Integration of RFID and WSN Technologies in a Smart Parking System

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***Abstract*—In this paper, a Smart Parking System (SPS) based on the integration of Ultra-High Frequency (UHF) Radio Frequency Identification (RFID) and IEEE 802.15.4 Wireless Sensor Network (WSN) technologies is presented. The system is able to collect information about the occupancy state of parking spaces, and to direct drivers to the nearest vacant parking spot by using a customized software application. Such application also leverages an NFC-based e-wallet system to allow users to pay for the parking fee. Furthermore, a software application based on RESTful Java and Google Cloud Messaging (GCM) technologies has been installed on a Central Server in order to manage alert events (e.g. improper use of a reserved space or expiration of the purchased time). In such a case, it promptly informs the traffic cops through an Android mobile app, which has been designed ad hoc for the considered scenario. A proof-of-concept has demonstrated that the proposed solution can meet the real requirements of a SPS.**

Keywords—RFID; WSN;NFC; Integration; Smart Parking.

I. Introduction

Finding a vacant parking space during the rush hours is a common problem in most of the cities. It is estimated that 30% of the daily traffic congestion in an urban downtown area is caused by vehicles cruising for parking space, and that a driver spends on average 7.8 min to find a parking spot [1]. This not only causes waste of time and fuel for drivers looking for parking but also increases air pollution and drivers' frustration. The recent achievements in the Internet of Things (IoT) enabling technologies [2] open up opportunities to develop innovative smart parking systems, able to significantly reduce the traffic congestion and improve the citizens' quality of life.

Among the emerging wireless technologies, the Radio Frequency Identification (RFID) and Wireless Sensor Networks (WSNs) represent two of the most promising candidate to implement a complete smart environment. In particular, RFID is a low-cost and low-power technology consisting of passive devices, called tags, which are able to transmit the stored data when powered by the electromagnetic field generated by an interrogator, called reader. Since passive RFID tags do not need a source of energy to operate, their lifetime can be measured in decades, thus making the RFID technology well suited for many application scenarios [3]-[5]. However, the main drawback of RFID technology stems from the fact that tags can operate solely under the reader coverage region, thus making the use of this solution limited to object identification in small areas. The integration of RFID and WSN technologies could be a well-suited approach to overcome this limit, thus enabling the development of complex, next-generation applications. Basically, WSNs consist of a large number of low-power embedded devices, called sensor nodes, which are able to self-configure and self-organize. These characteristics make them suitable to be deployed even in harsh environments in order to capture important parameters (e.g. temperature, light, humidity, etc.) without human intervention [6]-[8]. The collected data are usually delivered, in a multi-hop mode, to a central point for a proper utilization and processing.

Although RFID and WSN were originally designed with different objectives, the benefits provided by both technologies suggest the development of an integrated solution, at physical layer, able to combine the identification capability of the RFID technology and the advanced communication features of the WSN solutions [9], [10]. This could significantly enhance the effectiveness of both technologies, giving new perspectives to a broad range of innovative applications, such as smart parking solutions.

Over the last years, several works aiming at improving parking management have been proposed. Most of them are based on the use of intelligent parking guidance and information (PGI) systems able to provide the drivers with information on the location and the availability of spaces in car parks and direct them to vacant parking lots. The proper operation of these systems is based on the use of sensors able to detect the presence of vehicles placed in the vicinity of parking spaces. In [11], [12] video camera sensors are used to collect information of vehicle parking fields. However, such devices usually generate a large amount of data that are difficult to transmit in wireless networks. On the contrary, WSN technology represents the ideal choice for implementing smart parking services, since sensor nodes can be easily deployed in existing parking spaces without installing new components. Furthermore, the parking information retrieved by each node can be processed in a collaborative mode in order to evaluate important metrics, such as parking times, billing and payment. In, authors used WSN nodes equipped with a light sensor to detect the state of each parking lot in an indoor area and to report the retrieved information to a Web server via the

WSN. The information was also sent to a central server using a Wi-Fi network, and make accessible to the drivers through a mobile phone. In [14] authors proposed a detection scheme using magnetometer signature measurements able to track available parking spaces in public areas in real time and communicate the information to the users. Moreover, a new reservation-based smart parking system, which not only broadcast real-time parking information to the driver, but also provide reservation service was proposed in [15].

However, to the best of authors' knowledge, none of the parking systems already presented in the literature is able to identify unauthorized uses of reserved spaces. Often drivers, frustrated by the lack of parking spaces in large metropolitan areas, use the parking spots reserved for particular categories of people, such as disabled or law enforcement. The introduction of an innovative parking management system capable not only to drive users toward the vacant parking lots, but also to allow traffic authorities to adequately monitor the status of reserved parking spaces, could significantly improve the citizens' quality of life. Additionally, the ability for a user to automatically pay for the occupied parking space should be a core system feature, as it would allow the user to deal with a single application and, at the same time, it would enable traffic authorities to perform real time checks.

To meet these needs, a smart parking system based on several innovative technologies, such as RFID, WSN, NFC (Near Field Communication) and mobile phone, for the automatic monitoring and management of parking spaces, is introduced in this paper. The system augments standard WSN functionalities through the deployment of advanced network nodes featuring both WSN communication/sensing and UHF RFID identification capabilities. The system is able to collect, in real time, information about the occupancy status of parking spaces (reserved and not), and, to direct drivers to the nearest vacant parking spot by using a customized software application specifically designed for mobile devices such as smartphones, tablets, etc. Such application allows users to pay for the occupied parking space, leveraging an authors' previous work called IDA-Pay [16]. The revised version of IDA-Pay we present takes fully advantage of the Mobile Proximity Payment (MPP) increasing trend, for which more that 50% mobile phones in Italy will be NFC-enabled in 2017. Furthermore, in case of improper use of a reserved space or expiration of the purchased time, the system is able to promptly inform the traffic cops equipped with a smartphone connected to a small portable UHF RFID reader.

The remainder of the paper is organized as follows. Section II outlines the architecture of the proposed smart parking system along with involved hardware and software components. Section III describes and experimentally validates a proof-of-concept implementation of the system. Finally, concluding remarks are given in Section IV.

II. System Architecture

The proposed Smart Parking System (SPS) is characterized not only by the combined use of different innovative technologies, such as NFC and mobile applications, but also by the physical integration of UHF RFID and WSN technologies. In the following the overall architecture, shown in Fig.1, is described.

A. *Architecture Overview*

Basically, the SPS provides innovative services for the automatic supervision of paid parking spaces through the deployment of an IEEE 802.15.4-based WSN able to collect and deliver data to a Central Server. A customized application on the server analyses the received information and sends an alert message to the mobile application of the traffic cop in case of unauthorized use of a reserved space or expiration of a parking receipt. Drivers can also use the system to pay the fee. The infrastructure of the system consists of WSNs, Smart Gateway (SG), Central Server (CS) and two different mobile applications, called Parking App and Policeman App, designed for vehicle drivers and traffic cops, respectively.

The main components of the deployed Zigbee network are Router (R) and Coordinator (C) nodes (Table I). The R nodes provide forwarding and routing capabilities, while the C node collects the received data and forwards them to the Central Server. In the RFID-WSN integrated system, the Router Reader (RR) node typology has been introduced, which identifies a R node interfaced with an UHF RFID reader.

The designed system consists of a WSN with several R and RR nodes scattered in the parking area. In particular, R nodes, equipped with a light sensor, are placed on each parking lot to monitor their state, while RR nodes are placed on poles located near the reserved parking spaces. The information retrieved by the nodes is delivered, in a multi-hop manner, to the C node, which sends them to the SG. This last one, in turn, analyses the collected data and sends them, together with the position of parking zone, to the CS. The SG

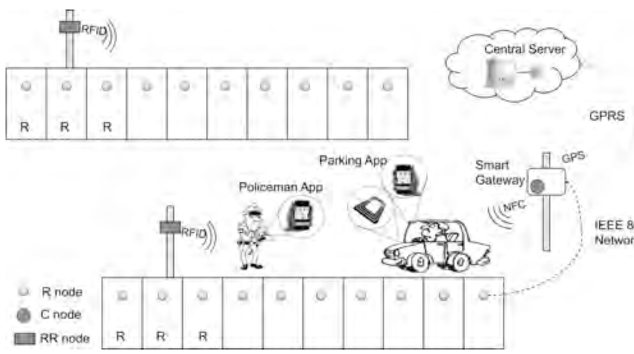

Fig. 1. The proposed architecture of the Smart Parking System (SPS) based on the integration of UHF RFID and WSN technologies.

TABLE I. Types of nodes making up the SPS system

	Node typology
R	Router Node
C	Coordinator Node
RR	Router Reader Node

provides also an NFC way to finalize user's payment of the parking fee. The main function of RR nodes is to control that the reserved parking spaces are occupied only by authorized cars, labeled by UHF RFID tags. More specifically, when the CS receives the information that a reserved parking space has been occupied, it checks if a new RFID tag has been read by the RR node responsible for controlling that specific reserved space, and, in such a case, it verifies its authorizations. The CS maintains a database handling a lot of information about parking spaces availability and user's payments. In case of improperly use of a reserved space or expiration of parking receipt, a parking monitoring application on the CS informs the traffic staff, exploiting the Google Cloud Messaging (GCM).

B. Wireless Network Topology

To develop all the WSN components, as well as for integrated RR nodes, the XM1000 sensor board from Advanticsys [17] has been used. The board is equipped with a 16-bit ultra-low-power TI MSP430F2618 MCU and embeds 8 Kbytes of RAM and 116 Kbytes of Flash memory. The board integrates a CC2420 wireless transceiver compliant with the IEEE 802.15.4 standard. The featured MCU is optimized to provide high performance at very low power consumption. In addition, the board integrates temperature, humidity, and light sensors.

The other key component of the system is the RR node shown in Fig. 2. It has been implemented by interconnecting an RFID reader to the XM1000 sensor board. The selected reader is the Sensor ID Discovery Gate UHF [18] which can be easily configured and controlled by the XM1000 board via the UART interface. The reader supports standard Read/Write Gen2 commands for reading/writing data from/to the tag user memory up to approximately 8 m of distance. The choice of using RFID hardware equipments working in the frequency range from 860 MHz to 960 MHz avoids any possible interference with the selected WSN devices.

The Contiki Operating System (OS) [19] has been chosen to develop the firmware for the WSN nodes. It is a popular open-source operating system targeted to small microcontroller architectures and developed by the Swedish Institute of Computer Science. It is highly memory efficient and provides a set of useful mechanisms for memory allocation. These features make Contiki the ideal choice for the development of innovative, smart applications, capable to exploit the new possibilities offered by the integration of RFID and WSN technologies. In particular, for the RR node, several functions to set hardware parameters, configure the UART communication interface, and manage the memory of the tags have been developed.

C. Smart Gateway

The Smart Gateway receives the parking lots state from the WSN, analyses these data and send them to the Central Server, exploiting the GPRS communication features. It is also equipped with an NFC reader, which enables the billing procedure described in the following section.

Fig. 2. The RR node embedding the UHF RFID reader.

In this work, the SG, shown in Fig. 3, has been realized by connecting a Rasperry PI board [20] to the C node. It has been also equipped with a GPRS module, a GPS mobule, and the SCL3711 multi-protocol 13.56 MHz contactless reader [21]. Raspberry Pi is a credit card-sized computer powered by the Broadcom BCM2835 system-on-a-chip (SoC). This SoC includes a 32-bit ARM1176JZFS processor, clocked at 700 MHz, and a Videocore IV GPU. It is equipped with 512 MB of RAM and powered by a 5 V micro USB AC charger.

To analyze the parking spaces' data transmitted through the deployed WSN, a Standalone Java Application (SJA) has been implemented and installed on the SG. Such application collects the data received from the nodes by using the jNetPcap SDK, parses and sends them to the CS through RESTful requests, using the Apache HTTP components. Note that jNetPcap SDK is one of the most advanced open source tool for packets capturing at the time of implementation.

D. Billing System

We designed an innovative billing system based on

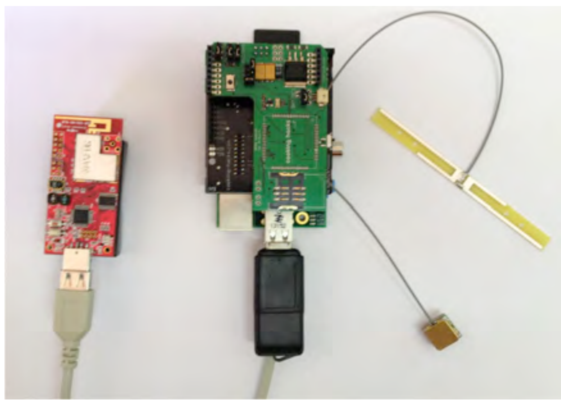

Fig. 3. The Smart Gatewaty with the GPRS module, the NFC reader and the C node.

advance payments that uses customer's personal devices to forward billing information. Mobile Proximity Payments (MPP) is the most promising payment service, with biggest growth rate for the next years. It is foreseen that in 2017 more than one out of two mobile phones will be MPP-enabled. MPP is safe, pleasant and convenient for costumers, hence its success.

NFC is the MPP-enabling technology. It allows a mobile phone to be used as it was a contactless credit card. When a NFC mobile phone falls within the short range (2-3 cm) of an NFC Point-of-Sale (POS), an RF link is established between the two devices. Google is probably the top name in the NFC world, because of the effort pursued by the IT giant in providing strong, affordable and customizable NFC features in Android mobile phones. Usually, cards are emulated by a separate chip in the device, called 'Secure Element' (SE). Android 4.4 (codename KitKat) introduces an additional method of card emulation that does not involve a SE, called Host-based Card Emulation (HCE). It allows any Android application to emulate a card and talk directly to the NFC POS.

An author's previous work, called IDA-Pay, allows to divert the expense to a pre-configured credit card via the use of an Android NFC mobile phone. The IDA-Pay NFC POS is embedded in the smart gateway, which also contains the logic to communicate with a third-party payment processor service. For this work we have furtherly extended the IDA-Pay system in order to support the novel HCE technology. In Fig. 4 the billing subsystem architecture is depicted.

The Parking App calls the IDA-Pay app via the use of the Intent-Filter Android paradigm. The IDA-Pay can talk to the smart gateway exchanging Application Protocol Data Units. At the end of the payment process, a confirmation is packaged and the Parking App show up back.

The billing subsystem is composed of four main entities: (i) the user's NFC mobile phone, (ii) the smart gateway embedding the IDA-Pay POS terminal, (iii) a third-party payment processor server, and (iv) the proprietary payment networks.

The Raspberry board has a NFC reader attached via USB. The Raspberry runs the IDA_Pay POS Java application that can talk to the NFC reader using the PC/SC standard protocol. In Java, this protocol is implemented in the smartcardio package (available from Java 1.6). Using the PC/SC standard, the POS application send a "SELECT AID" command to the NFC reader, passing an Application IDentifier as argument. In ISO7816-4, specifying an AID is mandatory to select the smartcard function to be used. Main Credit Card networks like Visa and Mastercard have their own AIDs. We defined a custom AID, which will be recognized by the IDA-Pay's HCE service running on Android. Once the AID is selected, all the future messages exchanged between the POS and the mobile phone will be handled by the IDA-Pay app. The Java application also embeds a SOAP client, which is able to interact with the Web services exposed by the third-party payment processor we selected for our prototype. Such interaction is needed in order to validate the credit card information retrieved via the NFC link and then to charge the user with the due fees.

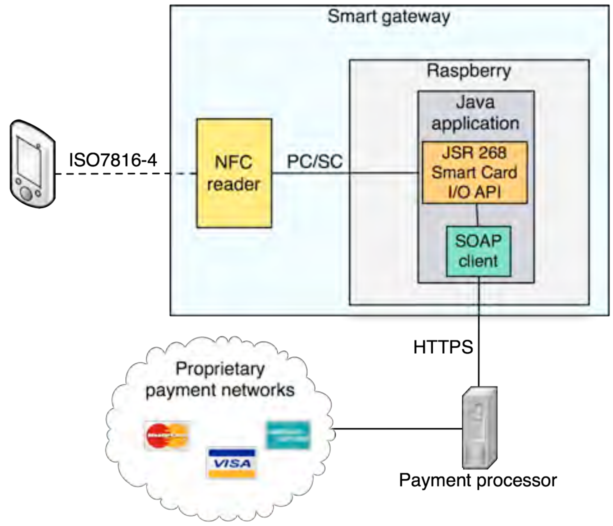

Fig. 4. The payment sub-system architecture

What happens between the Payment processor service and the proprietary payment networks (e.g. Visa) is a black box for our system.

E. *Central Server*

The Central Server (CS) represents the core of the proposed system. It is in charge of data collection and processing, system management and service execution, thus controlling the overall behavior of the system.

To store and analyze the parking space's data coming from the SJA running on SG, the CS runs a RESTful Java Application (RJA) which is able to receive, process and reply to requests, in JSON format, coming from the SG and the two mobile applications. It has been developed by using the Jersey Framework and it is deployed on the Apache Tomcat 7 application server installed on the CS. The RJA stores the information received from the SJA, concerning parking spaces availability and user's payment on a MySQL database.

RJA is also able to send push notification to mobile devices using Google Cloud Messages (GCM). It is important to note that the use of the GCM instead of other technologies (e.g. GSM) allows us to directly interface with the mobile App and, therefore, to access all the information about the parking spaces stored in the database. In particular, we decided to use Amazon SNS coud service, since it can seamlessly scale from a handful of messages per day to hundred of messages or higher. This situation is not so remote considering big cities. Further, it adds an abstraction level, which allows programmers to use the same APIs for sending notifications on different platforms (e.g., iOS, and Android). This is very important feature, compliant with the software engineering principles.

The overall architecture of the CS is shown in Fig. 5.

F. *Mobile Applications*

As previously described, the SPS provides two different mobile applications, the Parking App and the Policeman App. They have been implemented on the Android OS, because it

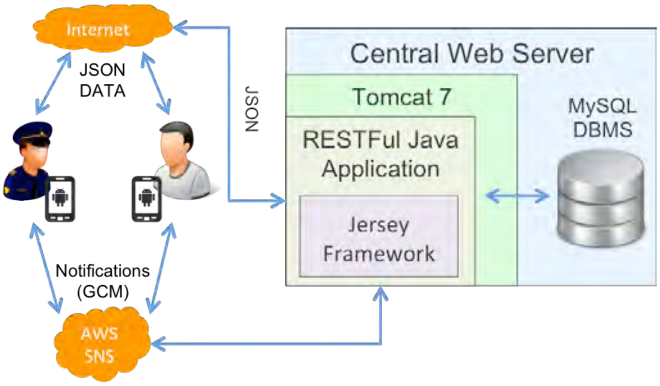

Fig. 5. The overall software architecture of the Central Server.

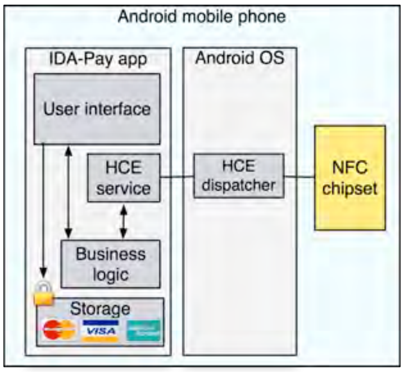

Fig. 6. The IDA-Pay costumer application architecture

supports completely the NFC technology. Moreover, the SPS leverages the payment services exposed by the IDA-Pay ecosystem (i.e. SPS is one of the services using IDA-Pay as a payment platform). Hence, also the IDA-Pay app must be installed on the driver mobile phone.

The main features of the designed mobile applications are the following:

- Parking App: it allows the driver to find the parking spaces available in a given area, get the right directions to the selected parking spot, pay the parking fee by using the IDA-Pay application, check the remaining parking time and receive notifications when the purchased time is expiring.
- IDA-Pay: it uses a secure storage to retain and retrieve credit cards data (Fig. 6). This data box is located on the usual smartphone memory, but it is secured using an encryption mechanism (as foreseen in IDA-Pay). Only the smart gateway contains the logic needed to understand the data retrieved from the App secure storage. The HCE dispatcher running in the Android OS knows that the IDA-Pay's HCE service, listening for a precise AID, is up and running
- Policeman App: it is installed on the mobile device of the traffic cops. They are equipped with a smartphone connected with a portable UHF RFID reader. The App allows traffic cops to check the notifications related to the detection of an unauthorized use of a reserved space, directly reading the information stored in the RFID tag placed on a machine, and to issue any fines.

III. Experimental Validation

In this section, a prototype implementation of the proposed SPS is described and validated. A simple proof of concept has been developed in order to demonstrate the validity of our system.

The considered scenario, depicted in Fig. 7, includes a driver with a special grant: a permission to stand the vehicle for an extra time after the parking time has expired (for example, for business needs). In this case, the traffic cop should recognize the driver's grant and avoid issuing the fine.

In our implementation, the car is equipped with a passive UHF RFID tag containing the Electronic Production Code (EPC) and information about the grant. In the prototypal implementation the Alien ALN-9654 G RFID tags have been used. This choice has been mainly done due to their extreme low-cost and compliance with the EPC standard. Let us observe that the aim of this paper is to demonstrate the feasibility of just one of the several possible use-case scenarios of the proposed SPS. Therefore, finding the best tag to use to detect a car is outside the scope of this work. Furthermore, a Nexus 4 mobile phone (with Android 4.4.3 “KitKat”) connected to the UHF RFID reader BlueBerry [22] of TERTIUM Technology was used as portable reader.

The considered use case relies on the following operations:

1. The driver uses the Parking App to find a not reserved vacant parking unit (Fig. 8.a). The App drives the user to the selected parking space (Fig. 8.b). Hence the relative WSN sensor detect the car presence.
2. The WSN node continuously updates the smart gateway about the car presence.
3. The driver selects the amount of parking time (e.g. 1 hour) and click on ‘Pay’ button in the Parking App (Fig. 8.c), so IDA-Pay shows up. The driver touch his/her device to the smart gateway in order to settle the transaction.
4. The smart gateway sends payment information to the payment processor and receives a positive response.
5. After 1 hour the bought time expires, but the WSN sensor still notifies about a car present at the parking unit. Hence the traffic cop mobile phone gets notified about the parking unit to check (Fig. 9.a).
6. The traffic cop reaches the parking unit (Fig. 9.b) and identifies the driver by reading the car's RFID tag (Fig.9.c). The traffic cop confirms to the CS that the user is allowed to stand his/her car for an extra time because of a special permission

Let us observe that our system can be easily extended to support different application scenarios, such as the one proposed in [23], in which a parking reservation system is presented. Specifically, by implementing a custom reservation

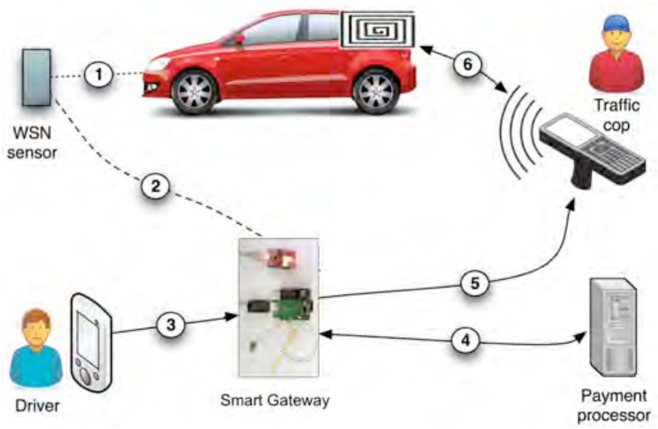

Fig. 7. Validation scenario depicting the interaction among the driver, the smart gateway and the traffic cop when the driver has a special permission.

application on the Central Server, also accessible by the Driver App, a user could book a parking lot inside a reserved area prior to her/his arrival and, at the same time, the traffic cop could easily check, using his/her mobile device, that a reserved parking lot is actually occupied by the driver who booked it.

CONCLUSION

In this work a Smart Parking System (SPS) based on the combined use of several innovative IoT technologies, such as WSN, RFID, NFC, and mobile has been presented. The system exploits a heterogeneous network of hybrid UHF RFID and IEEE 802.15.4-based WSN devices which can be rapidly deployed in any outdoor parking. A central server implementing advanced database management techniques and a running a RESTful Java software application constantly monitors the parking lots and, in case of unauthorized use of a space or expiration of a parking fee, promptly sends a notification to a smart App installed on the traffic cop's mobile phone. A different mobile application allows the drivers to find a vacant parking lot and pay the parking fee. An extension of this application in order to allow the user to increase the paid fee will characterize our future work.

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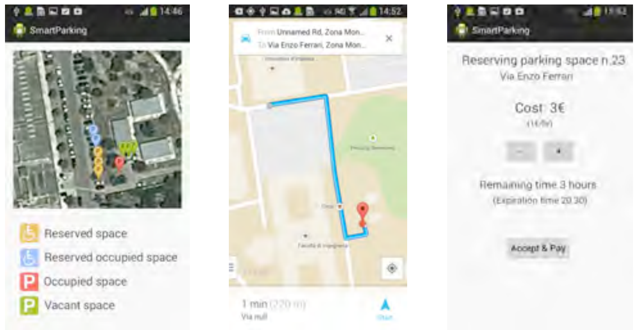
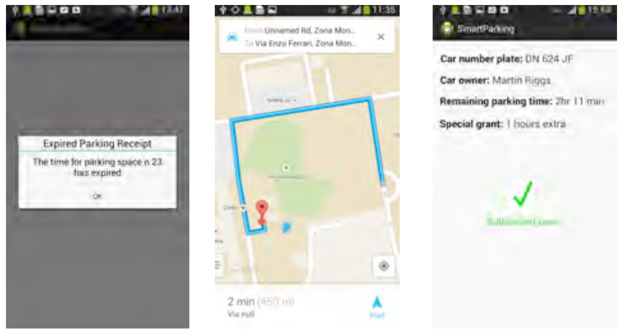


(a) (b) (c)

Fig. 8. Some screenshots of the Parking App: (a) the user visualizes the vacant parking spaces on the mobile phone; (b) the App drives the user to the selected parking spot; (c) the user pay for the occupied parking spot.



(a) (b) (c)

Fig. 9. Some screenshots of the Policeman App: (a) the traffic cop receives the notification on the mobile device; (b) the App drives the traffic cop to the occupied parking spot; (c) the traffic cop reads the information stored in the tag.

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