SMART PARKING SYSTEM IN THE CITY OF DUBROVNIK

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Abstract:
The Internet of Things (IoT) concept enabled us to connect to different devices in our environment and gather data from various sensors integrated into such devices. This modern approach allows us to integrate IoT network-based solutions to receive information from the environment around us, and based on it change the behavior of people in such environment. It is our idea to influence the movement of citizens in modern smart cities, in our case specifically the movement of vehicles that people drive, as well as their parking habits and decisions. In this paper, we reflect upon one of such smart connected systems – Smart Parking System implemented in the city of Dubrovnik, Croatia, as a part of a new smart city system strategy. The paper starts with an overview of the smart parking concepts and technologies and a short review of existing smart parking systems' implementations and classifications. We explain the importance of tracking mobility in our cities and propose a way how we can influence it, with emphasis on vehicle mobility. Details of implemented Smart Parking Systems are described as well as how it is integrated into a top-level smart city platform system, together with hardware and software implementation details. This paper concludes with our preliminary findings, potential improvements, and future research possibilities.

Keywords: Smart Parking, IoT, Dubrovnik, Smart City

1. Introduction

The continuous development of computing and communication technology in the past few decades influenced the increase in usage of modern smart devices equipped with many sensors that fit into the category of the Internet of Things (IoT). IoT devices are by definition connected to the Internet, mostly continuously and often serving as inputs for the other systems, which can, after appropriate processing of received data, provide valuable information to the community. On the other side, we witness increased use of modern mobile communication personal devices with powerful computing power and memory that can serve on various occasions to provide us with valuable information about the environment that surrounds us. Regardless of actual microprocessor power, operating system and applications those *smartphones* use, they changed our lives in a way which resulted that modern people started living in constant connectivity to the Internet by using such ubiquitous computing and communication.

Ubiquitous computing is the growing trend because it adds the capability for common everyday objects like sensors to become "digital and connected," i.e. to continuously communicate using technology and to provide data for various useful never-before-possible tasks. In general, the increase in ubiquitous computing and pervasive technologies started numerous new trends of digital communication by connecting: *people to people* using smart connected devices like smartphones, but also *people to smart things*, mostly involving various connected smart IoT devices and associated background systems, which usually gather the data from the environment using IoT sensors, as well as *smart things to smart things* directly where multiple IoT-based devices and systems communicate with each other directly, exchange and process data to make it the most useful information for other purposes.

This newly enabled omnipresent connectivity of devices with sensors provides huge amounts of data every second, which, if properly stored and processed, can be used for analysis in real-time and leads towards better control and prediction analysis of everyday situations that people encounter. However, these new datasets are larger and more complex in comparison to those of the past, thus making it possible to give us more insightful information after analyses. Our cities became one of the best places to extensively gather such data and use the subsequent information to discover relationships within the data, monitor real-time situations, and react to them, but also to use prediction methods which could give us the ability to avoid crisis and unfavorable outcomes in various situations, in our case, specifically associated with traffic and the movement of people.

Today more than half of the world's population lives in urban settlements, and cities are growing in size and population, which is leading them to become overpopulated with various other issues emerging, which diminish the quality of life of its citizens. However, some cities become extremely overcrowded for other reasons, for instance during tourist season due to the influx of tourists visiting such popular cities. In the case of the city of Dubrovnik, one the most beautiful and most prominent tourist destinations in Croatia, which is also on the UNESCO list of World Heritage Sites, the problem is even larger. According to data from 2011, the city of Dubrovnik's population was only 42,615, and in 2016 just below one million tourists visited Dubrovnik, mostly coming from the more than 500 large cruise ships docked in the port of Dubrovnik, as well as many airplanes landing in Dubrovnik Airport at Čilipi, near the city limits. Therefore, the city of Dubrovnik took actions to limit the number of visitors to the city, and particularly entrants to the old town of Dubrovnik to no more than 8,000, as well as to start monitoring and controlling the movement of people and vehicles near the old town and Dubrovnik as a whole.

The issues mentioned above are becoming very common recently for many cities globally, and we propose to solve them by introducing a general smart city concept together with its subsystems. The primary goal of a smart city is to improve citizens' (and visitors') life quality by using technology to improve the already existing services and to create new ones. The usage of modern technologies in everyday life can lead to improvements in various areas, especially in our cities. Integrating new technologies such as IoT-based systems in the existing municipal infrastructure and services in cities can potentially bring us closer to improvements in areas of sustainability and budget saving. These kinds of integrations include various solutions that we call smart city subsystems, and by implementing them, we can achieve an interconnected smart city platform, acting as a hub for all future subsystem integrations.

This paper covers the Smart Parking System project – one of the smart city subsystems and its implementation in the city of Dubrovnik. In 2015 the city of Dubrovnik adopted a general smart city strategy and started with the development of actions to implement smart city subsystems which will integrate into already existing municipal services. One of the first action plans concerned mobility, including movement of vehicles, transportation, and walkability of urban areas in the city. Since 2015 the city of Dubrovnik took the initiative to implement many other different smart city subsystems which are now under development. In this paper, we focus on the Smart Parking System and its implementation.

The potential advantages of implementing the Smart Parking System are numerous, and they include:

- Efficient use of vehicle travel
- Full utilization of parking space
- Significant reduction of search time for free parking spots
- Reducing traffic congestion
- Reducing the level of pollution in the city by decreasing vehicle emissions of air pollutants
- Parking pricing strategies manipulation considering (real-time) demand
- Fewer vehicles parked illegally by the roadside
- Improvements in general mobility and future development of smart city mobility solutions

The remainder of this paper is organized as follows. Section 2 reviews the existing Smart Parking Systems globally and presents general findings and current classifications, as well as lists the most common technologies. Section 3 provides analysis of our method and design of already implemented Smart Parking System in the city of Dubrovnik. This section also covers technical specifications and possible improvements. Section 4 concludes the paper with our results, recommendations, future research and improvement possibilities.

2. Smart Parking Systems

In the last decade, there were several reviews and surveys of smart parking systems, varying from concept ideas to actual smart parking systems. In this section, we will present some of the most relevant findings in the smart parking system implementation and associated technologies, and match them with our developed and implemented Smart Parking System.

2.1. Smart Parking Systems review

Various implementations of smart parking systems have existed for more than two decades, however, with the rise of technology, mostly smart mobile and IoT devices, smart parking systems have become extremely popular and are now implemented in many cities worldwide. One of the first comprehensive surveys of the smart parking systems (Idris, et. al, 2009) reviews the evolution of vehicle detection systems used in smart parking systems and presents numerous examples of the implementation process of the smart parking system with the focus on sensor technologies used in detected vehicles. Major categories of smart parking systems are classified, namely Parking Guidance and Information Systems (PGIS) which aid in locating vacant parking spaces and assists during a driver’s decision-making process, Transit Based Information Systems (TBIS) which concentrate on guiding users to park-and-ride facilities, Smart Payment Systems (SPS) designed to overcome the limitations of conventional payment methods using RFID and similar technologies, e-parking systems inquiring availability and possible reservation of vacant car space in advance, and Automated Parking Systems which uses computer-controlled mechanisms to automatically place vehicles in vacant allocated spaces. Our solution fits best in PGIS category, and will be explained later how it can easily be extended or integrated with other systems.

Occupancy detection of parking spaces relies on vehicle detection technology, which can be used using intrusive sensors and non-intrusive sensors (Mimbela & Klein, 2007). Intrusive sensors are typically installed by using invasive procedures to the road or parking surface, and include various technologies such as active infrared sensors, inductive loop detectors (ILD), induction or search coil magnetometers, piezoelectric sensors, pneumatic road tube sensors, and weigh-in-motion (WIM) sensors. On the contrary, non-intrusive sensors are easily installed and later maintained without invasive procedures of the road or parking surface, limiting the disruption of traffic, and tend to include modern technologies including acoustic sensors like passive acoustic arrays, microwave continuous-wave radar sensors, passive infrared sensors, RFID, ultrasonic sensors, and cameras with video image processing. We will later explain how our solution fits into the category of non-intrusive sensor technologies.

One of the later smart parking system and sensor survey (Revathi & Dhulipala, 2012) offers extended classification of smart parking systems, where they added Centralized Assisted Parking Search (CAPS), Non-Assisted Parking Search (NAPS), Opportunistically Assisted Parking Search (OAPS), Car Park Occupancy Information Systems (COINS), Parking Reservation Systems (PRS), Intelligent Transport Systems (ITS), Intelligent Parking Assist Systems (IPAS) and Agent Based Guiding Systems (ABGS), as an addition to previously mentioned PGIS, TBIS, Smart Payment Systems, E-parking Systems, and Automated Parking Systems. Additionally, the classification of sensor technologies used for parking systems was also extended to include sensor boards with multiple sensors (e.g. light, temperature, acoustics), and vehicle license plate recognition as a specific form of video image processing.

In a survey on drivers’ needs for parking infrastructures (Polycarpou, Lambrinos & Protopapadakis, 2013) authors presented findings of public parking infrastructures and drivers’ behaviors. They also presented an overview of parking availability monitoring using different types of sensors, depending on the parking type, location, cost, connection (wired or wireless), and sensitivity to external factors, as well as parking guidance and information using PGIS. Various ultrasonic, magnetic, infrared, luminosity, weight, and acoustic sensors, as well as different modern IoT technologies combined with wireless networks, could be used for vehicle detection purposes, standalone or in combinations for more accurate data. As an addition, authors also present smart parking concepts, including parking reservation systems and parking payment systems with dynamic pricing. Considering existing municipal smart parking deployments, authors also emphasized the importance of information dissemination and interoperability.

A bit of a different review is presented in a paper (Delot, et. al, 2013) where authors classify several existing car parking information systems based on their main focus (parking lots, garages, on-street parking and/or parking spaces controlled by parking meters), interaction mechanism used (vehicle-to-vehicle, vehicle-to-infrastructure, infrastructure-to-infrastructure, and/or client/server), data dissemination mode (push or pull), communication mechanism (WAN and/or be ad hoc), support infrastructure and/or monitoring sensors, supporting reservation of parking spaces and competition mechanisms. Another survey of intelligent car parking systems (Faheem, et. al, 2013) classified the current smart parking systems a bit differently and explained their features, including expert systems and mobile multi-agent based interactions between drivers and parking systems in a dynamic, complex, traffic environment, fuzzy logic and neural network based systems for human-like intelligence and expertise, wireless sensor network (WSN) based systems for the detection and monitoring of the parking facilities, GPS-based systems providing real-time location and guidance systems, vehicular communication systems for parking information distribution services among mobile vehicles, and vision-based systems for parking lot occupancy detection and vacant space recognition.

The most current and one of the most comprehensive surveys of smart parking solutions (Lin, Rivano & Mouël, 2017) focuses on the development and evolution of smart parking, through studying many academic publications, urban development projects, and commercial products. It proposes an exhaustive classification with an overview of different disciplines. Additionally, it presents the most common Smart Parking System use cases for administration (Figure 1) and operations (Figure 2), together with the categorization of the smart parking literature, visualizing findings in detailed comparison tables and figures. Finally, it provides engineering insights on the challenges of the current proposals as well as the subsequent open issues, thus helping in deciding which technology should city apply to deploy a large-scale smart parking system and to avoid repeating bad practices.

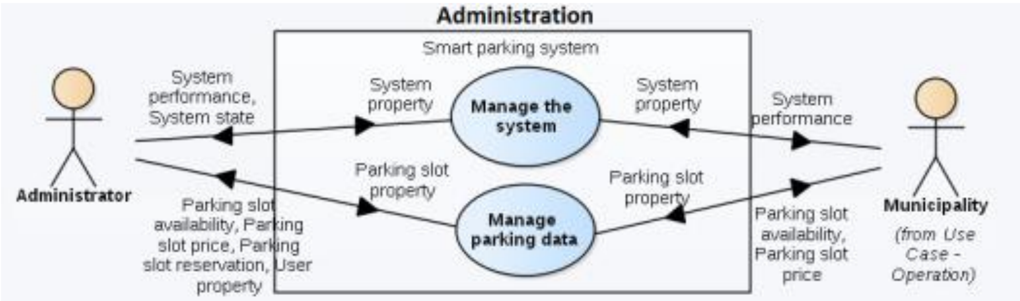

Figure 1: Common Smart Parking System Administration Use Case (Lin, Rivano, and Mouël, 2017)

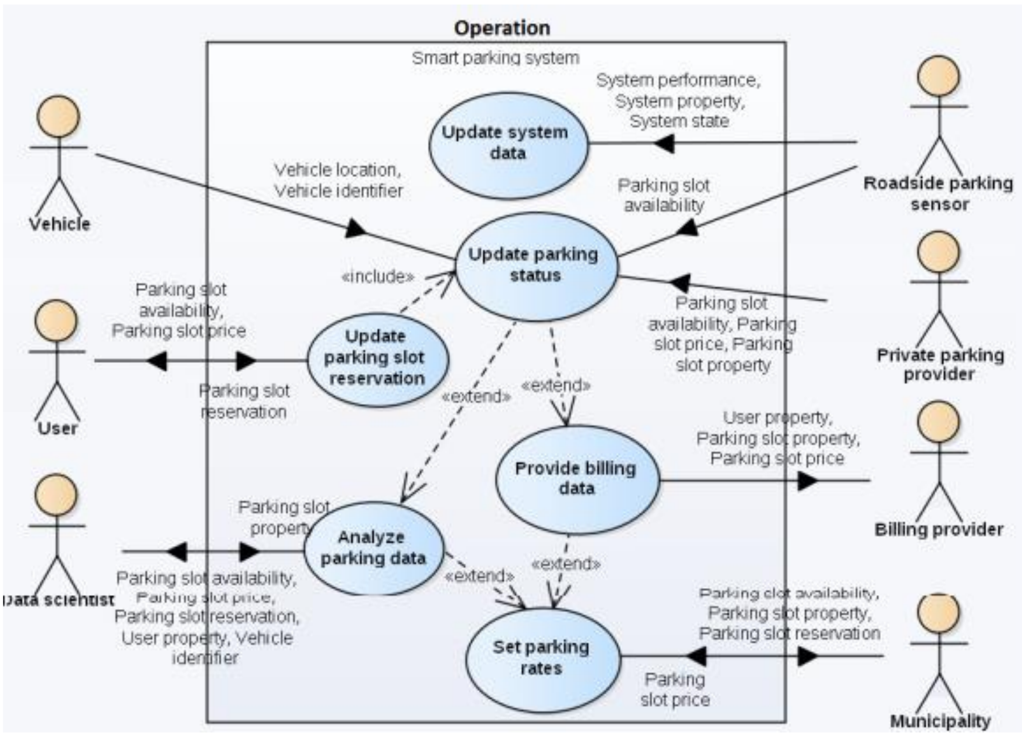

Figure 2: Common Smart Parking System Operations Use Case Overview (Lin, Rivano & Mouël, 2017)

A Smart Parking System implemented in the city of Dubrovnik can be classified as a general Parking Guidance and Information System (PGIS) because it locates vacant parking spaces and presents that information to users who make the decision where to park based on the information provided by the system. Sensors used by the system for parked vehicle detection are infrared sensors. They are classified under non-intrusive sensor technology because they are easy to install and maintain. The installation procedure is simple, and they are easily upgradeable without the need for additional procedures. Over-the-air software updates are possible because the device is connected to the internet. Most of the above-mentioned smart parking system administration (Figure 1) and operations (Figure 2) use cases *are* or *can be* applied to our Smart Parking System.

2.2. Smart Parking System as a Smart City Subsystem

Mobility and efficiency of transport are a couple of the most crucial factors for cities to function properly. One of the main goals of smart city systems is to achieve full integration of already existing subsystems into the smart city platform, including data sharing and common control mechanisms, together with additional system events and triggers. This city-wide smart platform allows the control of different subsystems by reacting to events and changes in the environment, which can be derived from multiple data sources. The smart parking system is often the foundation for achieving better mobility in cities through its integration into the smart city platform, also allowing co-operability with other smart city subsystems.

The smart city platform that our Smart Parking System uses together with other smart city subsystems integrates into a top-level system which uses the smart city framework to ensure usage of standardized protocols and data interchange formats. Smart city platforms most often offer two common ways of integration for subsystems: Deep linking or Superficial linking. Deep linking is a full integration of a subsystem that includes a database, server, and backend hosting on the platform for the whole subsystem. Superficial linking allows the subsystem deployment outside of the platform and external hosting. In the case of the superficial linking subsystem shares data with the platform through predefined standardized protocols included in the smart city framework.

Our Smart Parking System used superficial linking during the development phase and in the first few months of production, after which it was switched to deep linking for better stability and less downtime. Overall deep linking is favorable for the smart city subsystems because it achieves full integration and the platform has more control over it, as opposed to superficial linking where the subsystem needs to give access to controls and data.

Achieving integration of different subsystems into the smart city platform is possible because the smart city framework defines universal and generic standardized inputs and outputs, protocols and procedures to which the subsystem will adhere. One of the core components of the smart city system is a framework for connected IoT devices, defining a *schema* that will bring the logic down to the IoT device and define sensor readings and controls. This approach enables easy device-client configuration which is important for flexibility, which is especially useful in the case of a smart parking system because of a large number of sensors installed.

In our case, the implemented smart city framework supports both JSON and XML based data interchange formats because JSON is currently the most widely used data interchange format and XML is needed to support legacy systems and backward compatibility. Specifically, in the case of our Smart Parking System, it supports the JSON data interchange format because it is lightweight and easy for computers to parse and for humans to read.

Transfer protocols supported by the smart city framework are HTTP protocol (Fielding & Reschke, 2014) for REST-enabled services, which include platform and subsystem communication, and MQTT protocol (Banks & Gupta, 2015) to leverage its instant messaging capabilities which are crucial for IoT systems with critical performance deployed on different kinds of networks. In the beginning, HTTP with REST was used in our Smart Parking System. Later it was changed to MQTT because of its clear advantages and in the future, our Smart Parking System will completely function using MQTT.

Steps for the Smart Parking System to fill out requirements for integration were:

- All devices need to use the defined schema to map their controls, sensors, and readings
- Using the same framework and reading schema to read data from devices and control
- Adopting the REST service which enables smart city platform connection and data transfer

Upon successfully implementing Smart Parking System into the smart city platform, the city of Dubrovnik got access to significant information about the current state of transport and parking, as well as some control over it, which is described in the following section in details.

3. Implemented Smart Parking System

3.1. Smart Parking System

The Smart Parking System (Figure 3) implemented in the city of Dubrovnik is a full smart-city subsystem solution that was developed and installed in production more than a year before writing this paper. Since the beginning of the development, the goal was for it to be easily replicable and installable at any location in the city. It is a fully scalable solution because of the cloud-based implementation which allows the system to be implemented in the same way, regardless if it is covering only a few parking spaces, a small parking lot or multiple complex parking lots in a large city. Development of the solution towards the above-mentioned goal was in multiple iterations, reducing the technical hurdles and increasing overall functionalities of the system. This solution includes both software and hardware development, so it focused on fast prototyping concerning the software as well as a significant amount of time invested in hardware research, which was the most important for making this system easily replicable and installable.

Parts of the Smart Parking System solution that are discussed:

- Software – Web and mobile application
- Hardware – Sensor nodes and routers

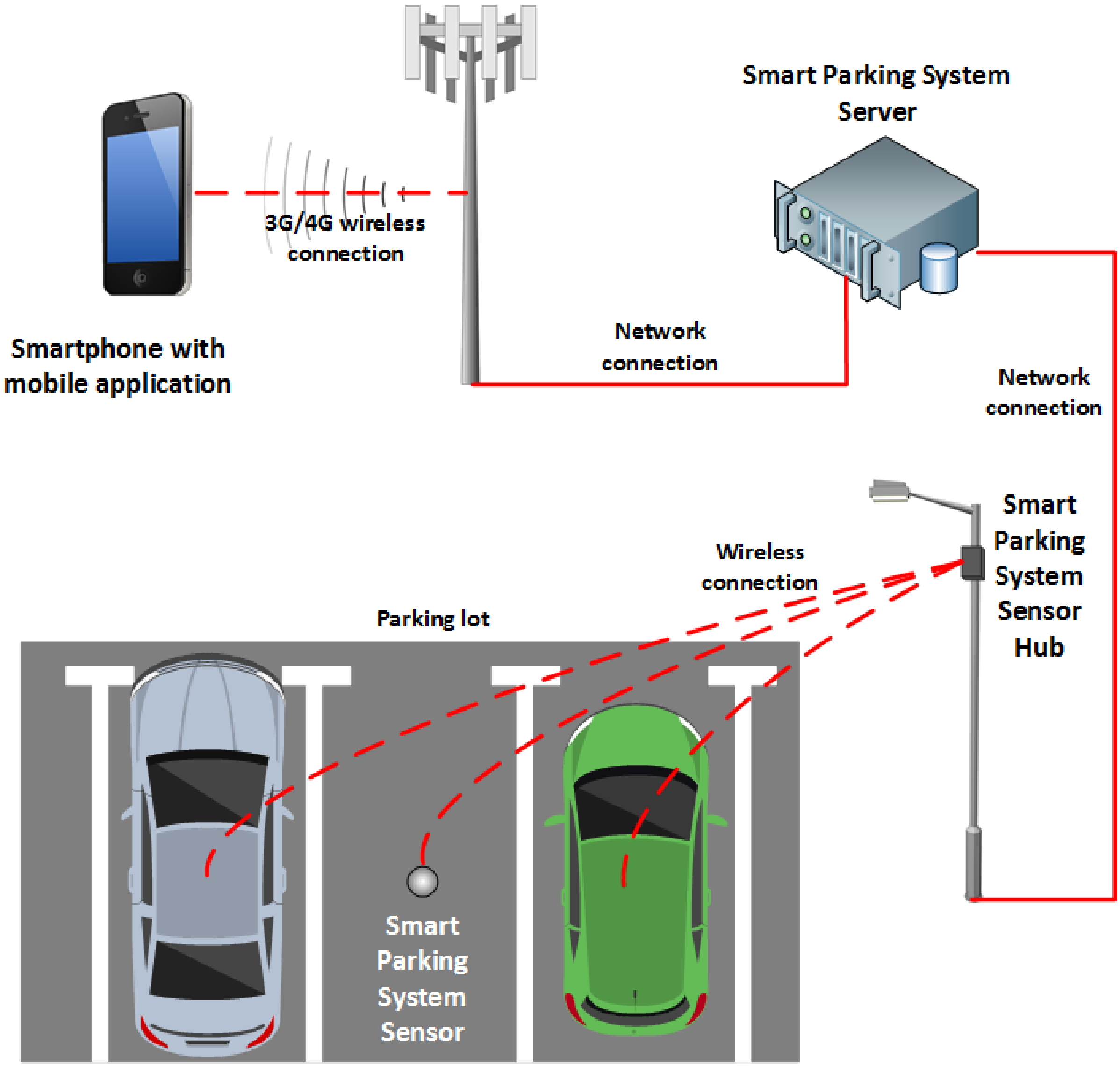

Figure 3: Smart Parking System Overview

3.1.1. Smart Parking System software including web application and mobile applications

The Smart Parking System Web application provides a publicly available website and user interface for the general public that allows citizens and visitors to see the current state of the parking in the parking lots where smart parking is installed in the city of Dubrovnik. To easily see the current state, the website has an integrated interactive map that presents the data regarding vacant and non-vacant parking spots.

In addition to the publicly available user interface, there is also an administrator's web-based dashboard that is only accessible to city officials and administrators. The main reason why this part is not publicly available is that it is used for general monitoring of the Smart Parking System and its components, specifically routers and sensor nodes. The dashboard also provides important functionalities to control the smart parking system such as remotely restarting or enabling and disabling sensor nodes.

Mobile smartphone applications are available for both iOS and Android platforms (Figure 4) and can be used by anyone to check the current state of parking in the city of Dubrovnik. In addition to showing end users information about parking lots and parking space vacancy using interactive city maps, they also provide additional features such as navigation and the possibility of paying for the parking in-app. In the background, applications gather usage data used for analytics and improvements of the already existing services.

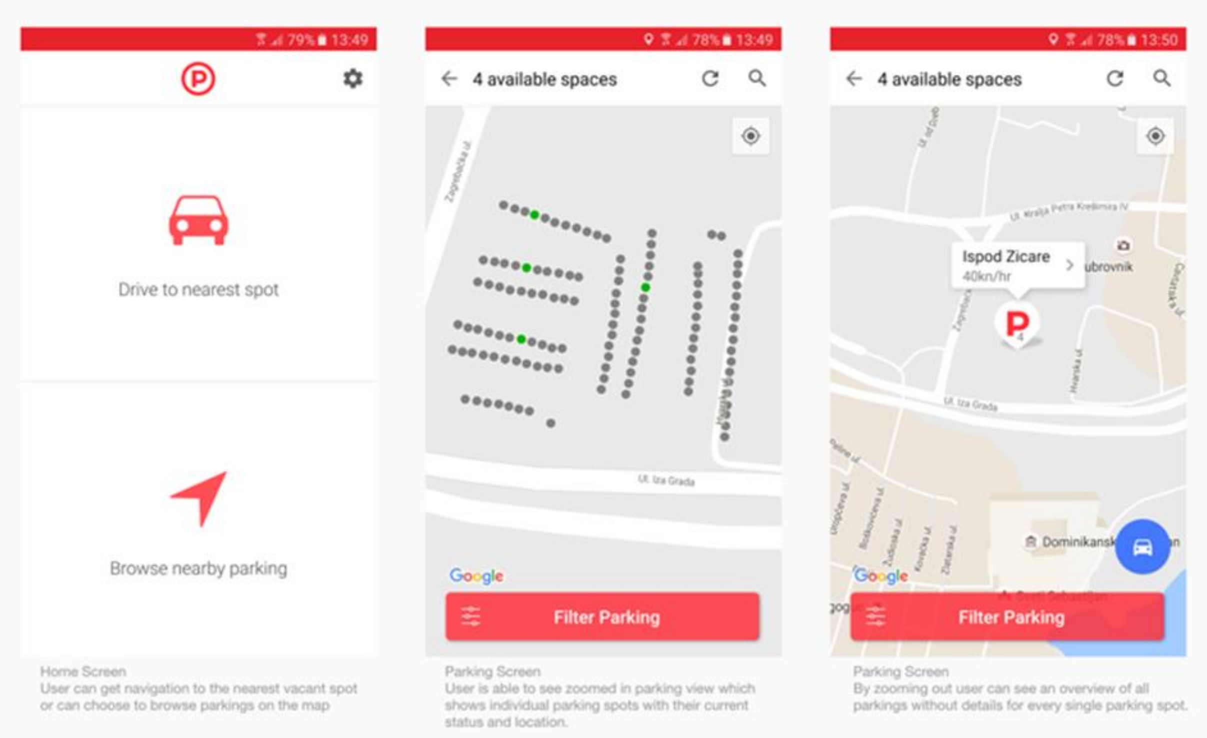

Figure 4: Smart Parking Mobile Application user interface

3.1.2. Smart Parking System hardware parts including sensor nodes and routers

Sensor nodes, as a part of this solution, are composed of battery-powered wireless sensors that use infrared technology to deduce whether a parking spot is vacant. The decision to use this technology was made because this allows them to be easily placed on each parking spot in any type of parking lot. This solution uses wireless sensors that are battery-powered with battery life expectancy estimated to three or more years. This is an advantage comparing to other solutions because installation of sensor nodes is simple and fast, instead of having extensive construction work to install power and communication lines for every smart parking system sensor node to work properly.

Sensor node (Figure 5) is a hardware device whose main task is to detect whether the current parking spot is vacant or not and to provide the Smart Parking System with that information in real time. The most important task of the sensor node is to send this information to the router as fast as possible over HTTP protocol using MQTT transfer protocol, thus exploiting advantages that those protocols offer in terms of instantaneous and reliable messaging capabilities.

Aside from the main task of vehicle detection and data transfer, sensor nodes have other features including:

- Network reconfiguration in the case of router failure
- Automatic registration and network configuration of newly added sensors
- Error state and malfunction reports sending using already existing channels for simplified maintenance and diagnostics

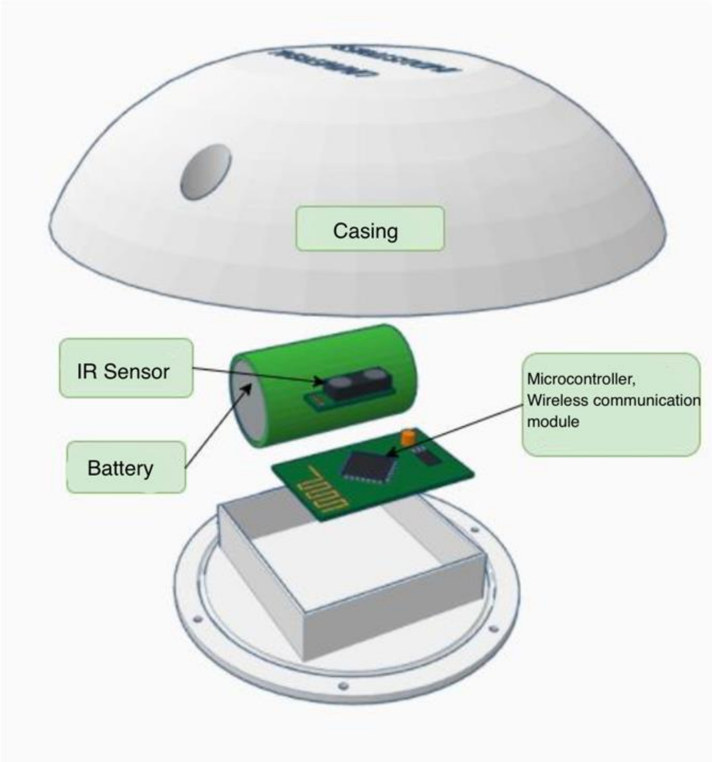

Figure 5: Sensor Node used in Smart Parking System

The router component of the Smart Parking System solution is needed for transferring data to the server using two communications, first one used to get information on parking spot vacancy from sensor nodes, and second to forward gathered data from all nodes to the server in the cloud using the wireless network.

The server receives the complete information about current state of all sensor nodes from routers over the network. Information is gathered for single nodes using their IDs and includes GPS location and other sensor node metadata. The server is responsible for storing information into a relational database, which can later be used for statistics, analytics, and other system diagnostics and overviews.

4. Results, Possibilities for Improvement, and Future Work

Implemented smart parking solution proved to be useful in the area of vehicle mobility because it helps with common issues of efficient use of vehicle travel, full utilization of parking space and significant reduction of search time for a free parking spot. Data collected from sensors and client applications are useful in statistics. Particularly in terms of deducting at which time of the day parking lots are mostly full and at which time of the day people are leaving parking lots the most. This data can be used to predict possible traffic congestion in nearby streets and track behavioral patterns. We are presenting typical parking occupancy data for one day per hour graphically in Figure 6.

After doing a seven-day analysis of the data received from parking sensors that are installed in a parking lot that can accommodate 123 cars, we were able to deduce that on average only 3% of parking spaces are free. The largest number of vacant parking spots occur during the week between 15:00-19:00 which is to be expected because of people's work habits. An interesting finding is that a lot of people tend to leave parking at night from 22:00 to 09:00 next day. Using these simple findings we can conclude that there is a lot of vehicle movement during the night on the roads nearby the parking lot and that when appropriate, police presence should be increased at those hours.

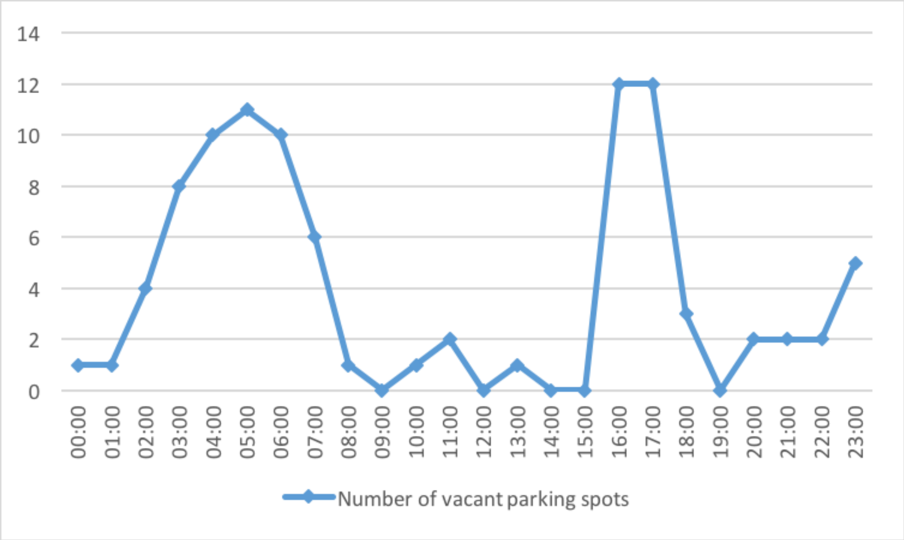

Figure 6: Graphical analysis of parking occupancy data for one day per hour (Parking lot can accommodate 123 cars)

Possible improvements can be made in the areas of developing dynamic pricing strategies considering demand analyzed from existing parking data, as well as achieving better integration with other transport services in the city of Dubrovnik. In terms of technical advancements, this solution's scalability still needs to be tested in different environments such as large multi-level parking lots, and this solution needs to be upgraded with sensors that will enable detection in semi-obstructed environments such as heavy weather conditions like snow.

Since this system relies on network reliability for data exchange other improvements such as integrating fog and edge computing into the system could be done. Other improvements can be made towards the end users by improving features that they can use such as a parking spot reservation feature which would allow users to reserve parking spots by blocking the entrance to it using their mobile application, as well as integrated payment system which would allow seamless payments through a mobile application.

5. Conclusion

In this paper, we have presented an overview of Smart Parking System currently implemented in the city of Dubrovnik, as a part of smart city subsystem. In the current version of the Smart Parking System solution, we were able to cover major concerns in the area of vehicle mobility in the city of Dubrovnik, which we hope to lead towards new advances in smart city mobility solutions implemented in Dubrovnik and elsewhere. Our future research and development will focus on improving existing smart parking solution and extending it in regards of how will new disruptive smart, mostly IoT-based and mobile, technologies influence vehicle mobility and parking solutions in the urban area.

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