Car Park Management with Networked Wireless Sensors and Active RFID

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Abstract—This paper considers automatic car park management, which becomes an inevitable option to rationalize traffic management in modern cities. Integration of networked sensor/actuator and radio frequency identification (RFID) technologies is explored to enable sophisticated services via the Internet in the emerging Internet of Things (IoT) context. Based on this integration, we propose a scalable and low-cost car parking framework (CPF). A preliminary prototype implementation and experimentation of some modules of the proposed CFP has been performed. The clustering of sensors (sensing boards) into a single mote using the standard I2C protocol has been explored in the prototype, and experimental results demonstrate considerable reduction in cost and energy consumption.

I. INTRODUCTION

With the constant increase of vehicles in agglomerations worldwide, finding a car park with available spots becomes a worry for the citizens in modern societies. A driver may spend a large amount of time looking for a car park with available spots. Once such a car park is found, he may still waste time there looking for a free park spot. This results in high fuel consumption, increased traffic congestion, and dramatic impacts on the environment, drivers’ health and well-being. New devices emerging from sensor/actuator [1], and Radio Frequency Identification (RFID) [2] technologies may play a pivotal role to modernize and improve car park management, and to provide modernized services via a new first mile of the Internet called the “Internet-of-Things (IoT)”. This promises access to a broad range of services, not only anytime and anywhere, but also using anything. These devices can be endowed with an IP address and outfitted to the objects of the smart parking and/or its infrastructure to become smart objects, which may be interconnected into a smart IoT platform with sensor devices used for empty park spot localization, while the RFID devices are used for parking spot authorization, car localization, and theft prevention. Integration of these two technologies yields a heterogenous environment with many challenges in terms of deployment, communication and protocol engineering [3].

A. Related Work

The state-of-the-art solutions related to car parking management can be divided into two classes, i) the smart car parks based on gate management, and ii) those based on lot management. The smart car parks based on gate management provide some important services for drivers such as the possibility to check free spot availability, reservation over internet, etc. These basic services are enabled by the gate management model, where information about the entries/exits are used. Lot management represents another model to manage a smart car park. Each parking spot can be equipped with a sensor to detect the presence/absence of vehicles. The main advantage of the gate management model is its low cost and simplicity over lot management model. However, car parks with lot management provide more services for drivers, such as driver guidance systems that orient the drivers towards the nearest free spot, free lot maps, etc. This is achieved by equipping parking lots with sensors. [4], [5], [6].

Smart car parking based on lot management can be classified into two categories; multi-parking management vs. mono-parking management. Multi-parking management systems can manage different parks in different areas. These areas may be indoor, such as mall or airport parks, or outdoor, such as street parks in urban areas. Multi-parking management may provide guiding capability for drivers to the most appropriate car park. Many solutions belong to mono-parking management, whereas only few solutions are proposed for multi-parking management. Mono-park solutions are generally targeting indoor parks and focus on a single park management. They may provide guiding capability for car drivers within the car park. The authors of [7], [8] propose a systems using image detection. In [9], [10], [11], a wireless sensor network based mono-parking system is described. In this system, wireless sensors are deployed into a car park field, with each parking lot equipped with one sensor node. All these solutions have used TinyOS (A WSN operating system) for developing customized networking stack. ZigBee stack is chosen for many mono-parking solutions [12], [13], [14] due to its efficient energy consumption and flexibility in topology management. Authors in [15] propose a multi-parking systems to extend the services at a scale larger than a single car park. For instance, outdoor car parking management in streets, guidance towards an appropriate car park within a city. This may need a collaboration between multiple car parking managers.

In [16], the authors propose KATHODIGOS, which is a smart parking system that uses wireless technologies and
wireless applications to acquire information about the status of roadside parking spaces. The obtained information is transmitted to a central information system through gateways. The solution in [17] proposes a framework of parking management, called iParking that monitors incoming/outgoing vehicles using a sensor network. iParking calculates the number of available parking spaces, and disseminates the information to the parking’s customers. In [18], the authors describe a street parking system(SPS) based on a wireless sensor network. The system can monitor the state of every parking space by deploying a magnetic sensor node on the space. To accurately detecting a parking car, a vehicle detection algorithm is proposed. An adaptive sampling mechanism is used to reduce the energy consumption. Nawaz et al. [19] present ParkSense, a smartphone-based sensing system that detects a driver vacates a parking spot. Most of the solutions proposed thus far consider the use of either WSN, or RFID. However, we think that the integration of both technologies in a single framework have potential impacts, as it will enable effective object tracking and environment perception. This represents the purpose of our work.

B. Contribution and Outline

This paper addresses the issue of automation and modernization of car parking management by proposing a Car Parking Framework (CPF), and assessing its relevance with respect to the engineering and economic efficiency. The proposed frameworks is based on the integration of WSN and RFID technologies and builds around a modular approach to enable a variety of services. These include driver guidance, automatic payment, parking lot retrieval, security and vandalism detection. Its partial implementation as a lab prototype is also described in this paper, where some modules have been tested and evaluated by real experiments. Smart parking solutions that are closely related to the one proposed in this paper have been presented in [9], [10] and [12]. These solutions use a single wireless mote per parking lot, which is outfitted with a sensor for vehicle detection. The sensor can be a magnetic sensor, an ultrasonic sensor, an optical sensor, etc. When a car is in sensing field of some sensor (a parking spot), the sensor status will change and a signal will be transmitted to the connecting mote. The latter processes the incoming signal to decide about possible detection. If the event is considered as a car detection, then it is transmitted to a gateway, possibly through multi-hop communication if the distance is important. Using a mote in every spot has drawbacks. First, the cost will be high (both in terms of financial cost for deployment, and energy consumption when in operation). Second, it increases the collision domain and creates more interference. An interesting study about indoor communications in [11] shows the dramatic impact of mobile metallic objects over the mote on wireless communication channels, which is a typical scenario that takes place when detecting a vehicle that parks over the sensor mote. It is thus useful to separate the communication module from the sensing area. To overcome the drawbacks of using a single mote per parking spot, we propose the clustering of a bunch of sensors and the use of hybrid wire/wireless communications. Every sensor-board is connected to a micro-controller unit (MCU), then the bunch of sensors is connected in serial mode to a single mote using serial wired communication (Fig. 1). The mote is considered as a master of the communication, and the sensors are considered as slaves. Wireless communication is used to connect the mote to the rest of the network. This pattern considerably reduces the cost and the interference, as it will be illustrated in the upcoming sections.

II. CAR PARKING FRAMEWORK (CPF)

The proposed CPF integrates RFID and WSN technologies to provide advanced features and services for car park managements. It uses an active RFID tag per vehicle. The tag can be allocated to a subscribed customers over a long period of time (private parks), or it can be dynamically provided to the transient customers at the entrance. Each parking lot is equipped with a sensor (ultrasonic sensor are used in the implemented prototype) that is connected to a wireless mote. The mote will manage a bunch of sensors connected in serial mode. This is much more efficient than using a mote per lot as in most state-of-the-art solutions.

A. Parking Level Manager Pattern

The lots manager can be viewed as the atomic component in the level (floor) management.

![Fig. 1: Parking level manager pattern](image)

The level management is illustrated by Fig. 1. A WSN that contains several types of nodes is used. The included nodes are: i) the mote of a bunch of lots that clusters a set of sensor boards (one per lot), ii) a hybrid node, where an RFID reader and a wireless mote are integrated, iii) guiding nodes that are connected to a VMS (Variable Message Screen), and finally, iv) a sink node that is connected to Ethernet plug to forward data to the parking manager. The use of the proposed lots manager pattern, as well as the multi-hop communication paradigm between motes (masters) provide a scalable level manager.
B. CFP Architecture

The CFP proposed in this paper builds upon a four-layer ubiquitous architecture. A sensor layer (hosting the hybrid sensors) is used for parking spot detection and security. A network layer is layered above the sensor layer to enable dissemination of the information between sensors and gateways. It uses both wired and wireless communication. Sitting on top of the network layer, a middleware storing data and enabling visualization is used as an interface between the network layer and the application layer, where different services related to the smart parking are implemented. The implementation of the CFP includes three parts that are connected using a LAN network (WLAN or Ethernet). The first part is the parking manager, where all data are stored. It may provide some information for clients over internet, e.g. parking spots availability. The payment service is also provided by the parking manager within a park. The second part is the gate manager, its main function is to control the gate using WSN, and to forward the gate status to the Parking Manager. Finally, the parking spots manager is responsible for monitoring the parking spots and the cars within the level. WSN is used within the level to carry the status of spots and cars to the sink in a level. This would be transmitted using a LAN network. The proposed CFP scales to a multi-level car parks.

C. Data Gathering Protocol Within a Level

Event detection at the sensor mote (Master) needs to be forwarded to the sink of a level using multi-hop communications. For this purpose, we propose to use our previously published gathering protocol, LIBP[3], [20]. The main utility of LIBP in car parking management is the management of energy consumption in heterogeneous wireless sensor networks. In WSN with multiple types of motes having different levels of consumption, the aim is to ensure the network traffic can be managed to achieve balanced lifetime for all the motes in the network. This is a typical utilization in the car parking management, featured by the co-existence of: i) simple node as guiding node with moderate energy consumption, ii) the master node responsible for parking lots management, which consumes more power, and iii) the hybrid node (integrating the wireless mote and RFID reader) that is the most power consuming.

D. Services Using Car Parking Framework

1) Guidance Service: Each vehicle is assumed to be equipped with an active RFID tag. This latter has a longer communication range compared to passive RFID tag, and it is used for more advanced services. The hybrid nodes (Integration of Wireless mote and RFID reader) should be placed at strategic points, where they can detect the coming car and identify it using the RFID tags. Depending on the type of parking, there are two scenarios for guiding service:

   - **Predefined parking spots**: This is when every entered car has a predefined parking spot. In this case, the hybrid node gets the tag’s ID of the car, then it will retrieve the predefined spot of the car from the parking manager using the WSN within the level, as well as the LAN network between levels and the parking manager. After that, the direction will be displayed in VMS using the guiding node.

   - **Random parking spots**: If the entered car has not a pre-defined parking spot, then when the hybrid node detects the coming car using the RFID tag, it would retrieve the nearest available (optimal) parking spot from the parking manager. The calculation of the optimal parking spot is made based on the current location of the car, and the map of free spot in the park that is stored in the server.

2) Car Retrieval Service: A common problem for clients is when they forget where they park their cars. The proposed CFP provides a service that assists in retrieving a forgotten car location using the integration of WSN and RFID in the hybrid node, and an active RFID tag to be kept by customers. When a customer requests his car’s spot using a trigger in the active tag, a hybrid node gets the tag’s ID and transmits it to the parking manager. This latter checks the occupied parking spots in the database and in the parking field using the WSN. The response is returned to the appropriate guiding node for display in the VMS.

3) Illegal Parking Detection Service: The CFP provides a mechanism to solve this problem that may take place when the customer has a specific parking area. When a car is detected in a parking spot, an event will be transmitted to the parking manager. This latter will request the tag’s ID of a car’s tag from the hybrid node where the car is parked. Using the tag’s ID, the car parking manager can check if this car is authorized to access this area.

4) Security Service: In the proposed CFP, a driver may either have a priori the RFID tag (case of private parking), or he may get it at the entrance. The tag must be kept in the car when parking. Meanwhile, the system confirms that a car is in a parking spot using sensors, and it matches the ID and the parking spot (refer to Sec. II-D3). Next, the customer can keep the RFID to take advantage of other services such as the "find forgotten car service". However, when a car is leaving a parking spot, the system will check the IDs of existing tags in the area using Hybrid nodes. These IDs will be matched with the parking spot and the parking manager commits this matching using the parking database. This is to confirm whether the customer’s tag is in the area or not. In other words, it will check if the driver is in the hybrid node range, in specific level, or close to a bunch of sensors, etc. The system will trigger a car stolen event if the car owner is not close to the car. Timestamping of the events and time synchronization between nodes is needed to assure this service. Mechanisms such as [21] [22] may be used.

5) Other Services: The flexibility of the integration of WSN and RFID network enables the CFP to provide many services beyond the above mentioned. The following are some examples of these services:

   - **Parking spot reservation**: Bunch of sensors can be enhanced with a source of light in each parking spot. These lights are controllable by the wireless mote. They can
provide information about the status of a spot, e.g., red for occupied, green for empty, yellow for reserved, and blue for out-of-service.

- **Payment service**: RFID tags have many utilities in the CFP. They can be used for contact-less payment calculations.
- **Gate management service**: Another use of RFID tags is gate management. As an example, a gate can be opened automatically using an RFID reader and the vehicle’s tag at the gate.
- **Availability checking over internet**: The CFP provides a real-time availability checking over internet. Cars can be checked if they are in spots and drivers if they are in a car parking using their tags.
- **Parking management using desktop and smartphone applications**: Advanced application for both desktop computer and smartphone can be designed based on the proposed CFP.

### III. Prototype Implementation

The proposed CFP has been partially implemented and tested in lab prototype as presented in Fig. 2. Client devices have been connected via TCP/IP protocol to a parking database. The latter is updated in real-time with the status of parking lots. Two kinds of client applications have been considered for parking lots monitoring: mobile device application, for phones and tablets, and desktop application for laptops and desktop computers.

In the prototype implementation, ultrasonic sensors are connected in serial mode using micro-controllers. All events are first transmitted to a master mote, then forwarded to the based station. This latter stores the events in Mysql database for the client application. I2C protocol has been used to transmit the event from the parking lots (micro-controllers with ultrasonic sensor) to the master wireless mote.

In the prototype, ARM-based development boards have been integrated to the level gateway. Further, the proposed portable and efficient design for lot manager pattern has been implemented. In order to test the efficiency of the CFP prototype, real-world experimentation on a bunch of lots has been carried out in our campus at CERIST research center. One of the main challenges was to bend the I2C for our application, given that the latter has not been designed to operate at long distances. Some changes to some I2C parameters have been necessary, such as the pull resistance and clock frequency. Other challenge was the power supply connection for all the sensor motes with efficient power consumption. We have used for this experiment:

- Two wireless motes, a transmitter and a receiver. The transmitter is the sensor bunch master, and the receiver is for connection to the gateway, i.e., it is plugged to the gateway.
- Three micro-controllers equipped with ultrasonic sensors, one is used per lot.
- A PandaBoard: an ARM based board, as a gateway.
- LCD Screen.

When a car is parked in the free lot, it will be detected by the mote through the appropriate sensor. The event will be transmitted from the wireless mote (transmitter) to the receiver mote that is connected to Pandaboard. The event will be stored in the gateway of the level, which is in our case a Pandaboard ARM based computer. The Pandaboard provides the service of checking the free parking spot using JSON web server over the local network using WiFi or Ethernet.

### IV. User Interface

In this section, we present a user application for car park management that we developed under Android. It enables to obtain the number of free spot using mobile phones or tablet that are equipped with internet connection. The user application accesses the database using web services and has two modules: i) smart parking module, ii) web site administrator for the management. Different technologies have been used. Android as the underlying operating system, and Java as the programming language with the android integrated virtual machine. The use of Java language enables developers to take advantage of Android library set up by Google, in addition to the standard Java libraries. Further, the interface of applications is constructed using an XML file, which allows for an SDK (Software Development Toolkit) that provides a graphical help interface for their construction. The paradigm of web services is based on a components’ architecture that uses Internet protocols to manage the communication between components, interact with a database, make the link between an external application and the database, provide access to content while keeping it safe. REST (REpresentational State Transfer) has been chosen for its stateless architecture that generally runs over HTTP. REST involves reading a designated Web page that contains an XML file. The XML file describes and includes the desired content. Database server, MySQL, is defined as a management system database. A set of APIs for the development of business-oriented applications is used. The J2EE architecture is based on the Java language that allows the deployment of components on various platforms, independently of the programming language. The API that we used in the application are Servlet and JSP. We used WEB server Apache Tomcat, which is a server provided by JBuilderX to compile and execute Servlets and JSP. It contains a Java virtual machine, and associated elements to provide a complete development environment for Java.

### V. Performance Evaluation

We conducted a number of experiments and simulations to quantitatively investigate the impact of the proposed framework in terms of engineering and economic efficiency. Two classes of performance metrics are considered. the first class is the **engineering efficiency** expressed in terms of energy consumption of a bunch of lots for locating parking spots, as well as the energy consumption for data gathering from the sensors to the base station. The use of a bunch of sensors clustering is justified by the easiness to use a common power source (usually a battery) for those sensors, given their close
positions. This feature limits the wires used for connecting the bunch of sensors in the real deployment. Moreover, the replacement of the batteries per bunch of lots would be more practical than the separate replacement of each single sensor node. Energy efficiency for data gathering consists in the selection, among a set of algorithms, one that can efficiently route the traffic form sensor nodes to the gateway while being the most frugal in terms of energy consumption. The second class is the economic efficiency expressed in terms of the deployment financial cost. Usually, an economically efficient deployment is expressed in terms of how much does the monitoring of a number of parking spots cost. We have expressed the economic cost in US Dollar ($).

We compared the proposed approach of using hybrid wired/wireless communication (integration in a bunch of nodes) with the standard approach of using a wireless mote per spot, as in [9], [10], [11]. Empirical experimentation using real equipment has been conducted for this comparison. For practical limitations, limited number of nodes are used in the experiments, but it is obvious that the difference will increase with the number of nodes. For each number of nodes (from one to six), the two approaches are compared. Fig. 3 depicts the cumulative energy consumption. It numerically demonstrates that the proposed solution is more engineering efficient than using one sensor per parking spot. Fig 4 shows the cumulative economic cost vs. the number of sensor nodes. This figure also confirms the relative economic efficiency of the proposed framework. From these two figures, it is clear that the difference with the standard approach considerably rises with the increase of the number of nodes. This confirms that the proposed framework scales much better than the single sensor per parking spot based solutions. Figure 5 compares by simulation different potential protocols for smart data gathering in terms of energy frugality. This is for a parking lot specified by a 30-nodes mesh network. The results reveals that the data gathering protocol used in the framework (LIBP) outperforms the CTP and TOB (two state-of-the-art data gathering protocols).

VI. Conclusion

CPF, a novel smart car park framework that uses the integration of both wireless sensor network (WSN) and radio Frequency identification (RFID) technology has been proposed. The framework is scalable and provides advanced services. It is a modular solution that uses multiple patterns, which divides a parking to levels, a level to bunches of lots, and a bunch of lots to lots. Smooth integration of RFID and WSN, along with the sensor clustering with a single mote per bunch of spots, represent the most relevant features and contribution of the proposed CFP. A prototype implementation with real equipments has been presented and used for some quantitative empirical evaluation. The results show that the clustering of a bunch of spots with a single mote considerably
reduces the cost, as well as the energy consumption. The gain becomes more important as the number of clustered spots increases, which confirms the scalability. The use of a efficient data gathering protocol further improves power-efficiency compared to state-of-the-art solutions.

The prototype proposed in this paper has been tested outdoor using CERIST’s parking lot in Algeria. The experimental testing of our prototype in indoor settings is an avenue for future work. The challenges associated with such experimentation might require using QoS routing approaches such as proposed in [23], [24], and complex routing architectures where networks of hybrid sensor/RFID devices are layered above networks of hybrid wired/wireless network.

Fig. 5: Data gathering efficiency

REFERENCES