollution through a restriction of CO_2 emissions and other pollutants, and the increasing of life quality. So, the smart city concepts aim to provides ecosystems (Fig. 1.1) able to manage a set of services through the widespread usage of Information and Communication technologies (ICT).

Frequently, the introduction of IoT in a traditional city, causes the use of a large amount of sensors, or smart objects that gather information or change

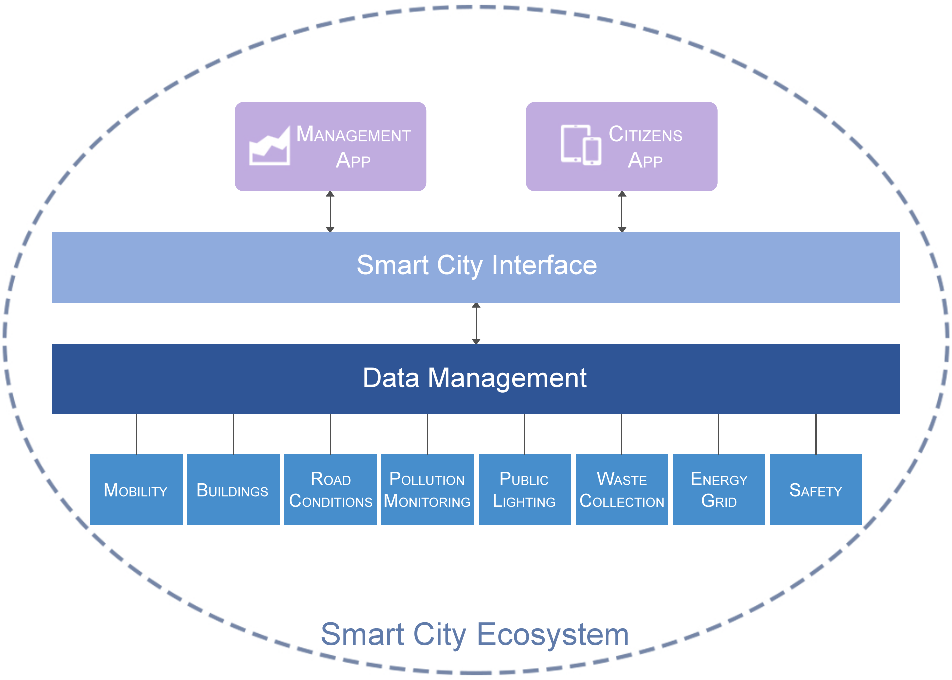


Figure 1.1: Smart City Ecosystem

environments' conditions: for example, the use of smart sensor for cities' lights to realize a smart managing for reducing the energy consuming, the traffic (reducing of traffic through a real time managing of semaphores, and the proposition of alternative routes), the accidents and critical situations (through a set of messages shared between the vehicles that could raise alert signals).

In the mean time, the use of a large number of sensors placed within the cities and vehicles also allows the monitoring of roads conditions (the sensors gather information used as input for several algorithms or system able to detect roads' defects [6–9]), the planning of waste collection service, and the monitoring of air pollution, highlighting the presence of certain pollutants. Then, a smart city involves innovative smart objects and sensors such as cameras, screens, speakers, smart vehicles and others able to communicate among them through the establishment of networks.

The smart city ecosystem involves a set of Smart Objects placed within the city which gather information managed by a Data Manager Layer. This layer aims to store information, obtain knowledge, and convert the data in the appropriate format. In this way, the data will be provided to the Smart City Interface, an access point of smart city knowledge for a set of Applications addressed to the citizen or management organizations.

Due to its inherently large deployment area, a smart city requires a set of link layer technologies able to cover a wide geographical area and support a large amount of traffic [10]. This link layer includes LAN, MAN, WAN traditional technologies (Ethernet, WiFi, UMTS and LTE), which have an high reliability and transfer rates with low latency, and other technologies which are characterized by low energy consumption, and a constrained transfer rate. These constrained technologies include the Bluetooth, the Bluetooth Low Energy(BLE), the NFC, and the RFID, implementing power saving policies to save energy and guarantee a long life-cycle. These technologies are very useful to implement Smart objects able to retrieve, manage and exploit information in accordance with the Context-Aware Application paradigms.

1.3 Smart City Platforms

In this section, a set of smart city platforms, which implement the Smart City Ecosystem paradigms described before are introduced.

In particular, the Authors in [11] describe a real Smart City Ecosystem which corresponds to the city of Barcelona, with a particular attention on the layers responsible for collecting the data generated by the deployed sensors. As [11] reports, the Barcelona Smart City component collecting all data from sensors and actuators is named Sentilo. The Sentilo layer is a piece of Smart City architecture that collects data from more than 1800 sensors spread in the city of Barcelona for all type of applications.

In [12], the Authors introduce a framework for the realization of smart cities through the Internet of Things which aims to gather information provided by a huge amount of sensors using a Cloud layer, to obtain a unifying information management platform able to deliver a capability across application domains critical to the city.

A micro-service architectural style was applied in [13] to build a Smart City IoT platform for a variety of applications involving different stakeholders to increase the energy efficiency of a city at the district level.

These frameworks implement Smart City Ecosystem concepts, and they could be interpreted as pilots for different IoT services, in order to collect data and actuate management strategies.

1.4 Context-Aware Applications

The advancement of mobile and wireless technologies have produced a rapid change of information in terms of volume and accessibility [14]. A large amount of data is available for users, but is important to discriminate the usefulness of information depending of the context. The context is a concept widely exploited within the IoT world through the Context-Aware Applications.

First definitions of "Context" term was provide by Schilit et al. in [15] [16], where they intend the context awareness as "the ability of a mobile user's applications to discover and react to changes in the environment they are situated in [15] [16].

Several years later, Dey and Abowd [17] refined the definition given by Schilit et al. and defined context in the following way: "Context is any information that can be used to characterize the situation of an entity. An entity is a person, a place, or an object that is considered relevant to the interaction between a user and an application, including the user and applications themselves".

Various researchers categorized the context in different ways, and in particular in two categories: Static and Dynamic. Static context could changes during system operation, such as a user profile, a common list, and so forth, while the dynamic context is an information affected by an high variability, like temperature, time, mood of the user and so forth. Furthermore, the context could be further classified in User Context, Physical Context, and Computing Context.

- User Context consists of social situation, user's profile and location.
- Physical context is made up of physical quantities such as weather, temperature, lighting etc.
- Computing Context which includes work stations, printers and displays, and other IoT devices.

Thus, the development of systems able to exploits the context information allows to use a reasonable amount of data to provide custom services. For these reasons, the Context-Aware systems sense and adjust their actions based on the changing of the contexts' information.

A Context-Aware system is composed by three layers which are Sensor, Middleware and End-User application. In particular, sensors and actuators represent the interface towards the environment, and sensor data produced by multiple sensors can be used for interpretation of context and analysis [18]. Moreover, these data are maintained in a persistent storage, and used for customizing services or activities for the users. The processes of collection, modelling, and managing of sensors define the “Context Life Cycle”.

A common life cycle is categorized by four main parts: context acquisition, context modelling, context reasoning, and context distribution:

- Context acquisition phase, in which the data are acquired from physical and virtual sensor nodes.
- Context modelling phase, in which the data are aggregated to provide a set of information useful to retrieve knowledge. In particular, the modelling depends on the domain and features of the context.
- Context reasoning phase, which allows to extract knowledge from the sensor data modelled.
- Context distribution, that delivers context to users.

Since sensors and actuators could cooperate to analyze and recognize context’s information, they are able to establish IoT networks with different features rather then traditional network.

1.5 IoT Networks

Within the IoT Domains, the sensors and actuators do not operate in isolation but are connected in order to form networks using wireless communication in most cases. These networks named Wireless Sensor and Actuator Network (WSAN) [19]. The WSAN networks, or just Wireless Sensor Networks (WSN) is a collection of distributed sensors that monitor physical or environmental conditions, such as temperature, sound, and pressure. Data from each sensor passes through the network node-to-node.

Inline with the IoT paradigm, the distributed nodes are composed of low cost devices which operate at low power so that they can run on battery, or even use other energy sources as solar power, thermal energy, wind energy, electromagnetic radiation, kinetic energy, and more.

WSN are typically connected to the Internet by Gateways (GWs). These gateways have to be able to communicate between the Internet protocol stack and the WSN protocol stack and to translate between them as needed. The following list involves some of main communication technologies exploited to build WSNs:

- WiFi, which represents the first obvious networking technology candidate for an IoT device. It could be a good solution for many applications, in particular for Smart Environments or Smart House applications, because every house that has an Internet connection has a WiFi router.

- IEEE 802.15.4, which is a technical standard which defines the operation of low-rate wireless personal area networks (LR-WPANs)

- Bluetooth, which is a technical-industrial standard to allow wireless data transmission in order to constitute a Wireless Personal Area Network(WPAN).

- Bluetooth Low Energy(BLE), a WPAN technology aimed to provide considerably reduced power consumption and cost.

The literature introduces several IoT networks within various heterogeneous domains.

The next sections reports relevant domains in which IoT networks have an important role: Vehicular and Museum Networks.

1.5.1 Vehicular Networks

During the last years, the electronics and information engineering have hugely influenced the automotive section with relevant technologies innovations. The introduction of Wireless Sensors Networks paradigms in automotive field allows to build the Vehicular Networks in which the main feature is the security as a set of instruments aimed to make trust and safe the drivers and passengers transportation, and safeguard all surrounding peoples and vehicles.

Vehicular Networks exploit wireless communication and localization technologies to allow the cooperation among heterogeneous vehicles to support the common security within the cities.

The fulfillment of a vehicular network is still an open challenge because of its dynamic nature. Thus, vehicular networks could be considered as dynamic wireless networks which involves accidental nodes (which are the vehicles) and static infrastructures such as receiving and transmission systems. The accidental term derives from the dynamic nature of the vehicle that changes frequently its position, and could leave a specific network and come into another one.

The Vehicular Networks concepts could be exploited to increment the safety through the sharing of information related to accident [20, 21], collisions, weather conditions [22] and several anomalies of streets conditions. In addition to safety issues, the information sharing could include traffic conditions [23], which allow the computation of less obstructed alternative routes, or the highlight of free parking areas [24–26], entertainment places, restaurants, pubs, and other interesting places close to the users positions.

As reported above, the vehicular networks contribute to enhance the drivers' safety and mobility, but several communication issues are still under the studies of researchers. In Particular, the security in vehicles communication is a challenge because of the importance of real time data that must be intact during the sharing process, and must reach the right destinations. Thus, the communication latency plays a relevant role, and it should be reduced to allow data exchange between vehicles that run very fast. In this way, the chances to send and receive alert messages between running cars could be considerably increased. So, this could be interpreted as an enhancement of communication availability through an decreasing of the communication latency.

Several authors have been proposed a trusted based framework [27] to make reliable the information sharing between vehicles. In this solution an "Accidental" node is considered as "Malicious" if intercepts and manipulates messages or breaks the communications. In a communication scenario, an algorithm routing must decide the nearest vehicles for sending a message in order to reduce the receiving delay.

Nevertheless, the nearest node could be malicious because it could modify important information. In this case, the malicious nodes will be ignored, while the use of trusted vehicles in favour of security will be encouraged.

Parking Discovery

Some interesting works in literature of vehicular networks regard the process of vacant parking slot discovery.

These works are often based on architectures that require many sensors and other infrastructures. For example, in [28] the available slots are detected through a series of images coming from one or more cameras. Subsequently, these images are processed through a computer vision algorithm that allows the detection of vacant parking slots. This system does not use additional sensors, but an accurate camera could be very expensive. If the monitored area is very extensive it could require more than a single camera and then higher costs.

Another prototype of Smart Parking Service System, in this case based on Wireless Sensor Networks, is presented in [29]. This system helps drivers to find free parking places through a Wireless Sensor Network that monitors the state of parking slots. The system makes also use of an embedded and a central web server. The status of a slot is detected in real time and this information is initially collected in the embedded web server and then forwarded to a central web server that can be queried by a mobile phone application to retrieve the available slots in real time.

Even though many Wireless Network Sensors implementations are low cost, the system itself is quite complex and requires a large number of sensors, about one sensor for each available parking slot. Furthermore, there are several web servers, necessary to manage and spread collected information, that have to be maintained. In (IS) [30] the concept of Info-Station is exploited for a VANET based on an on-street parking system.

The IS provides a wireless coverage to a parking zone. It stores parking policies, receives driver's requests to reserve a specific parking space, and provides several kind of information related for example to weather conditions, traffic status or Internet connection. This system also contains a Centralized IS (CIS) which controls all the other ISs. A CIS provides support to find alternative parking areas when a mismatch between the vehicle or driver profiles and the parking preference or parking policies is detected. Vacant parking spaces are detected using external sensors and a GPS mounted on the vehicle. The external sensors help to gather information about objects or obstacles around the vehicle. In this way, using a pre-loaded digital maps of parking areas, it is possible to establish which are the free parking spaces.

Authors of [31] introduced a Smart Parking System that exploits the smartphone's embedded sensors in order to detect parking actions of users. In this Smart Parking System the urban area is divided in a grid in which each cell contains a certain number of parking slots. These slots are classified as "available", "busy", and "undefined".

The current transportation mode ("walking" or "car") is detected through the analysis of data coming from smart-phone's embedded sensors and Bluetooth connection. The transition from one mode to the other and *vice versa* triggers an event that produces a change of the slots stats for the current cell of the urban area. There are two strategies of data dissemination. A global dissemination that needs a continue Internet connection to share all information among drivers, or a local dissemination performed through Device to Device (D2D) communication (which will be explained next) and occurs when two users are in the same WiFi Direct range.

1.5.2 Culture of IoT and Smart Museum

The technologies characterizing the Internet of Things domain allow realizing smart environments based on user-oriented localized services. In the last years, IoT has gradually acquired an important role also in the Cultural Heritage domain, in particular for Smart Museums, through the introduction of several solutions aimed to valorize artworks by means of innovative technological applications that create an interactive user experience able to reduce the distance among "cultural things" and people. Recently, several innovative approaches have been adopted, the most relevant of which include the use of headphones or robots for an immersive fruition of artworks, supported by smart-phone applications to collect opinions, wishes, and users' suggestions.

The term Cultural Heritage refers to a plethora of tangible and intangible elements regarding the culture of a group or a society [32]. Since most of these elements are linked to a physical place or area, the focus of the proposed work has been moved on the enhancement of the environments connected to the Cultural Heritage. These environments are, for example, museums, archaeological sites, and cities.

Several solutions aimed to provide smart services within the Cultural Heritage environments have been proposed in literature [33–35]. In general, working with smart environments requires to face several challenges, in particular, localization of entities and proper exposition of services. The most common localization techniques include vision, infrared, ultrasound, wireless Local Area Network (WLAN), RFID, and Bluetooth technology [36].

Among the others, the RFID technology is mostly placed within Smart Museums. For example, in [37] Personal Digit Assistants (PDA) manage the sharing of multimedia contents, with the support of RFID technology to uniquely identify each artwork and localize the user. The RFID technology is also adopted within the Smartmuseum solution [38] to enable the tracking of activities together with additional technologies such as mobile Internet, Geo-localization, and NFC. As suggested by this solution, the user is equipped with a mobile device to retrieve cultural contents according to his context and position.

Nevertheless, the use of RFID technology in smart museums is subject to some limitations: just as an example, not so expensive RFID-based solutions require a short distance among users and tags associated to cultural items.

Since the management of smart museums and/or archaeological sites represents an important open challenge, several systems able to support users within these environments were proposed in literature [34, 38, 39].

A recent vision which involves concepts and technologies typical of social networks has been proposed to enhance the world of things [40]. In line with these concepts, authors of [41] propose a Social Network of Object and Persons (SNOPS) framework to create a network of interconnected people (e.g., citizens and tourists) and objects (e.g., machines, edifices, and rooms).

To support this vision, in recent years, the BLE, has been exploited in indoor localization systems, since its low-cost technology is available in most of end-user devices (such as mobile phones, laptops, and desktops computers) and it is also easy to integrate in objects ranging from simple tags (called beacons) to the more complex embedded systems.

Indoor Location-Aware systems based on BLE are proposed in [33–35,39] to bring museums into the IoT paradigm. In these works authors combine computer vision algorithms, BLE-based localization services, and wearable devices to deliver multimedia content related to the artwork observed in a specific moment by users. Other systems based on BLE technology have been proposed in [42, 43] to share artworks-related multimedia contents.

1.6 Evolution of Communication Technologies

The new technology paradigms, in particular IoT, requires a massive data managing, and in particular during the communication methods as mentioned before. So, this paradigms needs to reach an increasing of communication technologies.

Today the evolution of communication has the name of 5G [44]. The 5G is an evolution of the 4G, and it is considered as a group of consolidated technologies like the 2G, 3G, 4G, and WiFi with other innovations able to increase the coverage and the reliability of transmission data with a reducing of the end-to-end latency.

The 5G is a very relevant resource for the IoT, especially for the creation of low power devices networks with lowered communication delays in order to cover several real time fields as mentioned above.

A particular communication practic is the Device to Device (D2D) communication, also called Machine to Machine (M2M) communication [45]. The M2M is a group of solutions for analysis and exchange data among embedded systems, and represents a relevant advanced technology respect to the classic ordinary acquisition data networks.

Thus, the M2M avoids to use a central gateway to allow communication between neighbouring devices, because this could be very inefficient, while it encourage the proximity communication in an environment that includes a huge number of smart devices. Examples of IoT services include security, payment, smart grid, and remote maintenance/monitoring.

A system based on Long Term Evolution (LTE) has been introduced to support M2M communication in IoT. This system is named Narrowband Internet of Things (NB-IoT) and it has been developed in order to involves low-cost devices, high coverage (20-dB improvement over GPRS), long device battery life (more than 10 years), and massive capacity [46].

In addition to NB-IoT another technology named LTE-Direct allows to exploits the M2M communication. This technology allows to exchange data, which include vocal data, within a range of 500 meters without the exploiting of radio modules of telecommunication operators.

The 5G communication could increase the transmission speed that could be reach the 10 Gbps in order to stream UHD contents with a reduction of used energy. Thus, the main objective is the creation of low-powered devices with

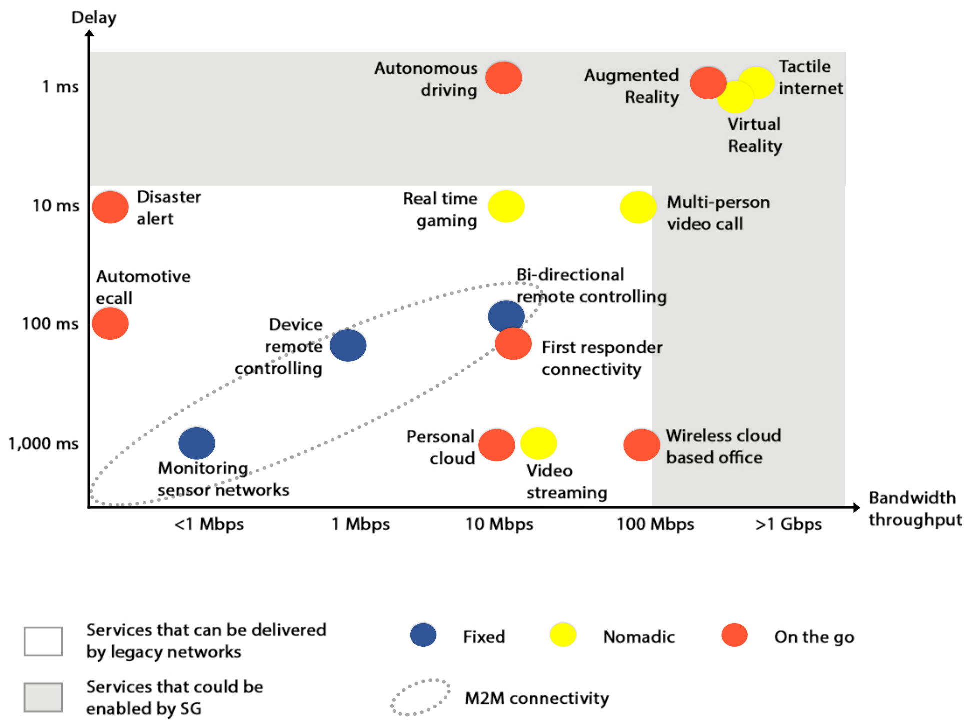


Figure 1.2: Communication Technologies Use Cases

high transmission data performance. The figure 1.2 shows a diagram which include several use scenarios of 5G, highlighting the band and transmission delay.

1.7 Data Management

One of main topics related to IoT is the management of information detected by smart devices (Data Management Layer Fig. 1.1). These information could be stored, processed, and shared within a network of smart objects and/or in a traditional network.

The heterogeneity which affects the detected data needs to data management strategies to promote the processing and sharing of information.

As mentioned before, each single smart device is free-standing and it is able to detect and store information about the environments in which is placed. In particular, a set of these data could be considered as a time serie which describes the evolution of a specific physical quantity and allows data processing useful to understand the environment state.

In literature, several techniques for IoT data acquisition have been described [47], and they aim to simplify the understanding of information, the decrease of data size to preserve the memory storage, and the enhancement of transmission data process to reduce the band exploitation.

In order to reach the aforementioned objectives, a data abstraction is performed, and it produces a semantic representation of information simplifying the analyzing of a huge amount of data.

In line with the phases each time series, which is intended as an array of values, is processed to obtain a specific semantic representation.

The first phase is a “Pre-Processing” of information that could be performed into the smart objects through a set of mathematical/statistic methods to filter the amount of not relevant data during the transmission phase.

In particular, the most used methods includes the Moving Average Window, Min-Max, Mean-Median, Low Pass, High Pass, and Band Pass filters.

The second phase provides a “Dimensionality Reduction” of data array (reduces the size of array) performed through Discrete Fourier Transform(DFT), Wavelet Transformation and others.

Finally, the “Features Extraction” and “Abstraction” phases extract the main features and knowledge from data using cluster algorithms as Kmeas and Markov chains that are able to represent the temporal relationships between the data. The information obtained through the cluster algorithm are modelled to reach a semantic structure which represent the output of blockchain.

1.8 Privacy Management

The implementation of IoT concepts in some devices has produced several open issues about the “Privacy”. Devices as Smart-phone and Video Cameras could provide a potential sharing of personal information toward the networks: a device is able to gather and share private data, but in the meantime, it could perform actions which are very malicious for users.

Furthermore, most of the time, the users do not have idea about the information collected by the devices e who could be the final addressees of these data.

In order to provide a way to manage the privacy settings, some systems allows to set a “Static Configuration”, in contrast with a “Dynamic Privacy” which adapts the settings to the different scenarios that.

The IoT networks are very dynamic networks, and they are able to adjust their configuration depending on the surrounding environments or user interaction.

Consequently, these systems are able to gather a huge amount of users’ data which could support the dynamic setting of privacy. In this case, the privacy becomes context-adaptive, and it aims to predict users setting depending on the surrounding context. In particular in [48], the authors have introduces a context-adaptive privacy model, in which the dynamic adjustment process of privacy preferences is composed about three phases, and it gets idea from the social interactions:

- *Awareness*, the users detect the context changing and know the actions to perform in order to maintains the desired privacy level. In this case, the individual user's perception has a relevant role for the evaluation of privacy risks.

- *Decision*, the user decides the action to perform in order to maintain the desired privacy settings, depending on its experience, and social/-cultural background.

- *Control*, is it possible to map the actions on the available commands within the currently context.

1.9 Contributions of the Thesis and Publications

The work performed during my Ph.D. days aims to provide several solutions that cover the main IoT concepts described in the previous sections. In particular, this Thesis introduces various Context-Aware applications in several fields, and shows the importance of using and context and users' information to provide customized services or improve already available services for increasing the quality of life in Smart Environments.

The provided contributions aim to give support in several IoT domains :

- *Vehicular Networks and smart city*: Chapter 2 "A Context-Aware Smart Parking System".

- *Smart Environments*: Chapter 3 "Intent-Based Interaction using Smart Cooperative Objects".

- *Culture of IoT*: Chapter 4 “smARTworks: a Multi-Sided Context-Aware Platform for the SmartMuseum”.

- *Monitoring air pollution and smart city*: Chapter 5 “Bus as a Sensor: a Mobile Sensor Nodes Network for the Air Quality Monitoring”.

These works have been presented as atomic solutions, but they could be interpreted as atomic services of a unique platform. The realization of a unique Data Store Manager, that are going to allow the building of a Smart City Ecosystem, is an important task still under development.

The research results obtained during this PhD research have been published in several conferences:

- A Context-Aware Smart Parking System (2016 12th International Conference on Signal-Image Technology and Internet-Based Systems (SITIS)).

- smARTworks: a Multi-Sided Context-Aware Platform for the Smart Museum (PEC 2018 3rd International Conference on Pervasive and Embedded Computing).

- Bus as a sensor: A mobile sensor nodes network for the air quality monitoring (IEEE 13th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)).

- Intent-Based Interaction using Smart Cooperative Objects (not yet published).

CHAPTER

TWO

A CONTEXT-AWARE SMART PARKING SYSTEM

The research of parking slots is a process very stressful for a person who would like to reach a specific place. It could be considered also expensive since it often causes an increasing of traffic with a consequent increase of pollution.

In this chapter, a smart parking system is introduced useful to reach a free parking slot, in a small area or a city, using context-aware information to help in the process. The proposed solution does not require an existing infrastructure of sensors spread in parking areas since it exploits the potential of modern smartphones with their capability of recognizing user activity and position.

This solution introduces an algorithm which compares routes of different drivers to find relations among them. A mechanism based on Bluetooth Low Energy Advertising (BLE Advertising) is then adopted to detect passengers and reduce the bias that would be introduced by the arrival of multiple users in the same parking area.

In order to test the system an application prototype that enables the gathering of contextual information and displays through a map an approximate distribution of free parking areas close to the user's position has been developed.

The proposed system does not require additional sensors or modern vehicles since it is based on an already widespread technology: smartphones. Smartphone's sensors allow to retrieve a big quantity of user contextual information such as position, current activity [49], and plans. The presented solution aims to attempt and minimize the cost and simplify user's life reducing the time to find and reach a vacant parking space. Furthermore, it can have a positive impact on traffic congestion, air pollution, and driver frustration.

A prototypical application to collect user contextual information and display mapped parking areas has been developed. In particular, the target of our client application, namely *Smart Parking*, is the Android mobile operating system. After an initial registration phase, the application evaluates the user activity listening for the "driving" status. Once the user starts driving, the application starts retrieving GPS position at regular intervals sending them to a remote server which builds a path joining all user GPS points received from the application until the destination is reached. In this server, The paths are stored within a database along with a series of maps that contain coordinates of parking areas. Then, the paths are compared through an algorithm that checks their similarity in order to estimate the number of parking slots still available. In parallel to this "path construction" process, the application starts BLE advertising using an identifier connected to the user account. Smartphones running *Smart Parking* analyze BLE packages to detect the presence of neighbors (other passengers) in the same vehicle. Each user can select his neighbors and send this information to the system. The system provides results to the *Smart Parking* which finally displays a heatmap regarding the nearest parking areas.

2.1 Smart Parking System Architecture

The architecture of the proposed *Smart Parking* system is shown in Fig. 2.1. As aforementioned in the introduction, this system takes advantage of some of the technologies integrated in recent smartphones such as GPS and Bluetooth Low Energy (BLE) to gather information about position and adjacent passengers. User position, path performed by user, user activity (driving, walking, etc.), and list of potential close passengers represent the main data inputs for the Engine entity which makes use of an algorithm to retrieve the details related to a parking scenario. An important task of the Engine is to collect information related to passengers of a vehicle, establishing how many and who are them, and evaluating the similarity among paths. This evaluation tries to determine whether more drivers have performed the same route with different vehicles, and then, if one or more parking slots have been occupied. The Engine holds a database that contains a GeoJSON description [50] of a set of parking areas, useful to track in real-time available slots. When a driver reaches a parking area and parks in an available slot, the Engine decreases in its database the number of available slots for this geographic area. Users can receive notifications or read the information sent by the Engine to their smartphones through the *Smart Parking* application developed for this purpose. The application shows available parking areas close to user's position or his points of interest, making the application context-aware as depicted in Fig. 2.2.

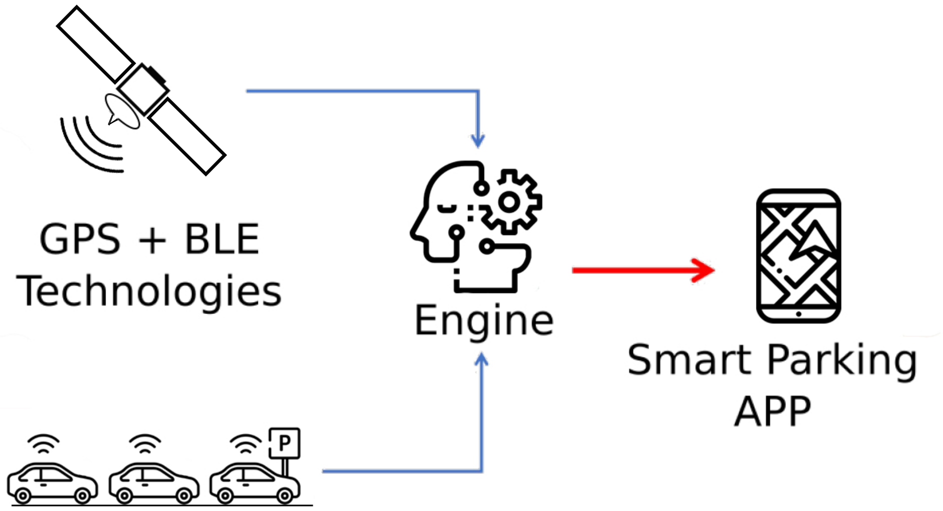


Figure 2.1: Proposed system architecture: sensing (GPS+BLE) and presentation (Smart Parking App) layers reside in smartphones while the Engine component is hosted in an external server.

2.1.1 Smartphone and Driver

The system described in Fig. 2.1 exploits the use of user's smartphone without additional sensors or a complex external infrastructure. Google provides a set of APIs to retrieve user's position and detect his activity in order to discriminate between a "driving" or "walking" state.

Determining whether a user arrives in a park zone is very important: this check can be carried out through the aforementioned APIs. The condition "user is in a parking area" along with the change of state from "driving" to "walking" represent the discriminant which allows the Engine to detect a "parking" action.

This case identifies the occupation of a parking slot. Similarly, an area has a new free parking slot when the change from the state “walking” to the state “driving” is detected.

The smartphone, in which our prototypical application is installed, periodically sends information while the user is driving. This frame contains some details, such as the GPS coordinates and a timestamp, as listed in Listing 2.1:

Listing 2.1: JSON information fragment containing user’s activity details.

```
{
    "latitude": 37.526084,
    "longitude": 15.074081,
    "activity": "DRIVING",
    "timestamp": "2016-07-16T19:20:30+02:00",
}
```

Data are saved into a database and used by the Engine to build a path. It also collects several paths (one for each monitored user) to verify whether they are related to users traveling together. When a user is driving, his smartphone also tries discovering neighbors to identify them as passengers of the same vehicle. In its first version, the *Smart Parking* application asks the user to confirm the presence of other passengers (as shown in Fig. 2.2). Possible passengers are discovered exploiting the BLE advertising mode. In facts, when a user reach the state “Driving”, the smartphone will start advertising an identifier which has been assigned during the registration phase to each user. The smartphone stop advertising this identifier when the activity status comes back to “Walking”. To discover just the passengers inside the same vehicle the lowest transmission power for BLE is set. This and some other data are used by the Engine to classify the users of the application discriminating possible drivers from passengers.

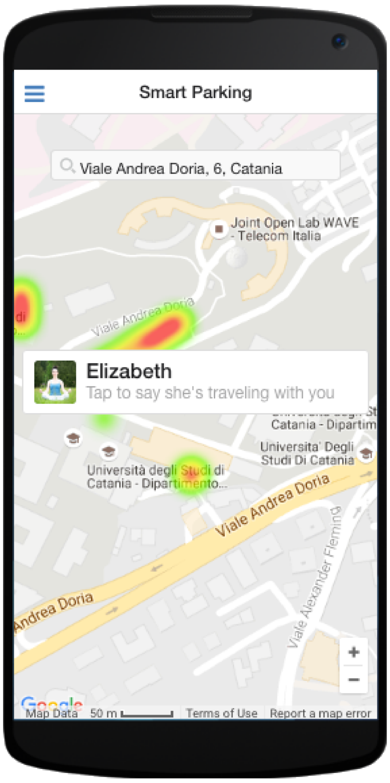


Figure 2.2: A screenshot of the Smart Parking Android app: the user is requested to confirm the presence of a passanger (in this case Elizabeth) in his vehicle.

2.1.2 The Engine

The Engine represents the core of the proposed system and includes several features. It receives from smartphones frames that contain information about current user activity. Information obtained from these frames are assembled to build paths identified by a timestamp which represents the arrival time of a user. Besides GPS data, the Engine collects other information such as user identifiers, in facts, as aforementioned, a user can select passengers traveling with him. These identifiers will be merged in a new single entity which represents a group of users. When the group will change its state from “Driving” to “Walking” the Engine will decrease the number of free available slots of one unit. If no information about passengers is provided, the Engine will take into account just the paths built during the different journeys. These paths are used by an algorithm to estimate the number of parking slots occupied. This process is needed to evaluate if two or more users filled two different slot (with two different vehicles) or if they used the same slot (one vehicles and two or more passengers). In this way, some paths could be similar each other because they are built from the same vehicle (users have used the same vehicle to reach the same destination), partially similar because users shared a part of path, or different because each user drove different vehicles.

2.1.3 Application (Presentation Layer)

The most important goals of the *Smart Parking* application are the presentation of results originating by the engine and the acquisition of the data (location and other contextual information) and the sending of these to the Engine. The presentation layer shows parking areas near the user’s position or interesting and visited locations. For each parking area an evaluation of vacant slots is displayed in the form of a heatmap as depicted in Fig. 2.2. The color of the area represents the probability of find a free slot parking. The green color indicates that there are a large probability to find a free parking. The red color highlights a very busy parking area. The yellow and orange represent the middle way between a full and a free parking area.

2.1.4 Algorithm to determine occupied parking slots

In the case passengers related information is not provided by the application users, the Engine tries comparing paths through the algorithm described in the followings.

The algorithm in Fig. 2.3 takes into account two paths called $Path_1$ and $Path_2$ and indicates, as output, whether they are similar. It compares paths under several constraints, in particular, the paths must share:

- the same arrival point (in terms of coordinates, inside a limited range);
- the destination must be reached by users at the same time. So, the arrival times must be "reasonably" similar;
- the information submission rate to the Engine is assumed to be constant.

Each path consists of a series of coordinates, latitude and longitude, with $Path_N$ the generic path in which:

$$Path_Z = x_1, y_1, x_2, y_2, x_3, y_3, ..., x_n, y_n$$

x_n is the n^{th} latitude value of the path and y_n is the n^{th} longitude value of the $Path_Z$.

Starting from a generic $Path_Z$ two arrays are built. The first array, namely Lat_Z, is composed of latitudes of a path, while the second array, Lon_Z, consist of longitudes coordinates of the same path.

$$Lat_Z = x_1, x_2, x_3, ..., x_n \qquad Lon_Z = y_1, y_2, y_3, ..., y_n$$

At this point, from $Path_1$ and $Path_2$ we build two other arrays, called, $DLat_{1,2}$ and $DLon_{1,2}$ where:

$$DLat_{1,2} = Lat_1 - Lat_2 \qquad DLon_{1,2} = Lon_1 - Lon_2$$

These latter arrays $DLat_{1,2}$ and $DLon_{1,2}$ let us build two polynomials, namely, $PLat_{1,2}$ and $PLon_{1,2}$ through a linear fitting function.

Each polynomial represents a straight line with an angular coefficient C.

$$yx = Cx$$

The goal of the algorithm is to find a correlation between the angular coefficient C and the similitude between $Path_1$ and $Path_2$. Starting from the comparison between the angular coefficient of the straight line, calculated with the above formulas, and a threshold T, if the angular coefficient is less than the threshold, the algorithm consider the paths as similar. The best case is represented from a straight line corresponding to the X axis of a Cartesian plane or having an angular coefficient near to zero. In this case, $Path_1$ and $Path_2$ would be similar and the subtraction vectors $DLat_{1,2}$ and $DLon_{1,2}$ would contain only zeros. An angular coefficient very close to zero indicates an high degree of similitude. Several tests highlight that the angular coefficient of the straight line calculated starting from two similar paths is proximal to 10^{-4}. For this reason, we have chosen 10^{-4} as threshold to say that two paths are similar.

Another measure of similarity between curves is the Fréchet distance which is defined as the length of the shortest leash between two curves that is sufficient for traversing both of them. The Fréchet distance can be used for evaluating similarity among several curves, but it does not determine an absolute value of similarity that is important to establish a threshold to evaluate the degree of similarity.

2.2 Experiments

A series of paths have been used to test the solution. For example, the paths shown in Fig 2.4 have been analyzed. The Path 1 in Fig. 2.4a and Path 2 in Fig. 2.4b are very different although they share the same arrival destination. We analyze now our use cases. They consist on the comparison among different routes made by several users in the case no one of them indicates passengers with him. In particular, for the first user case we have supposed that three users U1, U2, and U3 have driven through a route corresponding to the Path shown in Fig. 2.4a. So, we would demonstrate that these users have traveled in the same vehicle. In the second use case, the users drove through different routes, corresponding respectively to the Fig. 2.4a (user U1) and Fig. 2.4b (user U4), so, these user were in different vehicles probably.

In the first case, we have calculated the vectors $DLat_{1,2}$, $DLat_{1,3}$, $DLon_{1,2}$ and $DLon_{1,3}$. The angular coefficients calculated through our algorithm are of the order of 10^{-4}. These results are interpreted by the algorithm as "Similar Path" output. So, the path of user U1 are very similar to the path of user U2 and path of user U3. Probably, these user have reached their destination by the same vehicle.

The second case has the goal to analyze the angular coefficient obtained from two very different paths for users U1 and U4. In this case there is an angular coefficient major of 10^{-4}.

2.3 Results

This chapter describes the architecture of a free park slot discovery system demonstrating that it is possible to implement such a system without sophisticated and expensive infrastructures but taking advantage of currently widespread technologies available in common smartphones. This system offers better results with a large number of users since the discovery process relies on information gathered from their smartphones.

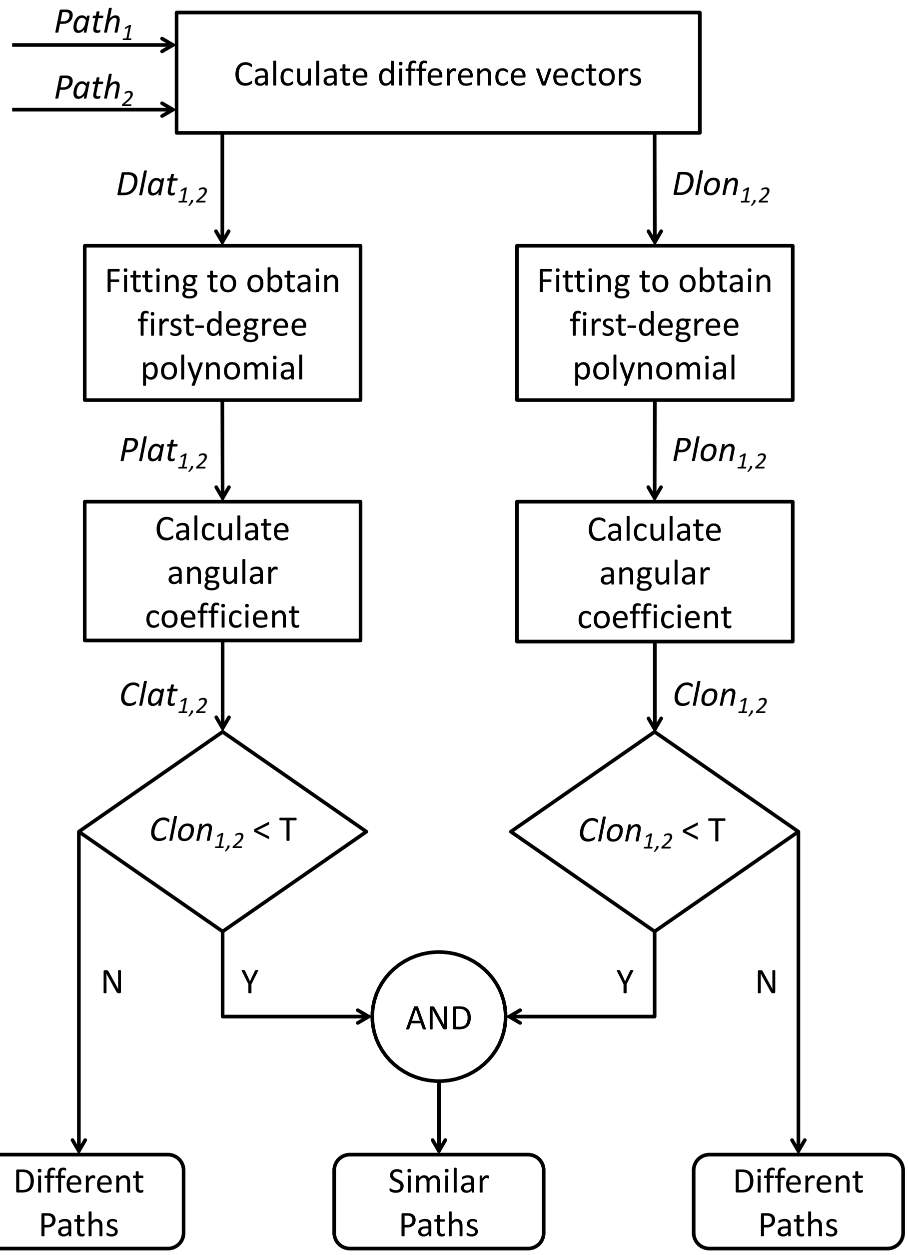
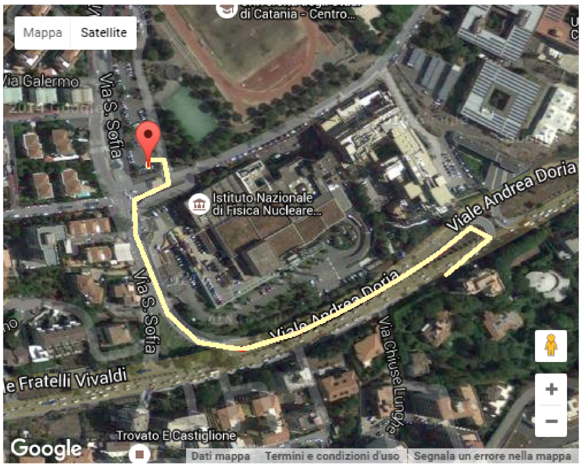


Figure 2.3: Algorithm adopted to evaluate the similarity between two different paths.

(a) Path I



(b) Path II

Figure 2.4: Two example paths which have different starting points and sharing the same destination point.

CHAPTER

THREE

INTENT-BASED INTERACTION USING SMART COOPERATIVE OBJECTS

Systems and solutions based on the Internet of Things (IoT) paradigm frequently rely on the use of smart objects, which represent an interface with the surrounding environment. The spread of smart objects in areas/spaces frequented during activities of daily life enables people to use a plethora of these services but, often, is not clear for users which services are available in a specific place at a specific moment. To cope with this situation, in this work, a system to improve the discovery of smart objects (and related services), based on user-related contextual information is described. The proposal moves towards a transparent and easy interaction among users and smart objects and it does not require complex registration and setup phases.

As mentioned above,the IoT has entered into people's lives by augmenting the capabilities of everyday objects in terms of computational power, connectivity, and intelligence [1–3]. In line with the IoT vision, a set of computing/sensing elements can gather information from the context and act to supervise and manipulate the surrounding environment accordingly to the needs of users [5, 51].

An interesting class of scenarios related to the everyday life is that of Smart Spaces: environments equipped with pervasive devices, sensors, and actuators that can perceive and react to people, sensing ongoing human activities and responding to them [52]. Smart Spaces range from single rooms, to cities, going through buildings and small areas such as campuses, and they, each one at a different scale, tend to present similar challenges. The widespread use of technological solutions leads to an increasing attention towards devices which are able to interact with domestic environments, offices or any place in which people spend their time. Nonetheless, these devices are at the first step of an evolutionary process and their smartness is evolving in the direction of a *social consciousness* [40]: smart objects communicate with others (friends) generating networks of objects and services.

The fact that more and more common objects are becoming capable of accessing the Internet, has generated interest on the development of hubs and management systems that collect and make accessible features offered by smart objects [53, 54]. For example, several frameworks allow the detection of smart objects in order to exploit services of interest using popular devices like smartphones. Various centralised architectures, presented in 3.1, have been proposed to achieve objectives defined by users or by their preferences and usually these solutions require a complex registration phase for each smart object to make it discoverable.

In contrast with a centralised approach, we prefer a solution based on the concept of Smart Cooperative Objects. The idea behind the proposed work is to create a way to gain control of devices, located into a Smart Environment, identified as “neighbours” in terms of spatial location with respect to the user's location and capable of performing or scheduling useful tasks. In particular, this work aims to introduce a system to enable users, through their handheld devices, in the processes of discovery and exploitation of indoor-localised smart objects using peer-to-peer (P2P) communication.

3.1 Related Work in literature

With smart objects, the Internet connectivity has entered into a wide range of devices enabling the arise of a plethora of solutions in a variety of domains such as those connected to the IoT paradigm [5]. Examples related to the scenario of smart environments, taken into account in this work, come from smart cities, smart offices, and smart homes. One of the main challenges, still open in all these domains, is represented by the discovery of smart objects and/or services. This process has been tackled by middlewares [55] and frameworks designed to handle IoT objects as localised services [56]. In [57] authors present the IoT Service Discovery Framework, a solution that tries simplifying the detection of IoT services by introducing users' preferences, specified through a smartphone application, to exploit services of interest. Currently an unified way to discover services in a smart city does not exist and this approach turns out to be useful for the detection of unknown services localised within a specific environment, while users' preferences represent the keys to discover nearby services that are not longer meant to be installed as single applications in smartphones or laptops, but are exposed in a specific Store. This framework supports various methods to discover devices, including beacons, which are small BLE radio transmitters that allow to broadcast an identifier related to a specific device, providing a point of access to gather information about it. The discovery of neighbour smart objects is an important issue within smart environments [58] and the related studies produced various approaches such as deterministic discovery [59], randomised discovery [60] or context aware power management discovery [61]. The BLE technology has been preferred in our proposal to create programmable beacons able to identify smart objects within a smart environment. BLE has been chosen because of the wide support provided, reduced power consumption, and costs while maintaining a similar communication range with respect to the traditional Bluetooth.

In order to improve the quality of people lives, it is important to maintain a high level of abstraction for the smart objects, allowing users to exploit objects' capabilities without a previous knowledge of their features. Consequently, some platforms following "service-oriented" and "Goal Oriented" approaches have been proposed to create smart environments. These platforms allow a user to choose one or more objectives that the surrounding smart objects try satisfying.

For example, FASEM, a framework proposed in [53], performs service monitoring and handles events that occur in smart environments. It is a service-oriented, user-centered, and event-aware framework that exploits the concept of "Ambient Service" *i.e.*, an action or operation achievable by a function that gets some data as input and produce event-context or effects on the environment as output.

Another framework in recent literature is Smart EDIFICE, a platform ables to determine and perform a set of tasks useful to achieve the objectives expressed by a user [62]. This platform makes easier the interaction between people and smart objects located in their homes through different phases such as discovery and filtering. It includes several blocks that cooperate together to understand the users' requests and transform them into machine-readable goals. It is important to highlight the use of an N3 semantic description file for each smart object within Smart EDIFICE, useful for the discovery of available smart objects, in order to achieve user-defined goals. Therefore, these description files become inputs for an N3 semantic Reasoner that determines a set of actions for the available smart objects.

This approach is also exploited in the proposed architecture: each smart object comes with a file containing the semantic description of its features. In this way, using the semantic Reasoner it is possible to identify those smart objects able to help users to achieve one or more specified objectives. Users can select available operations through a smartphone application that takes into account their preferences.

The proposed work does not involve a centralised approach as in Smart EDIFICE, but relies upon P2P communication among smart objects and control application. Each smart object holds its own semantic description, and is not expected a registration phase, but the smart object sensing is guaranteed from the BLE Advertising mode that permits to detect its availability inside the same home network. Our idea aims to reduce the architectural complexity by avoiding a registration phase for new smart object that can be directly used in a transparent way after the connection phase.

Authors of [63], present a Connected Home Platform (CHP) and Development Framework for the design, development and deployment of smart home services through the OSGi technology. To enable the development and deployment of services the authors introduce an Home Controller, an entity which is also used to integrate connectivity with home devices of various home control technologies as in our approach.

To conclude this section, we want to mention Lysis [54], a cloud-based platform for the deployment of Internet of Things (IoT) applications, that exploits the social IoT concept according to which objects are capable of establishing social relationships. This platform offers the possibility to start a cooperation among smart objects to reach goals defined by a user.

3.2 Smart Cooperative Objects Architecture

Each smart object, located in an indoor environment, can interact through the use of Bluetooth Low Energy (BLE) technology and can be detected by anyone who is listening in a particular room or area. Within the proposed system, a smart object is designed as a resource exposing RESTful web services thought to (i) configure the object itself, (ii) retrieve information concerning its capabilities, and (iii) take advantage of one or more of them. The system is designed to work across one or more domestic networks in which only an owner or a set of authorised users can register and then use smart objects.

To work within the proposed system, a smart object requires an initial configuration, namely bootstrap, to obtain access to the domestic network. After that, it will be ready to be detected and then controlled. The smart object discovery process consists in receiving, through BLE, some pieces of information regarding location and exposed features. The features that a smart object exposes are described by (i) a semantic notation, namely N3 [64], to identify "what the device is capable of" (ii) a syntactic notation to describe the functions that determine "how the object performs a specific action". These formats represent a common language for communications among devices and end-user applications. Smart objects will use a direct P2P communication without a need for third entities to keep track of all the available smart objects and their capabilities.

The proposed system enables users to exploit, in a transparent manner, one or more other smart objects, and smart objects to communicate directly among themselves. To avoid cases of ambiguity that can arise when two smart objects provide the same functionality through different actions, the user must be able to express a preference choosing a smart object rather than another.

The interaction can be split in two phases (i) a user express an intent, (ii)

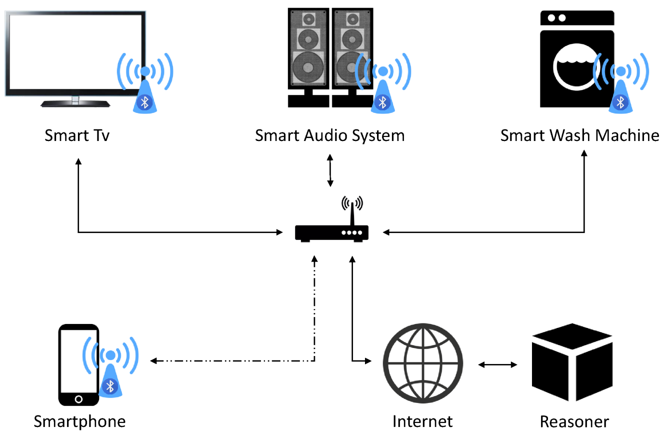


Figure 3.1: Smart Cooperative Objects System Overview

discovered smart objects cooperate to complete the tasks needed for accomplishing the user's intent. In order to make this approach work, we need to understand which of the smart objects available are able to carry out the requested action through one or more of their capabilities. In this regard, it is possible to take advantage of the *eye reasoner*, an N3 reasoner engine which takes as input a semantic description of the functions implemented by a smart object and the semantic definition of all the possible relationships between the actions to be performed and the available capabilities, providing as output the set of capabilities that can be exploited to perform the requested actions.

3.3 Proposed Architecture

The Fig. 3.1 presents a possible organization of a smart environment in which several smart objects are connected to the same network through a router. Each smart object comes with two descriptions: the first one is semantic (written in the N3 format) and regards the object's capabilities, the second one is syntactic (written following the Swagger specifications) and defines the APIs exposed by the object itself.

3.3.1 System Architecture

After the bootstrap phase (*i.e.*, the initial configuration), each smart object is connected to the same network in "advertising mode". In this mode, object simply advertise their presence since they are ready to be queried. Now, imagine that a user declares an intent with the help of the proposed system (*i.e.*, through the designed smartphone application); this intent has to be converted into a set of actions.

After that one or more actions have been identified, the application starts looking for available smart objects which are in proximity to the user. Each smart object is then mapped into a virtual object with the following attributes:

- the end-point of the smart object;
- the semantic description of its functionality;
- the list of features (APIs) with syntactic description to access them;
- for each feature, an attribute that identifies a degree of preference.

Along with these items, an additional descriptive N3 file, with the possible relations between the actions that may be required by the user and the atomic methods of each smart object, is provided. Next, the semantic description of the action, along with the semantic descriptors of available smart objects, are sent to a Reasoner, which in our tests is accessible via Internet.

Since, as aforementioned, specific actions may be performed using different methods belonging to the same or different objects, the Reasoner returns as output a set of methods for each smart object capable of completing those actions required to comply with user's intent. Also, It is possible that the returned methods do not represent the best choice for the user. Consider, for example, the intent to increase the brightness of a room: it could lead to "turn on lights" or to "open the shutters". In the proposed system, the initial choice is left to the application and it is based on some pre-configured specifications such as, for example, the power consumption required to perform the action, and so on. The user can give a feedback and, if necessary, can interact directly with each smart object by monitoring and invoking any of the methods exposed by available objects. The choice of a method determines an increase of its "preference" value. In this way, the application can choose methods with higher preference values for similar subsequent scenarios. The aim is to automate as much as possible the execution process reducing as much as possible user's interventions.

3.3.2 Smart Object Structure

An object can perform actions that strictly depend on its nature: it is obvious that an oven and an air conditioner are designed for totally different tasks. Given that, it is still possible that different smart objects can achieve the same objective through a number of actions that differ for example in terms of energy requirements. Each smart object has to respect some requirements in order to work in the system we have briefly described. Other than the features

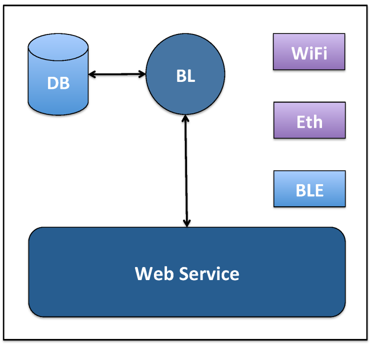


Figure 3.2: Smart Object Structure.

that characterize the object itself, each smart object has to implement a set of common modules to interact with other smart objects and the environment. These hardware and software modules, depicted in Fig. 3.2, are:

- a BLE module for advertising/discovery purposes;
- a secondary connectivity module (Wi-Fi and/or Ethernet) to expose the object over the Internet;
- a RESTful interface to expose resources and capabilities of the smart object;
- a Business Logic (BL) module to implement the glue-logic to access the basic capabilities of the smart object;
- a database to store data.

The common methods exposed in form of web service by each smart object are:

- a method to configure the smart object in the domestic network;
- a method to retrieve the semantic description regarding the capabilities of the SO;
- a method to retrieve the syntactic description of other smart object's methods (APIs);
- a method to reset the smart object.

One of the objective we want to pursue is to build a system to help users discovering nearby smart objects and setting up the communication. A user can interact with smart objects through an application designed for hand-held devices (*i.e.*, smartphone and tablet). smart objects configured inside a private network are available only to users that can access the same private network. Also, smart objects are indoor localised via BLE: a user can detect only "nearby" smart objects, where nearby means inside a specific area.

To work within the proposed system, as aforementioned, each smart object comes with a semantic description that describes the list of supported capabilities and is not shared with any central entity to enable a P2P interaction between users and smart objects. To support this kind of interaction each smart object has to include modules for Internet connection and BLE advertising/discovery.

The proposed approach, as described in Figure 3.3, is structured in three phases: (a) **enrollment**: A configuration method is supplied in order to set a connection between a smart object and a private network. Initially, the smart object serves as a Wi-Fi Endpoint. It implements a rest web service that provides configuration methods to manage network settings. (b) **advertising**: The enrollment phase supplies the configuration settings (*e.g.*, IP address) and after this setup, the smart object switches on BLE advertising its presence

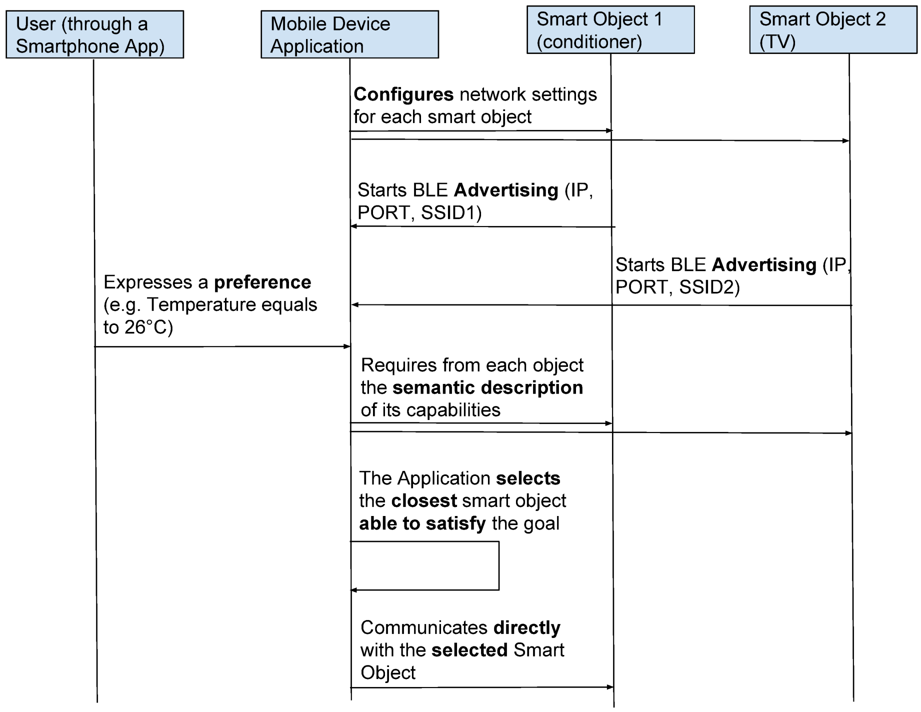


Figure 3.3: Sequence Diagram of Smart Objects' discovery

through a beacon containing the endpoint information set (*i.e.*, Wi-Fi SSID, IP, and port). This piece of information enables users (through the management app) and others smart objects to reach the advertising smart object and exploit its features. (c) **usage**. The figure 3.4 shows how the smart-phone application helps to complete the enrollment phase. Initially, the application shows all nearby smart objects detected. After the smart object selection, the information for home network access (SSID and password) are required, in order to make it usable within the own environment.

The proposed approach is useful for user-smart objects interaction or

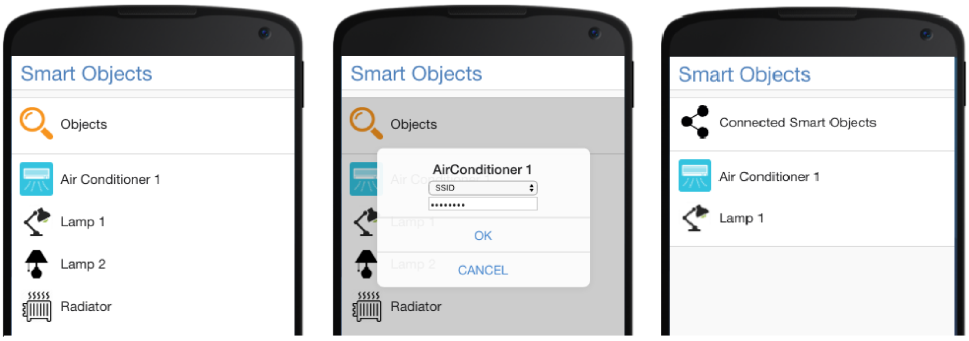


Figure 3.4: Main App - Configuration of a Smart Object

M2M scenarios in which smart objects are selected automatically after a filtering based on semantic description.

Exposing objects' features through Web Services enables a simple interaction via well-known interfaces, in this case RESTful APIs. An efficient use of these APIs, and then objects, requires a good knowledge of what is the behaviour exposed other than the set of parameters and output of each accessible method. The automation of the use of APIs is a challenge that can be overcome adopting a description of all the available features.

In this work, we rely on RESTful services and, to specify APIs syntactic description, use Swagger specifications. Swagger is a useful open source framework that helps in the design of RESTful APIs. A Swagger description can help a client to know "how" to consume REST APIs, since it describes a REST method listing required/optional parameters, expected outputs, routes to the available commands, and a set other useful data.

Furthermore, we rely on N3 an extended version of the Resource Description Framework (RDF) notation to express the behaviour of objects and methods, and determine "why" is better to use a method instead of another. N3 is useful to describe semantically a smart object and the features it exposes through the RESTful APIs.

Going back to the third phase, once a smart object is detected, a method to retrieve its N3 semantic description is called. Below in Listing 3.1, is reported a fragment of a retrieved piece of information:

Listing 3.1: Smart Object Semantic Description

```
data:@prefix obj: <http://example.org/objs#>.
@prefix funcs: <http://example.org/funcs#>.
@prefix foaf: <http://xmlns.com/foaf/0.1/>.

obj:SmartObject obj:Provide funcs:open-window.
obj:SmartObject obj:Provide funcs:close-window.

data:@prefix obj: <http://example.org/objs#>.
@prefix funcs: <http://example.org/funcs#>.
@prefix foaf: <http://xmlns.com/foaf/0.1/>.

{
    ?someone foaf:knows obj:SmartObject.
}
=>
{
    ?someone obj:Provide funcs:open-window.
    ?someone obj:Provide funcs:close-window.
}.

data:@prefix obj: <http://example.org/objs#>.
@prefix foaf: <http://xmlns.com/foaf/0.1/>.

obj:Me foaf:knows obj:SmartObject.
```

```
data:@prefix obj: <http://example.org/objs#>.
@prefix funcs: <http://example.org/funcs#>.
@prefix foaf: <http://xmlns.com/foaf/0.1/>.

{
    ?someone obj:Provide funcs:open-window.
}
=>
{
    ?someone obj:Provide funcs:increase-lights.
    funcs:open-window obj:Allow funcs:increase-
       lights.
}.

{
    ?someone obj:Provide funcs:close-window.
}
=>
{
    ?someone obj:Provide funcs:decrease-lights.
    funcs:close-window obj:Allow funcs:decrease-
       lights.
}.

query:@prefix obj: <http://example.org/objs#>.
@prefix funcs: <http://example.org/funcs#>.
@prefix foaf: <http://xmlns.com/foaf/0.1/>.
```

```
{
    ?a obj:Allow funcs:increase—lights.
    obj:Me obj:Provide ?a.
}
=>
{
    obj:Me obj:Provide ?a.
}.
```

This listing, presents some of the features in the N3 triple-based format, in order *subject*, *predicate*, and *object*.

In this case, the subject is represented by the smart object, the predicate is “Provide”, and the object is “set-ac-temperature”, which means that the smart object provides the functionality “set-ac-temperature”. The rest of the N3 response expresses that everyone that discovered this smart object is able to exploit its capabilities. This is useful during the discovery to filter objects that can perform a specific action needed to satisfy the intent specified by the user. The swagger description of each method contains a field, namely “Description”, which refers to the “object” field of the N3 triple related to the method itself. In this way, the semantic description is tied to the syntactic one and, both a generic client and the management app are able to know which are supported methods and how use them.

3.4 Implementation

Analysing some use cases, in which goals defined by a user can be reached through smart objects cooperation, is very important in order to highlight the M2M communication aspects. As described before, the user can choose an action within the environment or smart home. smart objects can be discovered using BLE through a smart device *e.g.*smartphone or tablet which selects the nearby smart object exploiting their semantic descriptions. Each smart object contains modules for Internet connection and discover end advertising BLE in order to detect the nearby smart objects or to become visible for each other. A smart object tries detecting the nearby devices able to perform actions related to an objective triggered by the user. As depicted in fig. 3.5, an explicative use case is the increasing of environment Temperature. If an air conditioner receives a command to switch on and emit hot air, it tries to understand if the environment contains other devices for the management of windows. The increasing of temperature in environment involves several processes such as switch on the air conditioner and close all windows opened. The perform of only one action, could make inefficient the action of the air conditioner. The smart object queries the Reasoner trying to recognize the actions related to user's objective. The reasoner contains an N3 description, as shown in listing 3.2, that allows to understand the bond among actions. The reasoner supplies a list of correlated action and the smart object will try to give a command to the nearby smart objects that provide one or more actions as highlighted by the reasoner. As shown in figure 3.1, the smart objects are capable to detect, communicate and command each other within an environment, without the direct user intervention.

Listing 3.2: Semantic Description of Bonds among Actions

```
data:@prefix obj: <http://example.org/objs#>.
@prefix funcs: <http://example.org/funcs#>.
@prefix foaf: <http://xmlns.com/foaf/0.1/>.

{
    ?func obj:Allow funcs:increase-temperature.
```

```
}
=>
{
    ?func obj:Involve funcs:on—air—hot.
    ?func obj:Involve funcs:close—window.
}.
{
    ?func obj:Allow funcs:decrease—temperature.
}
=>
{
    ?func obj:Involve funcs:on—air—cold.
    ?func obj:Involve funcs:close—window.
}.
```

3.4.1 The microclimate management use case

In this sub-section, we present a use case shown in Fig. 3.5 in which a user, Paul, wants to increase the temperature in a room equipped with different smart objects. Among them, there are an air conditioner and a window controller. In our use case, Paul is sitting at the desk of his bedroom while reading a book. It is a nice day and the window is open. With each passing hour, Paul begins to feel cold and, at some point, he begins to prefer a heated environment. So, Paul launches the management app from his smartphone and "declares" his intent to raise the temperature in the room. The application interprets that intent and then starts looking for smart objects available within the room, selecting the first one which exposes actions useful to achieve the objective coming from Paul's needs. The air conditioner receives the command to blow hot air, feature detected from its semantic description. Then,

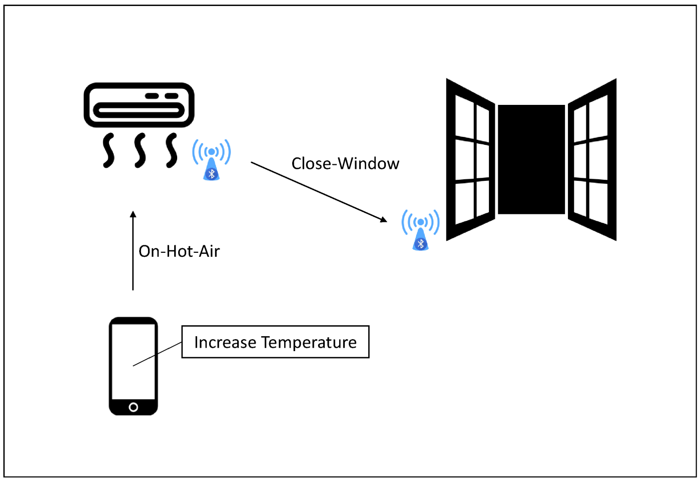


Figure 3.5: A use case for the microclimate management

since just starting the air conditioner may not be enough (*e.g.*, in the case windows are open), the smart object “air conditioner” needs to look for “smart neighbours” able to help it. For this reason, the air conditioner contacts the Reasoner asking for the list of actions that may be involved to achieve the wanted result. The Reasoner replies with the action “close-windows” to apply within the room. Finally, the air conditioner looks for smart objects that provide the “close-windows” feature (if any), sends them the command and starts blowing hot air, after that the window controller has performed similar checks with the Reasoner and the “close-windows” action.

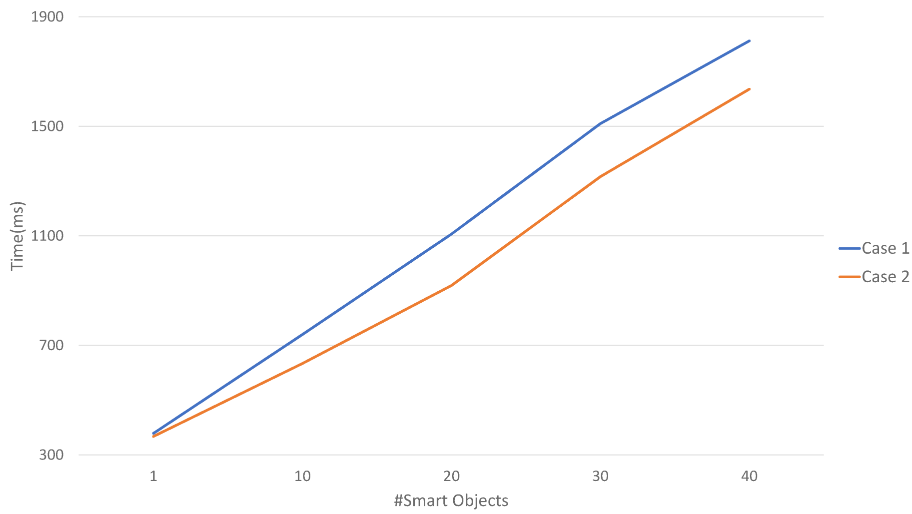


Figure 3.6: Response Time System in seconds for Case 1 and Case 2

3.4.2 Experiments

As reported above, the Reasoner is able to store and maintain an N3 description which includes the dependencies among actions. In addition, the Reasoner exploits this information to understand which smart objects are able to execute operations to reach a specific user-defined goal.

This section aims to evaluate the behaviour of the system in accordance with available smart objects within the environment and users' objectives. A set of constraints useful to analyse the results is reported below. Objects made available for these tests have been placed within the same office (a 25 square meters room) considering two different use cases (with the same objective of manage the luminosity in the office): (Case 1) each smart object expose the feature required to achieve the objective and (Case 2) only a smart object exposes the appropriate feature to reach the objective. All the smart objects involved in the experiment have been connected through the same private wireless network through a configuration phase, described in the previous sections.

The experiments give a feedback about the time required by the proposed system to retrieve the list of smart objects able to accomplish the same operation. The execution time is computed taking into account the effective time spent to select “useful” smart objects and the delay introduced by the wireless connection. This test has been repeated increasing the number the smart objects available in the environment and each test is repeated 10 times to obtain a mean value as evaluation measure.

The result of experiments, depicted in figure 3.6, shows that a reasonable response time is given in the case of slow dynamics (most due to the adopted Wi-Fi technology) and the number smart objects involved to achieve the objective is minimal. This is a limitation of many of the systems, e.g., those listed in the following related work section, and represent a direction for further investigations.

3.4.3 Results

The main idea behind this work was to introduce and test a system to enable/help users in some of the processes tied to the interaction with the smart objects that day by day are more and more embedded in environments such as homes, offices, and cities.

The proposed approach exploits smart objects that once discovered through an application for handled devices are instructed to meet a user-defined goal collaborating among them in a peer-to-peer (P2P) mode.

Performed tests have shown that the adopted distributed approach can work and can be applied in those cases in which it is preferable to resort to centralized entities to control the interaction.

CHAPTER

FOUR

SMARTWORKS: A MULTI-SIDED CONTEXT-AWARE PLATFORM FOR THE SMARTMUSEUM

In the last few years, IoT is gradually acquiring an important role also in the Cultural Heritage domain valorizing artworks by means of innovative technological applications that create an interactive user experience able to reduce the distance among "cultural things" and people.

Recently, several innovative approaches have been adopted, the most relevant of which include the use of headphones or robots for an immersive fruition of artworks, supported by smart-phone applications to collect opinions, wishes, and users' suggestions.

This solution is called smARTworks, a Multi-Sided Context-Aware platform aimed to enhance the user experience while visiting a museum, an archaeological site, or the monuments in a city, and to simplify the process of information retrieval connected with the discovery of nearby artworks. The smARTworks platform exploits widespread GPS and BLE technologies available in personal devices, i.e., smart-phones, supplying an application which exposes artworks multimedia contents.

4.0.1 Motivating Example

In order to involve more users and, above all, young ones it is necessary to provide for a significant technological improvement to ensure immersive and interactive user-experiences within cultural environments. We here propose to analyze an use case to validate the spread of IoT platforms within cultural spaces such as museums and archeological sites.

This solution aims to increase the interest toward the Cultural Heritage domain according to the IoT vision. The introduction of new technologies does not necessarily include a massive use of invasive and expensive instruments and, to further reduce infrastructures' costs, it is possible to limit the use of additional devices. For this reason, this work proposes the use of widespread devices such as smart-phones to gather information and multimedia contents about the artworks within the surrounding environment.

Let us suppose that Sam is visiting a museum: thanks to the smARTworks application, Sam is able to retrieve the list of works in his nearby. In this way, he can evaluate artworks details, included audio, video, and texture multimedia contents.

In the case that the cultural environment includes totems, TV or image projectors, it is possible to exploit them in order to enhance users' experiences, in support of sharing information.

During his visit, Sam is also able to express opinions, writing comments or putting "likes" related to the artworks he has seen. These pieces of information are collected to provide data to Decision Support Systems (DSS) for the management of the cultural site and of the artworks it hosts.

4.1 smARTworks Architecture

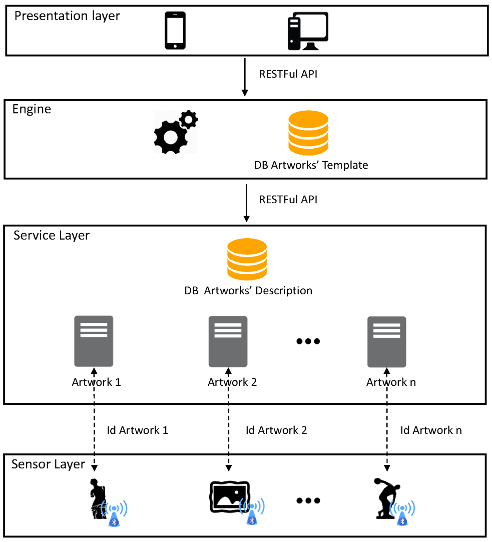


Figure 4.1: smARTworks Architecture

The smARTworks platform is thought to provide educational visits according to user's context and preferences by means of widespread devices (*i.e.*, smart-phones). These device exploit a centralized architecture, depicted in 4.1, which exposes "Artworks as Services".

Then, the smARTworks smart-phone application highlights the most interesting artworks, with the goal of optimize the quality and duration of each visit. Through this application, a user can also choose to view multimedia contents related to nearby artworks and express opinions such as "likes" and textual comments. These "likes" are very meaningful to build statistics aimed to the maintenance of cultural environments. For example, an artwork that has attracted more interest than others, could be supported by additional elements such totems or image projectors in order to improve the quality of experience.

Furthermore, the proposal involves the use of BLE Beacon devices to localize items within a Cultural Heritage environment. During the deployment phase the transmission power of these Beacons is regulated to reduce coverage overlapping.

In the following subsections, an overview of platform's layers is provided to detail the architecture of the proposed system.

4.1.1 Sensor Layer

The first tier in the architecture is represented by the Sensor Layer. This Layer manages all the Beacons able to cover the considered environment. Through a configuration phase, each Beacon's Identifier is linked (with an one-to-one relation). In this way, the BLE broadcasting process allows users to recognize an artwork and to retrieve proper pieces of information and multimedia contents.

4.1.2 Service Layer

The Service Layer includes all existing services connected to the network, and enables the management of artworks within the cultural environment. Each single service is able to give a "Virtual Sense" of an artwork and to handle the related information. In facts, a Database containing entries' descriptions (in JSON format) can be queried. In particular, Table 4.1 shows some artwork's features such as, id, indoor and outdoor coordinates, and URIs of multimedia content, stored in the DB.

Built in line with RESTFul paradigms, the service exposes several managing APIs for cultural items. Below, has been listed a series of the most relevant functionalities provided by Services.

- Method for the association of single artwork to a specific beacon.
- Method for the update of the artwork's description.
- Method for the addition of multimedia content as Video o Audio.
- Method for the retrieving of the artwork's information.

These functionalities, with other, are described by means of a JSON Template, which aims to give details of RESTFul request like type, request and response parameters. Practically, this template aims to describe the Service interface which has an high important in communication process between the Service and the Engine. For this reason, Template information are maintained in a Database accessible from the Engine Level. According with architectural requirements, it is possible to select until two type of implementation patterns: the first, which needs a single Service for each artwork(one to one), and the latter that provides a single service able to manage more artworks reachable from different URI.

4.1.3 Engine Layer

The Engine represents the core of the platform. As central part of the architecture, it covers several tasks including the collection of user context's information and the production of a list of artworks. Therefore, the Engine aims to share the artworks' descriptions towards smart-phone application as response to an incoming request. In details, the implementation of this layer

Table 4.1: Artwork's Attributes

Attribute	**Description**
Id	The artwork identifier
IndoorPosition	The ID related to the Beacon
OutdoorPosition	A geometric polygon representing the area that contains the artwork, represented through a GeoJSON format
ObjectWorkTypeWrap	Wrapper of work type information
TitleWrap	Wrapper of title information
DisplayCreator	Creator information
CultureWrap	Information about art movement
Images	Array of Images' URIs
Videos	Array of Videos' URIs
Audios	Array of Audios' URIs
Tags	Keywords useful for categorizing artworks

is in line with the RESTFul paradigms, and it equips the platform with a series of APIs, including functionalities for the management of opinions and affluence related to users and artworks. In line with results obtained, the managers can take decision aimed to increase the quality of visits. In order to give a complete vision of Engine capabilities, a full list of functionalities is reported below:

- Management of users' profiles.
- Retrieval of JSON descriptor for a specific artwork
- Retrieval of artworks' information.
- Management of comments and LIKEs for a specific artwork
- Retrieval of statistics information for each artwork(number of likes, number of user that express interest for artworks).

- Retrieval of statistics related to affluence.

In addition to these functionalities, the Engine take-charge of communication with all Services aiming to retrieve cultural items' information.

4.1.4 Presentation Layer

The presentation layer includes applications aimed to provide a User Interface (UI) that allow to exploit the functionalities of platform. For example, a smart-phone application is able to give an overview of the surrounding environment in term of services and multimedia contents linked to artworks. Is important to highlight the use of a Dynamic User Interface (DUI) to generate the appropriate graphical interface for the cultural item. The notation chosen to represent this description is SWAGGER. The DUI block is essentially a java-script script which transforms the SWAGGER definition of the artworks into an HTML page which contains the appropriate User Interface.

Furthermore, in order to supply functionalities for supporting managers decisions, an DSS dashboard ca be equipped with graphic instruments built on top of Engine layer.

4.1.5 Artwork Description

The structure of descriptive JSON file follows the CDWA Lite schema [65]. Thus, the CDWA Lite element set consists of twenty-two elements of which nineteen are for descriptive metadata, tree for administrative metadata and only nine are required. A main characteristic of the CDWA Lite format is the division of the descriptive metadata in display elements on one hand, optimised for presentation purposes, and indexing elements, optimised for retrieval on the other hand. Indexing elements, as they usually should refer

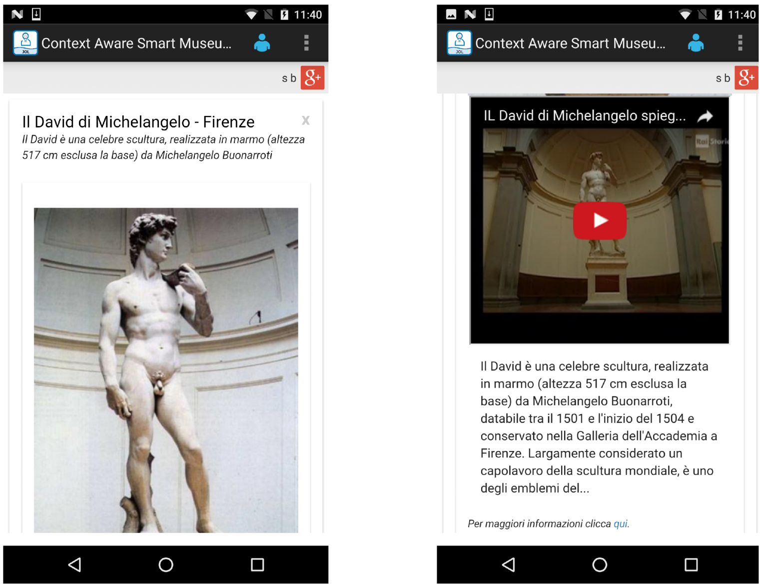


Figure 4.2: HTML Interface as output of DUI

to authorities for actors, places, or to controlled vocabularies, are provided with attributes for storing a respective URI (termsource and termsource ID), assuring the identity of a term in a larger context.

The use of CDWA standard allows to introduce the smARTworks platform within exiting environments that hold CDWA Lite description database. For this reason, a converter module has been developed, and generates a conversion from XML format to JSON format.

An example of User interface generated by DUI is depicted in 4.2. In particular, this picture show the UI as result of a specific use case, which involves the use of a service named Artwork-service. This service is able to give information related to several artworks by means of a Database that includes several JSON descriptors. Therefore, we have assumed to localize "il

David di Michelangelo" sculpture by means of a Beacon device, accompanied by a JSON descriptor object that include two multimedia contents (image and video).

4.1.6 Setting of preferences

After the installation process, this phase aims to collect information related to interesting art movements for users. In particular, the user has available a list that includes artistic movements, types of artworks and artists. Supported by this list, the user can select several meaningful options saved in a JSON object[Listing 4.1], in order to highlight the interesting items.

The database of artworks, is queried in order to retrieve the nearby items that meet the user's preferences, through discriminants such as artistic movements, types and authors of artworks. In relation to a selected item, a series of additional linked artworks provided, aimed to enhancing the cultural level of the visit.

Listing 4.1: Preferences JSON

```
Preferences = {
    id_user:00232,
    art_movements:[id_art_mov_1, id_art_mov_2...],
    types:[type1,type2...],
    artists:[id_artist_1, id_artist_2...]
}
```

4.2 Results

In this work, a low-cost system that introduces the IoT vision into Cultural Heritage environments has been proposed. The system aims at making the user experience more interactive taking into account contexual information and preferences. It also may help administrations to better understand which are the visitor-flows in order to manage exhibitions.

As reported on the table 4.2, the proposed platform is able to provide users' location within an indoor/outdoor smart environment, expose lists of nearby artworks of interest, and offer APIs to support the development and use of management tools such DSSs also thanks to the CDWA Lite schema thought to maintain a standard description of artworks.

Table 4.2: Comparison of main Smart Museum Solutions

Solution	Indoor positioning	Outdoor positioning	Support to DSS	CDWA Lite
[42]	IBeacon	No	No	No
[43]	BLE Beacon	No	No	No
[34]	BLE Discovery/Advertising	No	No	Yes
The Narrator [66]	Wi-Fi	No	No	No
[67]	Bluetooth tracking system	No	Yes	No
[35]	BLE Landmarks	No	No	No
smARTworks	BLE Beacon	GPS	Yes	Yes

CHAPTER

FIVE

BAAS: MOBILE SENSOR NODES NETWORK FOR THE AIR QUALITY MONITORING

Air pollution is a relevant problem which affects many cities worldwide. The air pollutants are responsible for many human diseases and they are possible causes of mutations of climate and ecosystems. Recently, air pollution has become a sensible argument that leads the municipality of many cities to employ instruments capable to supervise this phenom and plan solutions to reduce air pollutants' levels. At the same time, the introduction of technologies such as RFID, GPS and Bluetooth Low Energy, decreases the complexity and access-time of a large set of services. In particular, the Internet of Things (IoT) [1] paradigm has ensured the implementation of many solutions aimed to make a city "Smart".

The Smart City involves a large number of case studies [68] that range from simple smart services for the communities, to the monitoring of city resources. According with Smart City principles, we propose a solution to monitor the air quality of Catania (Italy). The solution we describe in this paper is designed and implemented with the collaboration of TIM Joint Open Lab based in Catania. Conventional methods of air quality monitoring usually

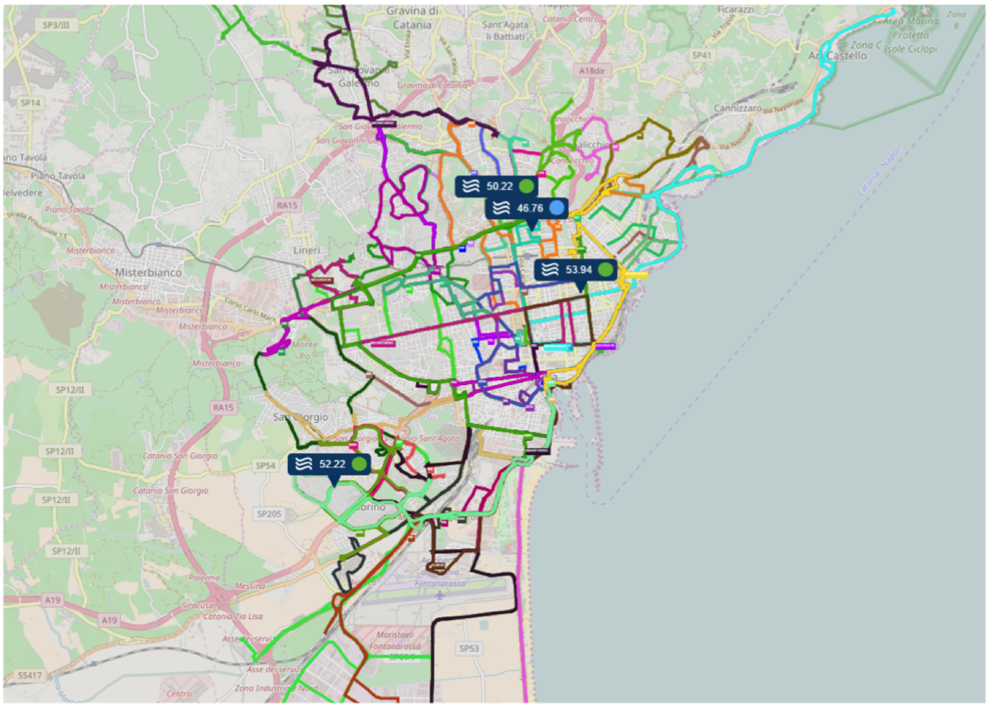


Figure 5.1: Catania bus lines

involve the use of static stations, that can retrieve information about Temperature, Humidity, Pressure, and also about several pollutants, e.g., Ozone (O_3), Carbon Monoxide (CO), Carbon Dioxide (CO_2), Sulfur dioxide (SO_2), Nitrogen dioxide (NO_2), and nanoparticles such as $PM1$, $PM2.5$, and $PM10$. Nevertheless, the static stations are very expensive and often do not cover large areas. In opposite with the fixed stations solution, we introduce a Dynamic Mobile Station able to cover the whole urban area. Figure 5.1 shows the monitoring area we can obtain using buses "as sensors", compared to the adoption of fixed stations.

The solution we describe involves mobile sensor nodes, installed on top of any available city buses, to cover the reachable sites of the city, supported from a series of monitoring static stations. The mobile nodes are equipped with sensors in order to measure the most relevant air pollutants (O_3, CO, CO_2, SO_2, NO_2, $PM1$, $PM2.5$, $PM10$). In addition, each node can be equipped with Temperature, Humidity, Pressure, and Noise Level sensors.

The described architecture, namely Bus as a Sensor (BaaS), aims to provide a Multi-Sided system for a real-time air quality monitoring through the exploitation of an algorithm defined by ARPA (Regional Agency for Environment Protection) which allows to compute the Air Quality Index (IQA). The IQA index is an adimensional number which expresses a synthetic state of the atmosphere pollution through the use of main air pollutants $PM10$, NO_2, and O_3.

The main objective of BaaS is to supply an interoperable and scalable system thought for municipalities and citizens useful to monitor the air quality and, at the same time, track bus services. Furthermore, the BaaS architecture provides an interface useful for the implementation of many applications: In particular, we present the BaaS Dashboard, a web application able to monitor the air quality and track bus services, supported by a real-time high-resolution dynamic map.

The BaaS Dashboard is organized as an extensible series of interchangeable overlays, with a particular focus on the Air Quality layer. The Dashboard displays a grid on top of Catania map that splits the urban area in squares. For each square, the IQA value or the pollutant measurements are reported.

In order to give a graphical feedback to users, a color scale with a specific opacity has been used to show the freshness of displayed data. In this way, each square changes its color in accordance to the value sensed from the BaaS system.

5.1 Related Work in literature

The method for monitoring air pollution, in most countries, involves the use of static air pollution monitoring stations. Fixed stations are able to sense highly accurate measurements from a limited number of sites. In opposite to the accuracy and precision of sensed data, the fixed stations are expensive, large, and power hungry. Nevertheless, the static stations have been exploited to achieve the implementation of indoor air quality monitoring systems. Indeed, in [69] authors built a hierarchical system for the monitoring of air quality through terminal sensor nodes within smart buildings. These sensor nodes send the air data to an information processing center for real-time displaying.

Inline with indoor air quality monitoring concepts, a system based on Android smart-phones [70] senses data from indoor environment around the user in real-time. In [71] an indoor air monitoring device prototype has been developed to measure the concentration of CO gas. These devices communicate with cloud system when the threshold of these gases is reached.

The introduction of IoT paradigm has led to implement air monitoring systems supported by electronic platforms. In [72] authors present the Polluino system to monitor the air pollution via Arduino, with the support of a Cloud-based platform able to manage data coming from sensors.

As opposed to traditional air quality monitoring stations, the use of dynamic and mobile sensors networks is quickly emerging, aiming to sense air quality data with high temporal and spatial resolution.

In [73] a collaborative sensing system based on bicycles is used for monitoring urban air quality. This solution is supported from affordable portable sensors mounted in a public bicycles sharing system to monitor air pollutants.

A further solution [74] implements an air quality system using mobile sensing for air pollution monitoring. This solution uses a sensor node able to forward collected data to a smart-phone able to communicate with a central sever used for the pollutants information storage.

With the spread of mobile sensors network, the idea to anchor sensor nodes to public transport vehicles takes hold. In [75] mobile sensors are placed on public transport vehicles for acquiring data along the path to send it to management systems. Furthermore, the solutions [76, 77], aim to generate a high resolution air pollution maps for urban environments. In particular, in [76] a data visualization based on a segmentation roads is used, while [77] provides an instrument able to supervise air pollutants with the support of a grid based representation.

Inline with the air quality monitoring concepts, the measurement of pollutants and weather variables in the city of Rio de Janeiro were used to characterize temporal and spatial relationships of air pollution in [78].

In order to determine how environmental data gathered from mobile networks should be represented, a study was conduced in [79], in which the authors evaluate different methods for showing data, reporting a great success for heat-maps visualization.

Our proposal involves the main concepts of the above cited works to accomplish an easy air quality monitoring system for the municipality of Catania. In particular, our system is equipped with a Platform Layer which aims to implement a more intelligent management of sensor nodes, supported by a Middleware Layer able to manipulate the data for the final user visualization. The Application Layer exploits a multi-level user interface with a grid to report air quality information. Furthermore, the sensor nodes used for this work have more accuracy and precision rather than smart-phone sensors.

5.2 Bus As Sensors Architecture

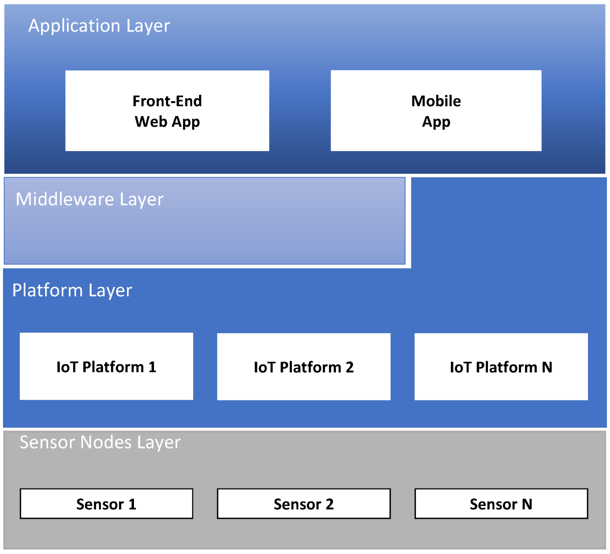


Figure 5.2: BaaS Architecture

The Bus as a Sensor (BaaS) project intends to support the Catania Municipality with a Multi-Sided solution that acts as a Decision Support System and instrument able to simplify the exploitation of services ensured by the city. Despite the traditional air quality monitoring system based on static stations, the BaaS exploits a network of sensor nodes fixed on public buses of Catania transport company. Thus, BaaS is able to provide information with a high temporal and spatial resolution map, while the coverage of the network dynamically changes over time, generating a solid snapshot of the air pollution current state at a specific time. As depicted in Figure 5.2 the BaaS architecture is composed by four layers: the Sensor Node Layer, the Platform Layer, the Middleware Layer, and the Application Layer.

5.2.1 Sensors Layer

The Sensor Layer of BaaS architecture includes a set of sensors that have been located on top of buses to build a dynamic sensing network for air quality monitoring, and other additional services such as bus position tracking and crowd monitoring, road quality monitoring. In addition to this mobile sensors network, a limited number of static monitoring stations have been located in several sites of city to cover areas inaccessible to public transport services.

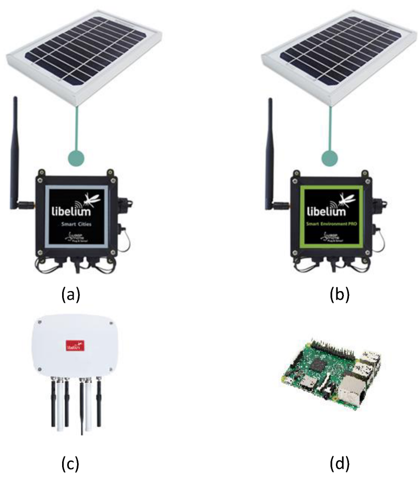


Figure 5.3: Sensor Node Layer - (a) Libelium Smart City Pro, (b) Libelium Smart Environment Pro, (c) Libelium Meshlium Extreme 4.0, (d) Raspberry Pi 3 board

A preliminary technology assessment leads to the use of Libelium sensor nodes for the BaaS solution. In particular, the Smart City Pro sensor Boards (Fig. 5.3a) are used for static sensor nodes, equipped with sensors of Temperature, Humidity, Pressure, Ozone (O_3), Carbon Monoxide (CO), Carbon Dioxide (CO_2), and Noise Level (LNS). The mobile sensor nodes consist of Libelium Smart Environment Pro (Fig. 5.3b) devices. Each one of these is equipped with sensors of $PM1$, $PM2.5$, $PM10$, CO, O_3, SO_2, NO_2. All sensors used in BaaS are calibrated by the manufacturers without further configuration efforts.

Libelium Plug & Sense devices allow to deploy Internet of Things networks ensuring low maintenance costs. Libelium Plug & Sense has a waterproof enclosure with specific external sockets to connect the sensors, the antenna, and the solar panel used as power supply unit [80].

According to the BaaS architecture concepts, the static sensor nodes gather measures from the environment and send the packets to the Meshlium Extreme 4.0 (Fig. 5.3c), a fixed gateway that forwards air pollution data to the Platform Layer. Furthermore, the mobile sensors nodes send the measured values to the Platform Layer through a mobile gateway anchored upon bus. This mobile gateway is implemented with a Raspberry Pi 3 board (Fig. 5.3d) equipped with a 3G connectivity and a GPS modules. The Raspberry board ensures to retrieve the GPS bus position for each measures sensed on the bus. Furthermore, the GPS positions are also used by the higher level of architecture to track the buses' positions.

The packets sent to the Platform Layer contain a bus identifier, the GPS position, and the measures of pollutants provided by sensors.

		GPSPosition		*AirPollutants*						
IdBus	*Timestamp*	*Latitude*	*Longitude*	O_3	*CO*	SO_2	NO_2	*PM*10	*PM*2.5	*PM*1
1	1498804903	37.523376	15.082340	37.3	0.8	1.2	16.98	30	28	26
2	1498804926	37.522525	15.082512	35.6	0.6	0.9	15.02	28	30	28

Table 5.1: Examples of data rows stored on IoT Platform

5.2.2 Platform Layer

The Platform Layer is able to manage the data supplied by Sensor Node Layer. We have used several proprietary IoT platform, but it is possible to mount different IoT open source solutions.

The first phase involves a bus registration towards the Platform Layer in order to assign an unique ID to each bus. IDs allow to store the data coming from the sensor layer, making possible the relation between data and bus service. As a way of illustration, in Table 5.1 we report a sample of raw measurement stored. Each stored row contains an Id to identify the bus, a Unix timestamp that represents the time in which the measure is sensed, the GPS Position and air pollutants data.

Inline with the BaaS architecture, the Application Layer can directly communicate with both the Middleware layer and the Platform Layer. The first provides aggregated data to monitor the air quality, while the second holds the GPS position data to track the bus and report the information for the users.

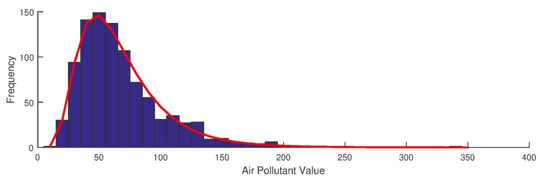


Figure 5.4: Air Polluntant's Log-Normal Distribution

For experimental tests, we use a simulator of air pollutants data. As described in several works [76, 77], the concentration of ambient air pollutants closely follows a log-normal distribution. We use a log-normal distribution to simulate the air pollution concentration within the city as the Fig. 5.4 reports.

5.2.3 Middleware

The Aggregation Framework is the level at bottom of the Middleware Layer as reported in Fig. 5.5, and it aims to aggregate the air pollutants data retrieved from Platform Layer with a specific aggregation function. This process is required by the Presentation Layer in order to report an air quality snapshot of the city with the help of a grid that covers the city area.

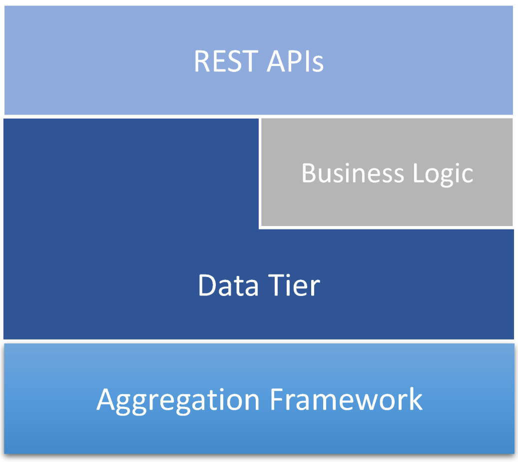


Figure 5.5: BaaS Middleware

This grid splits the area in several geo-localized squares centered in specific geo-coordinates latitude and longitude. Each square's side is 150 meters long. The aforementioned grid was previously built to support scientific studies about the presence of people related to urban locations [81]. The addressed case studies range from the classic human mobility and traffic analysis to energy consumption problems.

The Aggregation Framework gets air pollutants data from the Platform Layer at a fixed rate (AR) to process measures (we set AR value to 15 minutes). In Figure 5.6, an example of aggregation process is shown. The T value is a time-stamp, M the measure of pollutant, S the square, and AQ the air quality.

$$\begin{bmatrix} T_1,\ Lat_1,\ Lon_1,\ M_1 \\ T_2,\ Lat_2,\ Lon_2,\ M_2 \\ T_3,\ Lat_3,\ Lon_3,\ M_3 \\ T_4,\ Lat_4,\ Lon_4,\ M_4 \\ T_5,\ Lat_5,\ Lon_5,\ M_5 \end{bmatrix} \rightarrow \begin{bmatrix} S_1,M_1,M_2 \\ S_2,M_3,M_4 \\ S_3,M_5 \end{bmatrix} \rightarrow \begin{bmatrix} S_1,AQ_1 \\ S_2,AQ_2 \\ S_3,AQ_3 \end{bmatrix}$$

Figure 5.6: Aggregation process example

At first, the aggregation process maps each geo-located measures in the relative squares. The middleware gathers and processes all the measures provided by both the mobile sensors and static monitoring stations. This procedure is carried out by computing for each pollutant measure the relative circumscribing square.

As described above, a single measure M_j provided from a specific mobile sensor includes measurement of O_3, NO_2 and $PM10$. We used these values to find the relative pollutant concentration as described in equations (5.1),(5.2) and (5.3).

$$M_{PM10_j} = \frac{PM10}{50} * 100 \tag{5.1}$$

$$M_{O_{3_j}} = \frac{O_3}{120} * 100 \tag{5.2}$$

$$M_{NO_{2_j}} = \frac{NO_2}{200} * 100 \tag{5.3}$$

For a measure j we compute the air quality index f_{AQM_j} as the maximum value of the pollutants concentrations M_{PM10_j}, $M_{O_{3_j}}$ and $M_{NO_{2_j}}$.

$$f_{AQM_j} = maxM_{NO_{2_j}}, M_{PM10_j}, M_{O_{3_j}} \tag{5.4}$$

Finally, for a specific square S_i the Air Quality index will be the the arithmetical mean of the N air quality indexes contained in the square.

$$AQ_{S_i} = \frac{1}{N} * {}_{J=1}^{N} f_{AQM_j} \tag{5.5}$$

The data results of Aggregation Layer, are stored in logical database management entity (Data Tier level) which are directly available from Application Layer through REST API, or previously elaborated in the Business Intelligence level.

5.2.4 Application Layer

The Application Layer allows to display the data provided by dynamic bus network thanks to the support of a series of applications including a Dashboard and a mobile application. The Dashboard is developed in accordance with the web application principles and it is organized as a set of overlays on top of a Catania Map as shown in Fig. 5.8. The figure also reports the main functionalities of Dashboard, including:

- **Routes Layer**, shows the buses' lines.
- **Markers Layer**, depicts the static air quality stations with a preview of data sensed.
- **QA Grid Layer**, shows the air quality monitoring information.

The number of layers, and their relative functionalities, could be extended in accordance with the users' needs. In particular, the QA Grid Layer has a high relevance for the municipality since it provides a view of the air quality pollution degree through a high resolution air quality map (Fig. 5.7). Furthermore, the grid also allows to report each single pollutant contribution to discriminate and locate the variations of pollution causes in a specific site.

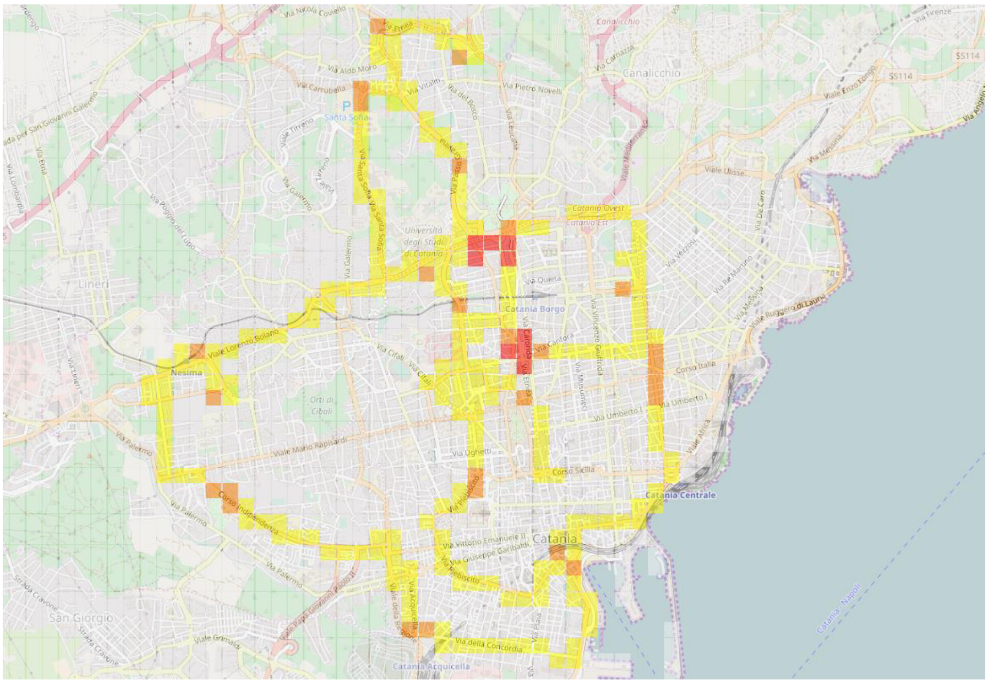


Figure 5.7: High Resolution Air Quality map

At first, since all buses are out of service, none available data are provided for the Middleware Layer while the Grid are not able to display any information. As result of buses activation, the sensor nodes start to monitor the air pollutants and send data towards the Platform Layer. Then, the middleware presents the result of aggregation process to the Application Layer.

The latter builds the grid and paints each square with a color that represents the Air Quality Index or a single pollutant. In order to recognize and monitor the city areas under sensor nodes activity, the grid of BaaS provides a specific color to highlight the air quality index and the freshness of the available data.

The coverage of the network dynamically changes over time and it is possible to not have data available in some city areas at a specific time.

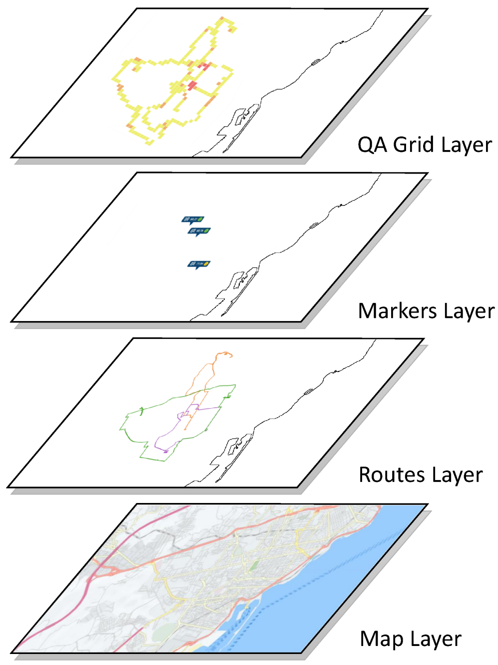


Figure 5.8: Front-End Layers

The freshness index takes into account the bus activity time parameter (*BA*) expressed in hours. In particular, the BaaS considers 12 hours of bus activity day. The equation (5.6) defines the *indexOpacity* value that identifies the freshness index and ensures an opacity value for a specific square.

$$indexOpacity = 1 - \frac{q}{Q} \tag{5.6}$$

$$q = \frac{timestamp_i - timestamp_{current}}{AF} \tag{5.7}$$

The q value is evaluated through the difference between the timestamp of the i aggregated measure and the current time expressed in minutes, over the middleware aggregation frequency (AF = 15 minutes in our case) as defined in equation (5.7).

$$Q = BA * \frac{60}{AF} \tag{5.8}$$

The Q (5.8) parameter is the product between the BA and the number of minutes in one hour (60) over the AF parameter.

The Marker Layer locates all fixed stations. Each station reports the last computed air quality value and let to retrieve the details of each single air pollutant. In addition with this layer, a Routes Layer shows the paths of buses to detect their actual position. This is an important feature that is helpful to track the buses services.

5.3 Results

The main idea behind this work was to introduce a mobile air quality monitoring system for the municipality of Catania. The proposed approach exploited a series of sensor nodes anchored on top of public transportation services, to create a sensor mobile network in order to increase the number of urban sites monitored. This proposal was implemented at a first stage using simulated data. In addition a real trial on field within the University campus has been carried out. The tests we conduct report a success in terms of usability of the web application. The BaaS also includes a mobile application able to gather the user context information about the position in order to suggest him the appropriate routes and places without an high level of pollution. This solution has been deployed within the Catania area and next steps are going to introduce new smart city services based on the actual acquired data. A set of tests performed in the Catania area has highlighted some inappropriate behaviours, that should be improved in order to obtain an high precision and a correct service. In particular, the autonomy of sensors could decrease rapidly with a wrong management of the deep sleep phase (which represents the IDLE state of devices). Furthermore, the devices should be disabled during the maintenance of the vehicles, in order to save the available energy, while a set of new totally Open Source devices could be used in order to reduce the development costs.

CONCLUSIONS

The recent research and development activities show that the IoT and Smart Object concepts play an important role in the ordinary peoples' lives. This Thesis aimed to analyse the IoT paradigm, and how these new concepts increase the quality of life through the providing of localized services and applications based on personal and context information.

The work provided in this Thesis focuses in several areas which exploit the IoT concepts. In particular, various Context-Aware Applications has been developed in order to provide useful information to the users by means indoor and outdoor localization technologies, and relevant context data.

These applications share the same central idea i.e. the creation of a smart environment, and the exploitation of IoT technologies to improve monitoring and managing services for the resources available within an environment. These represent the main concepts of Smart City, and these Thesis has introduced solutions that involves these concepts. These works have been introduced as single services of a unique Smart System Ecosystem, which is still under development.

The works presented include a smart parking application which has been developed to find vacant park slots within a city taking advantage of currently widespread technologies available in common smartphones, without the introduction of new expansive infrastructures.

In accordance with the indoor and outdoor localization technologies, several systems have been presented including the Smart Museums system to enrich the users' experiences, the management system for smart devices in smart environments, and the Air Quality Monitoring System(BaaS) with dynamic vehicles network.

Except for the BaaS (which required a set of relevant and specific sensors to sense air pollutants), the provided works aims to provide useful services without the need of additional devices.

In my opinion, we could provide services for users using common widespread devices to reduce the impact within users' lives. In this way, costs are reduced, and users are not forced to acquire new devices. In fact, today smartphones and wearable devices are equipped with relevant sensors and internet connection, and often they are enough to implement IoT solution.

The areas in which the IoT concepts could be used are extremely heterogeneous, and this Thesis wants also show the enormous potentiality of this new paradigm and its applications in ordinary peoples' environments.

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