AUTONOMIC INTEGRATED PARKING SYSTEM FOR SMART CITIES

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Abstract
The main objective of this research is to define an autonomic integrated parking system for smart cities in terms of coordination between parking management, traffic management and public transport management. The authors present an architecture of the system based on a multilayer approach (oriented on multi agent implementation) as well as the autonomic functions which are mandatory for designing this system. The requirements of these autonomic functions are also defined by authors, some basic algorithms are described in terms of local management of parking spots (based on local network of sensors) and routing (based on traffic conditions, public transport vehicles distributions and the travel preferences of the driver). The paper is concluded with a scenario for implementation in Bucharest having in mind the context and the specific approach for this city.

1. INTRODUCTION
Finding a parking spot in a crowded city is a challenging issue, and drivers searching for one are the cause for 30 percent of traffic congestions (Cisco, 2014). Combining different types of information from sensors, video cameras, traffic management systems or public transport management systems can solve many problems related with parking issues. Smart, intelligent or autonomic parking systems have been studied and proposed within the last years (Buntic et al, 2012) (García et al, 2014) (Wang & He, 2011). More of this kind of parking systems are developed and implemented across the globe. In the USA, Streetline provides cities real-time status of every parking spot (Streetline, 2014) helping drivers to find a free one, pay directly from their phone or even find the car later, all of these by using a mobile app. Another smart city system is Fastprk (Worldsensing, 2015), developed by Worldsensing in Europe, which helps drivers find a parking spot more quickly and allow cities to manage their parking resources more effectively. Kiunsys and Deutsche Telekom implemented in the city of Pisa, Italy, a sensory-based parking system providing drivers with targeted navigation to available parking spots (Telekom 2014). ExpressPark™ employs vehicle sensors and a real-time parking guidance system to optimize parking utilization in Los Angeles Area (Mitchell & Ghent, 2011).
As presented in (Skarmeta, 2013) giving autonomic properties to a system means that it will be able to self-manage, self-maintain and self-adapt, with the purpose of controlling systems that become more and more complex. Smart integrated parking systems are no exception and implementation of autonomic properties and functions is mandatory. In the following the authors will present an architecture of such parking system based on a multilayer approach,

the requirements of these autonomic functions, and a possible scenario for implementation in the city of Bucharest.

2. PARKING SYSTEM ARCHITECTURE

The integrated parking system introduced in this paper will have to meet the following requirements:

- To integrate a mobile application that will allow the driver to interact with the system.
- To take parking requests from the drivers.
- To reserve a parking spot in a convenient parking lot, considering drivers' preferences, traffic conditions, public transport vehicles distributions and timetable.
- To guide the vehicle from his location to the parking lot.
- To allow access of the vehicle inside/outside the parking lot based on license plate recognition (if the parking lot has an access control system).
- To guide the vehicle in the parking lot to the reserved parking spot (using guiding signs or GPS based navigation).
- To facilitate payment of parking fees.
- To implement P&R (Park & Ride) system in central urban areas.

The parking system architecture will be a hierarchical one and will be divided in three levels (Figure 1):

- The Parking System Coordinator (PSC)
- The Local Parking Management system (LPM)
- The Local Sensors and Actuators (LSA)

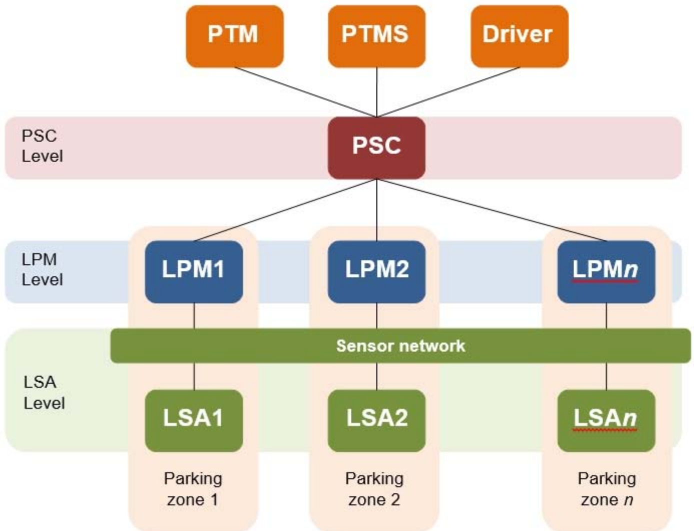

Figure 1. Parking system architecture

The system will comprise a single communication network which will connect all three levels between them, and also the sensors. Only the PSC will have a connection with external sources (Traffic Management System - TMS, Public Transport Management System – PTMS and the driver).

From a driver's point of view, the system will need to provide a mobile application in which the user will register its personal data and vehicle's data and complete a parking reservation request along with other preferences (regarding preferred parking zone, availability of public transport connections, etc.). Then, the driver will receive a confirmation (or rejection) of the reservation and will be guided by the system to the parking lot and then to the reserved parking spot. When the driver decides to leave the parking lot he will be guided to the exit, and based on the parking time he will be automatically charged. Besides the request for parking, the driver will not interact directly with the parking system.

In the next parts the authors will describe some details of the system architecture levels.

2.1 Parking System Coordinator

This system has functions related to:

- coordination of the parking lots network;
- data exchange with local parking management systems;
- communication and data exchange with the TMS and the PTMS;
- managing payment services;
- providing an interface with the driver.

Optimal routing is also decided at this level using different types of information, having as objectives minimum travel time or minimum distance between the parking zone and the current location or the final destination.

Needed traffic data list will include road traffic data (travel times, mean speeds, traffic incidents) and public transportation data (stops location, timeline/schedule, public transport vehicles location and travel time estimates).

Optimal routing is done, at this level, using a minimum cost routing algorithm and a transport graph is defined with nodes (which are intersection and parking areas) and arches. Every arch has a cost associated with it and this cost is an aggregate cost C_a. The components of this aggregate cost are: the time/speed on a particular arch (minimum time means minimum cost of the arch and maximum speed means minimum cost), the length of the arch (minimum cost of length is associated with the minimum length of the arch) and the preference of the driver (the most preferred route is associated with the minimum cost). A relative cost is calculated for time/speed, which is the amount of time / speed of a given arch divided to the minimum time/ maximum speed of a similar arch in the network. The cost related to the length of the arch is also a relative cost and this cost is calculated using the same approach as speed cost is calculated. For this case the shorter arch is defined as a reference and all cost are calculated based on this.

The aggregate cost of the arch $x_i x_j$ (which is defined between nodes x_i and x_j) is defined by:

$$C_a^{ij} = C_{t/s}^{ij} + C_l^{ij} + C_p^{ij}$$

where:

$$C_t^{ij} = \frac{time\ of\ the\ arch\ x_i x_j}{min(time\ of\ the\ arch\ x_k x_m)}$$

$$C_s^{ij} = \frac{speed\ of\ the\ arch\ x_i x_j}{\max(speed\ of\ the\ arch\ x_k x_m)}$$

$$C_l^{ij} = \frac{length\ of\ the\ arch\ x_i x_j}{\min(length\ of\ the\ arch\ x_k x_m)}$$

The authors propose a simplified scheme to calculate the cost for this algorithm and the following values will be considered (all arch's times is grouped in three main categories: 0.5, 1.0 and 1.5 and the time's cost is calculated as a relative cost using minimum value as a reference):

Table 1. Simplified scheme for time's cost

	Minimum	Medium	Maximum
Category	0.5	1.0	1.5
C_t^{ij}	1	2	3

A similar scheme is generated for speed's cost, length's cost and preferences:

Table 2. Simplified scheme for speed, length and preferences

	Minimum	Medium	Maximum
Category	0.5	1.0	1.5
$C_s^{ij}/C_l^{ij}/C_p^{ij}$	1	2	3

For example, if an arch has a minimum time cost, a medium length and a maximum for preference (the driver consider the arch lowest in terms of his/her preferences) the aggregate cost is calculated using the following formula:

$$C_a^{ij} = C_{t/s}^{ij} + C_l^{ij} + C_p^{ij} = 1 + 2 + 3 = 6$$

where the minimum aggregate cost is 3 and the maximum value is 9.

After the calculation of every cost for all arches in the associated oriented graph a method for solving the transport problem is applied in terms of finding the optimum route based on the preferences of the driver as well as time/speed and length.

2.2 Local Parking Management

This system uses locally collected data from sensor networks and has functions related to:

- managing parking spots;
- offering information about free/occupied parking spots;
- surveillance of the parking lot;
- guiding drivers to a free or reserved spot.

The LPM system does not have, in normal operating conditions, knowledge about the status of other parking lots connected to the integrated system, unless the PSC is asking it to take over management of another parking lot, usually in cases of local system failures. For that to be possible, every LPM system must have at least one direct connection with another LPM.

Local management involves constant surveillance of parking spots and tracking moving vehicles in the parking area. For street parking zones, vehicle guidance will be achieved by using it’s on board navigation system. For parking garages, it will be necessary to implement a sensor network to detect and identify the vehicle (for that, the system will use sensors placed above, below or in the zone of entrances, exits, access corridors and every parking spot), and an algorithm to track it and determine if it has followed the established path and reached the reserved parking spot.

The algorithm will start when the entrance sensor will be activated. According to the reserved parking spot, the system will provide the vehicle with an established path, from the entrance to that spot, which will mean establishing a list of sensors that it will activate, and the order in which they will be activated.

The algorithm (Figure 2) will check if the vehicle is following the path established and will react accordingly:

- If the vehicle follows its established path and reaches its designated parking spot, the algorithm will mark that spot as being occupied.
- If the vehicle deviates from its path (meaning it activates sensors that where not on the list) the algorithm will ask the system for an alternative path (if available) to the reserved spot (another list of sensors) and the system will guide the vehicle through the new path.
- If a vehicle deviates from its path and no new paths are available, the algorithm will try to allocate another free parking spot (if any available) or guide the vehicle to the exit of the parking lot.
- If a vehicle deviates from its path and occupies a random empty spot, the algorithm will verify if the spot was reserved for another vehicle. If yes, it will relocate the reservation for the other vehicle. If not, it will mark that new spot as being occupied and remove the original reservation.

(At the administrator’s choice, occupying another parking spot than the one reserved may incur warnings/penalties.)

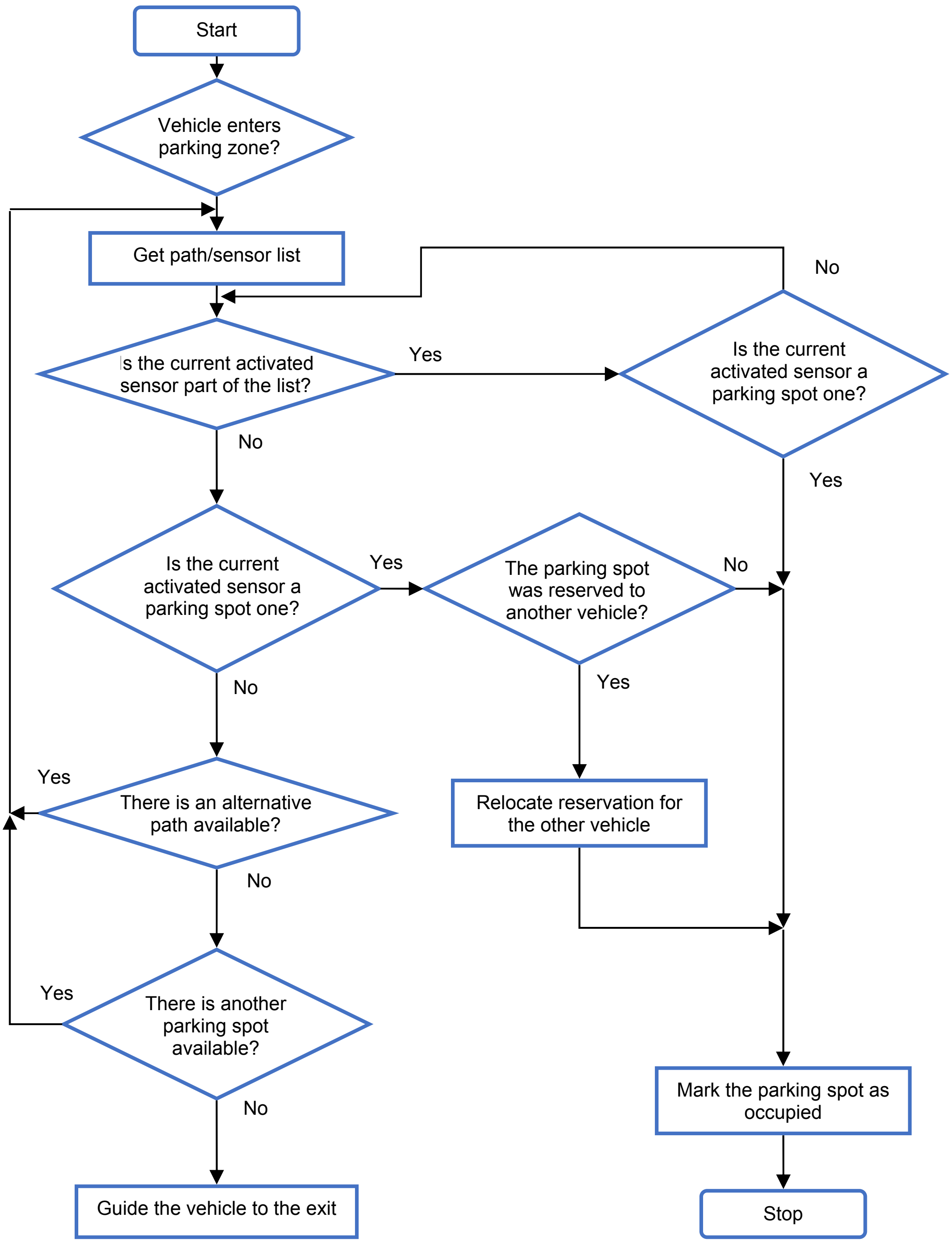

Figure 2. Flowchart of the local management algorithm

The algorithm presented is a basic one, as a more complex one would be necessary to include a similar algorithm for guiding a vehicle to the exit, a procedure for checking in real time for a new free parking spot, a procedure for dealing with failure of the sensors, detection of vehicles that are parking in restricted area and establishing system reactions to these issues.

2.3 Local Network of Sensors and Actuators

This system has functions related to:

- detecting vehicles and vehicle's movement;
- activation of guiding signs;
- license plate recognition;
- access barriers operation.

Detection of vehicles can be achieved in many ways, using different types of sensors that can be chosen considering accuracy, reliability, operating conditions, efficiency or cost. As an example one can choose between:

- Video cameras overseeing different areas of the parking zone, requiring specialized software for vehicle identification and even license plate recognition, if necessary.
- Magnetic sensors mounted in the surface of individual parking spots, sensing vehicles that disturb the uniform intensity and direction of the earth's magnetic field (Honeywell, 2005).
- Ultrasonic sensors mounted on the ceiling to measure the distance between the sensor and the first obstacle, which could be the pavement or a vehicle (Kianpisheh et al, 2012).
- Other types.

The sensors and actuators of a local system will be connected to the communication network individually. This will allow their seamless allocation to another LPM when necessary. This requires using data acquisition boards that collects data from sensors and transmits it to the LPM. One good example of a cheap and robust data acquisition and development board is Arduino Yun (Figure 3), which has the ability to connect up to 20 sensors and offers Ethernet and Wi-Fi connectivity with the sensor network.

Figure 3. Arduino Yun data acquisition and development board

Based on the same type of sensors, vehicle movement will be detected and its path will be determined depending on the activated sensors.

Activation of the guiding signs will be based on the vehicle position and path that will have to follow to be guided to the parking spot. This requires illuminated guiding signs (Figure 4), pavement or ceiling mounted, that will be gradually activated/deactivated by a LPM subsystem. Also, every parking spot will have a status sign, displaying that it is either free, occupied or reserved.

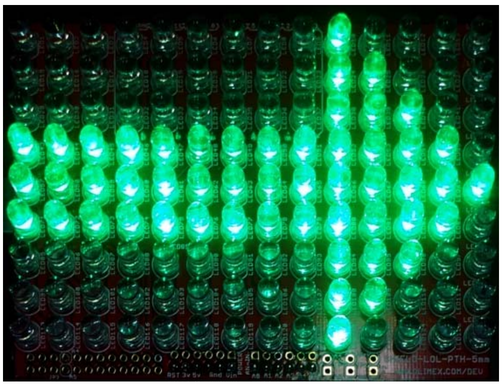

Figure 4. Programmable LED guiding sign

3. AUTONOMIC FUNCTIONS OF THE SYSTEM

Regarding the parking system presented in this paper, three levels of autonomic functions are defined by authors:

- Coordination level
- Local level
- Parking spot level

At the coordination level, if we take into account the flow of data and the operations between sensors and effectors (Skarmeta, 2013), an autonomic management of the parking system can be developed, as presented in Figure 5. Different monitoring subsystems are collecting data from sensors available at the parking zone, every parking spot status being monitored for availability/occupancy. Data from this process is analysed and an image of the parking lot is created, describing the number and location of free spots. Traffic data from external management systems and location information of vehicles intending to park are also monitored and analysed. Results from analysed data are aggregated and a new travel route is created or a previous one is updated. The newly created route is delivered to the driver. When it is necessary, sensors and actuators from the local level receive responses and commands directly from PSC.

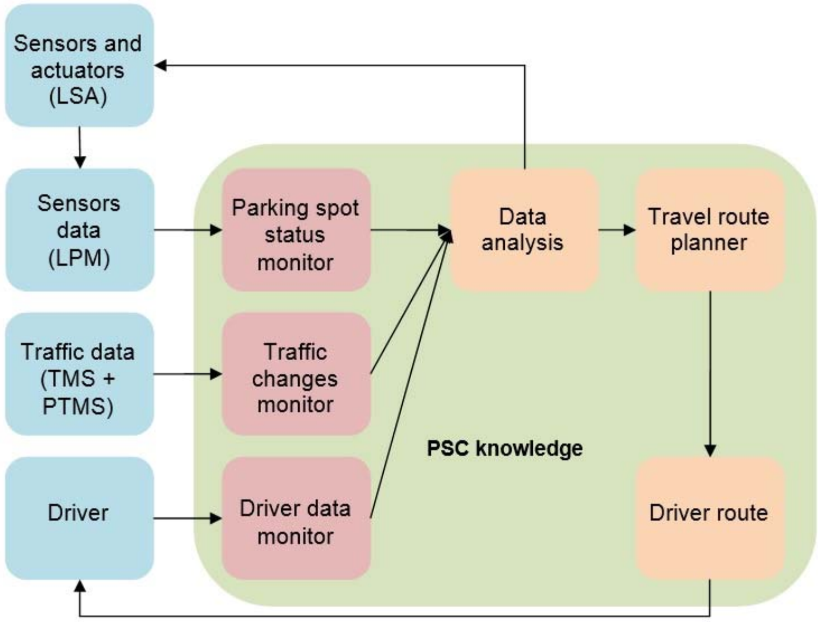

Figure 5. Autonomic management of the parking system

A self-managed payment service can be implemented, that will allow very little intervention from the driver. Using the same mobile application that allows the reservation of parking spots and guidance of the driver to the parking zone, the user introduces his credit card details, licence number and other characteristics of the vehicle. Parking fee will be determined automatically by the system, counting the time between the arrival at the parking spot and the moment when the vehicle leaves from it. Payment for the fee will also be done automatically by charging the registered credit card.

At the local level, the identity of the vehicle is necessary to be verified in order to check if a certain reserved spot is occupied by the driver that made the reservation. This can be done automatically by tracking the path of the vehicle from the entrance in the parking lot with help from the sensor network. If the driver did not made a reservation for that spot a warning will be sent to him (to his mobile device or by using warning signs), advising that penalties may apply.

Also, the identity of a vehicle must be recorded in cases when the driver does not have a credit card or use the reservation application and wants an unoccupied parking spot. The system will determine automatically if a free spot is available, and guide the driver to it, payment of the parking fee being made through other methods (automated payment machine, pay-by-phone, etc.).

At the parking spot level, vehicle detection sensor functionality can be checked automatically by implementing verification procedures at the software level, which depend on the type of sensor. For our examples of sensors, video cameras can be checked for the presence of, or changes in live feed images, magnetic sensors should have a specific answer when measuring the intensity and direction of the earth's magnetic field when a vehicle is absent, and ultrasonic sensors should return the same distance whenever a parking spot is free. The failure of a verification procedure will determine the system to use other types of sensors, if available, or to determine the presence of a vehicle by using various algorithms and data from other sensors, until the damaged sensor is repaired or replaced.

4. IMPLEMENTATION SCENARIO AND CASE STUDY

The authors select six parking zones in the city centre of Bucharest (Figure 6) and they define also the areas of interest among parking management system, traffic management system and public transport management system. The specific area of the autonomic integrated system where the system will manage the allocation of parking spots based on driver’s request is marked with dark orange colour. The dark orange arrows are the main roads where the drivers could come to the area of the system and they could send request for parking spots.

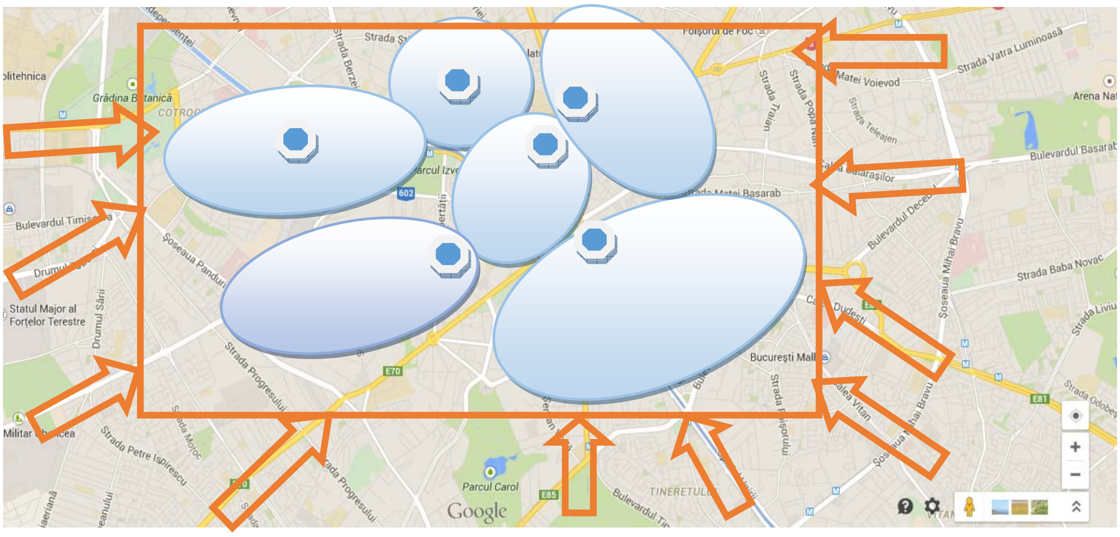

Figure 6. Area of interest for the city of Bucharest

When a car is entering the parking zone, the system will collect automatically the preferences of the driver in terms of parking services and in an autonomic manner will allocate the resources of the system and will generate a specific route for a specific driver. The influenced area of a parking zone is not fixed. There is the possibility to modify dynamically this area of influence based on the real information coming from Public transport management system and traffic management system. One important condition of is to modify those areas in the best way to cover the entire zone of the system.

The main benefit of the system is to consider a single integrated parking area based on six sub-areas and to allocate all parking lots having in consideration the inputs which are coming from: the driver, traffic management system and public transport management system as well as, internally, from parking areas and parking lots.

Depending of the time of the day and the day of the week (and so on) the real context of transport in this area is changing. The solution presented has the main role to identify the best parking lots for all cars based on the preferences of its driver and traffic context.

The solution will be prepared to be tested using existing parking management systems and the main role of this paper is to introduce the concept and to pave the way for application of this idea in the real world.
A cost benefit model will be generated based on the first application of the solution in exiting context of Bucharest and this analysis will present also the benefits of the autonomic behaviour of the system. The following benefits will be considered in this analysis: increased confidence in finding a parking spot, reduced time in searching for a parking space, easier access to the parking zones, increased parking occupancy and revenue for the parking owner, decrease of illegal parking, improved traffic flow and decrease of environment pollution in the area of the parking zones.

5. CONCLUSIONS

The authors present a solution for parking management system in urban areas characterised by intense traffic, high level of parking area's occupancy and public transport orientation.
The paper present an idea to use in a better way the existing parking lots in urban area and to allocate these lots to all cars based on traffic condition in a specific area, the level of service for public transport system in this area and the preferences of the drivers who are entering in this area and searching for parking spots.
The architecture of the system is based on multilayer approach in terms of defining three different layers of decision: central layer (Parking System Coordinator - PSC), local layer (Local Parking Management system - LPM) and micro-local layer (Local Sensors and Actuators - LSA) and the decision will be taken at all three layer based on the implemented algorithms. At every layer a set of self-* properties will be implemented in terms of assuring the autonomy of the system.
Two general algorithms are presented by authors to provide an initial solution and, after the implementation of the solution in a test bed, the algorithms will be improved in terms of maximising the benefits of the system. The algorithms are presented at the conceptual level and an implementation of these algorithms is needed.
An important issue for this type of system is to find an open hardware architecture which is able to support the implementation of different algorithms, the autonomic properties as well as a real implementation. The authors present a hardware solution based on Arduino, which is a real open system in terms of hardware platform for software development. Using this hardware solution the extension of the system is possible without any effort in terms of interfaces or interoperability (a network of these devices is possible to be set using TCP/IP protocols and applications).
The system has the following advantages (an analysis on this benefits will be conducted in near future): the reduction of the time which is spent in finding a parking lots in a specific urban area, the reduction of travel cost, implementation of park and ride solutions, reduction of pollution in this area and increasing of traveller/driver's satisfaction.
The next step is to implement the solution presented in the central area of Bucharest and to test the solution and the proposed algorithms in a test bed. Using this real implementation, a cost benefits analysis will be conducted and the autonomic properties will be tested.

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