A Social-Aware Smart Parking Application

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***Abstract*—The problem of finding parking spaces in big urban areas is one of the unsolved challenges of Smart Cities causing traffic congestion, increased carbon emission and time wasting. Network and sensor technologies available today allow to foresee Smart Cities equipped with applications able to provide real-time information on parking space availability, which can be used to assist motorists in looking for a parking space. In the present work, we propose a smart parking application that relies on the use of software agent negotiation as a mechanism to automate the selection of parking spaces according to the user preferences, but at the same time to take into account city needs in terms of areas motorists should avoid, or car pars occupancy at a specific time. Both city needs and user's preferences are dynamic information managed by the negotiation mechanism at the time a user's request is processed, so providing a dynamic-based selection of a parking space.**

I. Introduction

One of the big unsolved challenges to make Smart Cities a reality is the provision of Smart Parking applications. The overall objective of Smart Cities is to improve city life, so the provision of smart and sustainable parking solutions is becoming a key priority. In fact, several studies made it evident how the problem of searching for a parking space in high populated urban areas is a source of traffic congestion, increased carbon emission and, not least, a very frustrating and time consuming experience for motorists [1].

Several industry efforts have already produced solutions in this direction by making use of advanced Information and Communication Technologies including vehicle sensors, wireless communications, and data analytics in order to improve urban mobility. Some cities have adopted these solutions in pilot areas installing wireless sensors able to detect parking space occupancy in real time. In addition, smart parking meters, allowing for a wide variety of available payment methods, are being developed in conjunction with the dissemination of parking availability information.

Based on the information that can be collected on parking spaces occupancy, location and directions, applications assisting users in selecting a parking space are being developed. Many of the proposed approaches deal with the smart parking problem mainly as an optimization process from the drivers point of view. However, Smart City applications have to include benefits and revenues for the city itself. In fact, effective smart parking applications should be designed not only to make it easy for motorists to search for parking spaces, but also to take into account specific city needs that cannot always been known in advance and that may change in time according to volatile events effecting car circulation at specific time intervals. At this purpose in [2], we proposed a negotiation-based smart parking application in order to push motorists to consider parking spaces they would have not selected as their first choice, by making them a viable solution for parking.

In this paper, we present a prototype implementation of a web-based application for smart parking, based on the negotiation-based approach presented in [2], and provide an experimentation to assess the suitability of the designed mechanism as a smart parking solution. In particular, we are interested in understanding if the adoption of negotiation together with a dynamic pricing mechanism, is a viable way to satisfy both motorists and city needs, i.e. if it is possible to maximize *social welfare* represented by the utility values of both the user and the city.

II. A Smart Parking Application Scenario

A smart parking system is a complex system composed of several hardware devices able to detect the city occupancy level of parking spaces, and software components integrated to manage the allocation of these parking spaces by redirecting cars accordingly (see Figure 1). Usually, such systems are designed to assist motorists in the localization of available parking spaces, so that they can decide which space to select according to their own needs [3].

In the present work, we assume that Smart Cities will be equipped with such a complex system, and we propose to extend it with a software module implementing an application that can make decisions on where to park on behalf of a motorist, taking into account not only his/her needs, but also the social benefit for the city. In the proposed approach, a decision on where to park is the result of an automated negotiation process between two software agents: the *User Agent* (UA) acting on behalf of the motorist, and the *Parking Manager* (PM) who is responsible for managing parking spaces belonging to different car parks located in the city, which are offered to users as a global city facility. This means that different car parks owners agreed to subscribe to a *City Parking System*, managed by the Parking Manager, by delegating the selling of their parking spaces (partially or globally) to it. Hence, the Parking Manager is the authority responsible for allocating the parking spaces, virtually belonging to the City Parking System, but it is also responsible for collecting the information concerning specific city needs regarding transportation that will be gathered from the city council offices managing it.

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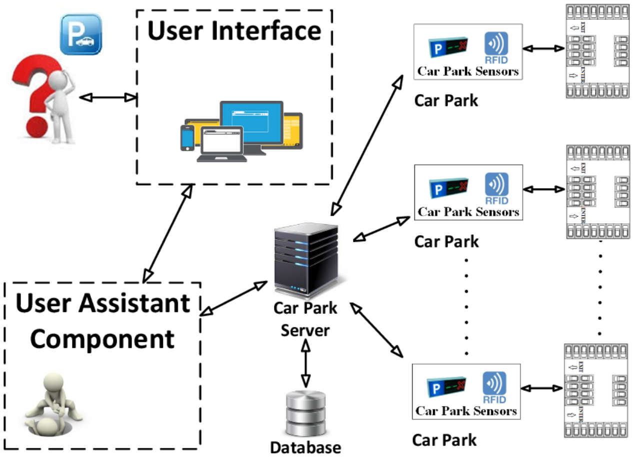

Figure 1. A general smart parking system.

Negotiation is used in order to accommodate both users and city needs that are different and, more importantly, conflicting. In fact, the Parking Manager has the objective to sell parking spaces to make a profit, but to prevent, as much as possible, motorists to park in a specified area, while users would prefer to save as much money as possible, and at the same time, to park close to the city destination they require.

III. A Social-Aware Parking Space Selection

In many decision-making situations in transportation, the competitive alternatives and their characteristics are reasonably well known in advance to the decision makers (passenger, driver). On the other hand, motorists usually discover different parking alternatives one by one in a temporal sequence. Clearly, this temporal sequence has a very strong influence on the driver's final decision about the parking space. In our work, the Parking Manager selects a set of car parks belonging to the City Parking System, but the temporal sequence in which they are offered during negotiation privileges first car parks meeting also city needs requirements.

The goal of the negotiation between the User Agent and the Parking Manager is to select a parking space that represents a viable compromise between the driver's and the city needs (represented by the Parking Manager preferences), so reaching a sort of *utilitarian social welfare*. In other words, we propose to find an allocation of parking spaces that is viable from a global social benefit point of view. The concept of social welfare, as studied in welfare economics, is an attempt to characterize the well-being of a society in relation to the welfare enjoyed by its individual members [4]. The proposed negotiation mechanism relies on the utilitarian interpretation of the concept of social welfare in multi agent systems literature, i.e. whatever increases the average welfare of the agents inhabiting a society is taken to be beneficial for society as well. According to the utilitarian concept, social welfare is interpreted as the sum of individual utilities.

A. The City Parking Cost Model

The possibility to monitor parking availability in real time opens up an opportunity for the provision of smart parking solutions that facilitate advance parking space reservation by setting up dynamic pricing policies, as in [1], [5]. By making such services available to motorists, operators may offer an enhanced level of service to their customers, while at the same time have the opportunity to increase their revenues. Parking pricing strategies play a crucial role in a comprehensive solution approach to the complex traffic congestion problems.

Dynamic pricing can serve a number of purposes. It can be used to maximize revenues for parking operators by setting higher fees during peak times and in more demanded areas [6], or as a results of current demand and supply. For example, traffic authorities, local governments and private sector could introduce higher parking tariffs for single drivers, or for long-term parkers in congested city areas, or they may provide special parking discounts for parking in specific city areas. Moreover, it may encourage motorists to use park-and-ride facilities. This may result in an increase of public transportation use, and at the same time it may reduce traffic and parking demands in city centers [1].

Obviously, parking pricing should be carefully studied in the context of the considered city. In this work, it is assumed that the Parking Manager tries to incentive drivers to park far from areas that are either highly congested, or where specific events affecting traffic take place, such as concerts, demonstrations, road works, and so on. The use of negotiation allows to consider these events at the time a parking request is issued, so managing the dynamic nature of such type of information.

In order to push users to avoid some city areas, a dynamic cost model is associated to the City Parking System. Once a specific zone to be avoided is selected by the Parking Manager, we refer to as a *red zone*, the area around this zone is divided in several rings, referred to as *sectors*, that account for the distance between a car park and the specific red zone. The first sector, named sector 1, is centered in the red zone with a radius that can be set according to some criteria. The price associated to parking spaces depends on the sector the corresponding car park belongs to, so the farther the car park is from the red zone, the cheaper it is. In addition, in order to incentivize the occupancy of less crowded car parks, a discount factor is applied to each car park in accordance to its occupancy w.r.t. its total capacity.

B. The Negotiation-based Parking Space Selection

In the present work, we adopt the negotiation mechanism reported in [2], whose protocol is based on the FIPA Iterated Contract Net Protocol, that is frequently used to mime the human contract negotiation process. The protocol is organized in negotiation *round*s, each one consisting of interactions between the UA, that is the initiator of the negotiation, and the PM, that is the agent proposing offers.

At the first negotiation round, the UA issues a request (i.e. a *call for proposal*) for a parking space specifying his/her destination location, the time interval he/she needs to park for, and the importance level (*weight*) for the considered parking space attributes. The PM may either reject the call, if there are not offers available, or it sends back an offer consisting in a parking space solution selected from the set of available offers. The PM calculates, at the first negotiation round, the entire set of available offers by selecting a set of car parks within an area centered around the user's requested destination location, and whose dimensions are set according to some criteria (e.g. a small area if the user wants to park far from the red, and wider in the opposite case). Once the set of car parks is selected, the PM calculates the corresponding prices to offer according to the price model previously described. Then, it ranks the offers according to its own preference criteria that take into account the city needs. The offers are sent one by one, at each negotiation round, in their ranking decreasing order. When receiving an offer, the UA evaluates it, according to its own evaluation criteria, to decide whether to accept or to reject it. In the case of rejection it can iterate the negotiation process by sending another call for proposal. It should be noted that an offer proposed by the PM in a negotiation round is not considered available in future rounds once it is rejected. This assumption models the possibility that a rejected parking space may be offered to another user in the meantime, or its price may change according to the parking market trends as in [7]. Of course, it is difficult for the negotiating agent to evaluate whether to accept an offer to minimize the expected cost of communication (at the risk of getting a sub-optimal result for the specific application), or to keep on negotiating to maximize its expected utility (at the risk of increasing the cost of negotiation and ending with a conflict deal). In our approach this aspect is modeled by associating to the UA an *acceptance threshold* value (in the interval $[0,1]$) representing the user's attitude to reach a compromise.

Both the PM and UA preference criteria on a parking space offer are modeled through utility functions based on the Multi-Attribute Utility Theory defined on independent issues [8], over the attributes to be negotiated upon. In particular, utilities are defined both for the UA and the PM, as weighted sum of specific normalized attributes that sum to one as follows:

$$U_{PM/UA}(offer_{PM}(k)) = \sum_{i=1}^{n}(w_i * \frac{attr_i}{normfactor_i}) \quad (1)$$

where n is the number of considered parking space attributes $attr_i$, $normfactor_i$ is the corresponding normalization factor, and w_i is the corresponding weight, with $\sum_{i=1}^{n} w_i = 1$.

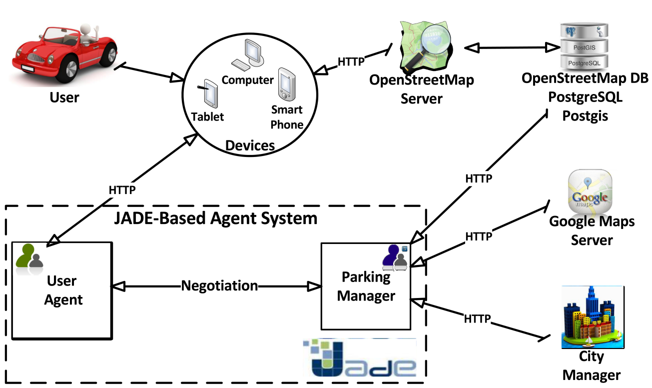

Figure 2. The prototype architecture of the smart parking application.

Here the same utility functions presented in [2] are used. The PM utility function depends on the car park occupancy percentage, at the moment the request is received, and on the distance of the car park from the current red zone (if any), normalized with respect to the maximum considered distance by the PM, that determines the area for the selection of car parks. The UA utility function depends on the parking space price, on the car park walking distance from the requested destination, and on the corresponding travel time distance with public transportation. The values of these attributes are specified for each parking space in the offer sent by the PM. Each attribute value is normalized for the UA with the maximum parking space cost, and the maximum walking distance and travel time between the parking space and the motorist's actual destination, that are specified as requirements in the user request [9].

IV. A Prototype Implementation

In order to provide Smart Cities with an intelligent smart parking solution to be integrated in a more complex City Parking System, we designed and implemented a web-based multi-agent application to automatically select parking spaces in reply to user's requests. The application was tested in a case study based on both real and simulated information, to assess the suitability of software agent negotiation in the context of intelligent parking. The architecture of the implemented prototype is shown in Figure 2 reporting its main components.

The negotiation module is implemented by using the JADE framework [10] to implement the UA and the PM, and relying on its messaging primitives to implement the adopted negotiation protocol. JADE is an open source software framework for developing applications that implements agent and multi-agent systems. It is a Java based agent development environment providing libraries designed to support communication between agents in compliance with Foundation for Intelligent Physical Agents (FIPA) specifications. The multi-agent system is composed of the UAs and the PM. The PM is enveloped in an application server, more specifically Apache Web Server extended with Tomcat, and it is able to communicate with external services and information sources:

- Google Map Server [11] to retrieve walking distance and travel time from a selected car park to the user's destination location,
- the Car Park Database to retrieve information on the available car parks,
- City Manager facilities to retrieve information regarding roads accessibility-related information.

The contents of the Car Park Database are retrieved from the OpenStreetMap application [12], and it is implemented using PostgreSQL, an object-relational database management system, and PostGIS an open source software providing support for geographic objects to the PostgreSQL database. The user's application also queries OpenStreetMap to obtain maps for the interface it interacts with.

A. A Special Event Case Study: The Football Match

In order to assess how software agent negotiation can be used in the selection of parking spaces in a urban area, a set

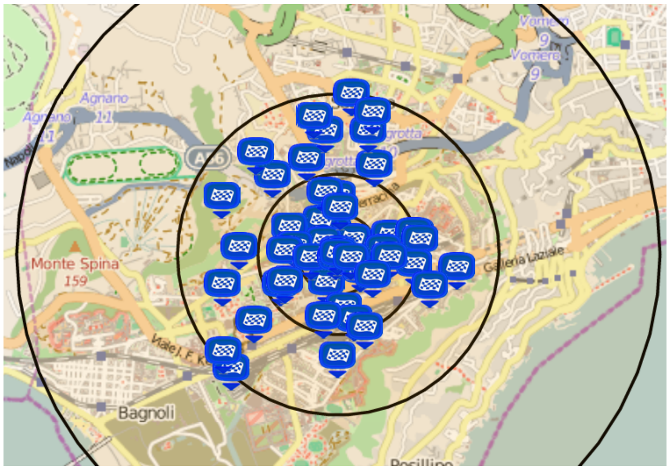

Figure 3. Queries distribution in sectors 1, 2 and 3.

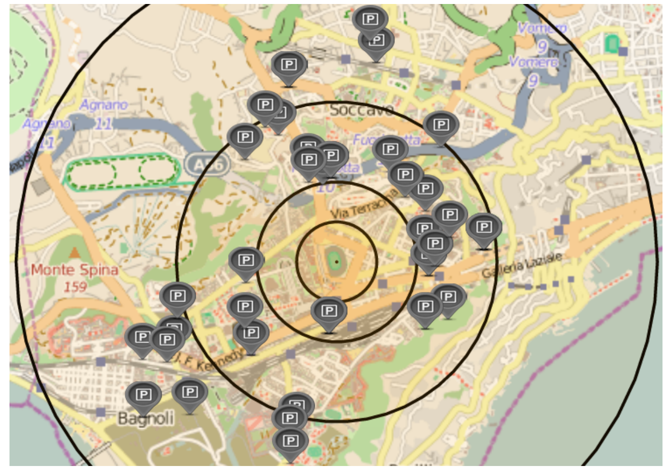

Figure 4. Selected parking spaces for the UA queries with negotiation.

of experiments were carried out considering the city of Naples as the target area. The negotiation mechanism is proposed as a means to incentive motorists to consider parking space solutions that are related not only to their own preferences.

Our reference scenario consists of a set of users that make requests to park in different zones of Naples on the day a football match will take place. For this reason, it is considered beneficial for the city to make motorists to avoid the area around the football stadium for parking, in order to limit traffic congestion. So, the red zone is represented by the city sector (sector 1) centered in the location of the football stadium, with a radius set to $500m$ (the radius value can be set by the PM according to several factors such as viability conditions in the surrounding area, the number of car parks available in the surrounding areas, and so on). The rest of the city is split in sectors as well, starting from sector 1, with an exponential increased radius. The experiments simulate 60 queries (q_i) with destination locations distributed in sectors 1, 2 and 3 (20 queries in each sector), as shown in Figure 3. The sectors are determined with respect to the red zone (target t), and the destination locations are randomly generated. The threshold value for all users is set to 0.7 in all the experiments.

B. Experimental Results

For each generated query the negotiation process between the UA and the PM takes place. In Table I we report, for each set of queries (respectively for sector 1, sector 2 and sector 3), the mean value together with the standard deviation of the following attributes of the parking space (s_i) selected after the negotiation: the UA and PM utilities (U_{UA} and U_{PM}), its distance from the red zone ($Dist(t)$), its walking distance ($Dist(q_i)$) and travel time distance with public transportation ($Time(q_i)$) from the query destination location, its offered price ($Price$), its position in the PM ranking ($Rank_{PM}$), and the social welfare value (SW), obtained as the sum of UA and PM utilities. The ranking position of s_i corresponds to the number of the negotiation round at which the offer was sent by the PM, so representing the length of the negotiation (i.e., the number of rounds necessary to reach an agreement between the UA and the PM).

The obtained results show that the PM and UA utility values for the selected parking space increase when users' destination locations are far from the red zone. Furthermore, the negotiation length increases when users want to park in the red zone, since it is more difficult to find a compromise. In fact, when users require destination locations far from the red zone the social welfare (last column of Table I) increases since the needs of both the PM and the UA are easily satisfied. The distribution of the selected parking spaces for the considered queries is reported in Figure 4, showing that the parking spaces are selected in accordance with the objective to prevent motorists from parking in the red zone.

In order to evaluate the benefit in using negotiation to find a compromise between the PM and the UA, we also evaluated the attribute values of parking spaces chosen respectively by the PM and the UA without negotiation. In this case, the PM and the UA select respectively the best parking space that maximizes their own utility functions. Of course, in order for the PM and the UA to chose the best parking space, it is assumed that they both share the same information concerning the available parking spaces.

In Table II the same attributes described in Table I are reported for the best parking space for the UA (UA_{best}). As expected, in this case, the UA preferences are privileged while the PM utility value increases only for locations far from the red zone. Note that the ranking position of the selected parking space for the PM is in average 20, meaning that in case of negotiation such parking space would be offered to the UA only after 20 rounds, so requiring a longer (and hence more costly) negotiation w.r.t. the case reported in Table I, where the average number of rounds is 5.5. Finally, the price of the UA_{best} is in the average higher then the price of the s_i because it corresponds to parking spaces nearer to the query locations and, hence, nearer, in average, to the red zone.

In Table III the same information as Table II is reported, but considering the best parking space for the PM (PM_{best}). In this case the PM preferences are privileged, while the UA utility value increases only for locations far from the red zone. Of course, the ranking value of the best parking space for the PM is 1, because it represents the best choice for the PM, whose utility value is 1 because it is normalized w.r.t. the max values of the parking attributes available for each query.

s_i	U_{UA}	U_{PM}	$Dist(t)\ m$	$Dist(q_i)\ m$	$Price\ e$	$Time(q_i)\ s$	$Rank_{PM}$	SW
sector 1	0.75 ± 0.04	0.83 ± 0.22	1089 ± 255	866 ± 228	2.8 ± 0.4	269 ± 109	11 ± 10	1.59 ± 0.23
sector 2	0.75 ± 0.05	0.91 ± 0.09	1650 ± 304	1053 ± 167	2.2 ± 0.7	212 ± 77	3.8 ± 3.3	1.66 ± 0.11
sector 3	0.83 ± 0.04	0.93 ± 0.11	2399 ± 377	1145 ± 219	0.9 ± 0.8	213 ± 59	2.2 ± 2.1	1.76 ± 0.13
total	0.78 ± 0.07	0.89 ± 0.15	1713 ± 624	1021 ± 234	1.9 ± 1.0	232 ± 87	5.5 ± 7.1	1.67 ± 0.18

Table I. EXPERIMENTAL DATA OF PARK SELECTION (s_i) W.R.T THE QUERIES q_i AFTER THE NEGOTIATION.

UA_{best}	U_{UA}	U_{PM}	$Dist(t)\ m$	$Dist(q_i)\ m$	$Price\ e$	$Time(q_i)\ s$	$Rank_{PM}$	SW
sector 1	0.91 ± 0.06	0.21 ± 0.20	390 ± 163	339 ± 232	4.5 ± 1.0	101 ± 86	34 ± 5	1.12 ± 0.18
sector 2	0.98 ± 0.06	0.66 ± 0.17	1114 ± 217	473 ± 106	2.8 ± 0.4	115 ± 62	17 ± 6	1.64 ± 0.20
sector 3	0.99 ± 0.05	0.75 ± 0.14	1830 ± 463	616 ± 282	1.5 ± 1.0	114 ± 63	9 ± 6	1.74 ± 0.16
total	0.96 ± 0.06	0.54 ± 0.29	1112 ± 666	476 ± 244	2.9 ± 1.5	110 ± 70	20 ± 12	1.50 ± 0.33

Table II. DATA OF UA BEST CHOICES (UA_{best}) W.R.T. THE QUERIES q_i WITHOUT NEGOTIATION.

PM_{best}	U_{UA}	U_{PM}	$Dist(t)\ m$	$Dist(q_i)\ m$	$Price\ e$	$Time(q_i)\ s$	$Rank_{PM}$	SW
sector 1	0.44 ± 0.18	1 ± 0	1332 ± 153	1496 ± 362	2.5 ± 0.0	385 ± 109	1 ± 0	1.44 ± 0.18
sector 2	0.56 ± 0.21	1 ± 0	1875 ± 241	1656 ± 920	1.9 ± 0.9	240 ± 85	1 ± 0	1.56 ± 0.21
sector 3	0.57 ± 0.26	1 ± 0	2580 ± 350	2006 ± 1057	1.5 ± 1.0	114 ± 63	1 ± 0	1.57 ± 0.26
total	0.52 ± 0.22	1 ± 0	1929 ± 576	1720 ± 849	1.6 ± 1.0	294 ± 123	1 ± 0	1.52 ± 0.22

Table III. DATA FOR THE PM BEST CHOICES (PM_{best}) W.R.T. THE QUERIES q_i WITHOUT NEGOTIATION.

The average values of social welfare, reported in the last rows of Tables II and III, are lower than the one obtained with negotiation, since in these cases only the needs of one agent (respectively the UA and the PM) are taken into consideration. By the way, the average values of SW in the three tables are very close, but the values relative to each sector differ, so showing that negotiation is useful to improve social welfare when users want to park close to a red zone (i.e., for sector 1), while for sector 2 and 3 the social welfare is comparable.

The distribution of the best parking spaces for the UA, reported in Figure 5, is similar to the distribution of query locations, meaning that without negotiation users are not prevented from parking in the red zone. While the distribution of the best parking spaces for the PM, reported in Figure 6, is similar to the distribution of the parking spaces selected with negotiation since in this case the PM needs are considered.

V. RELATED WORKS

Multi-agent negotiation was already used in Intelligent Transportation System applications. In [13] cooperative agent negotiation is used to optimize traffic management relying on shared knowledge between drivers and network operators about routing preferences. In [14] a negotiation algorithm is designed for negotiating routes based on the calculation of routes utility, while in [15] agent negotiation is used for dynamic parking allocation, focusing on satisfying driver's preferences on prices and distances. Negotiation in smart parking application was used in [16] to determine the price of a car park. In our work, the price of a car park is not negotiable, but it is dynamically set so to incentive users to select parking spaces located in specific urban areas.

Dynamic pricing mechanisms are being used in the context of parking applications. In [6] the authors presented, as in our case, a smart parking solution that tries to find a trade-off between benefits of both drivers and parking providers. To balance the needs of involved parties, they use a dynamic parking price mechanism, and utility functions for the drivers, to balance the convenience and cost in terms of parking price and parking distance from the user's destination. Differently from our approach, in [6] the parking selection is obtained

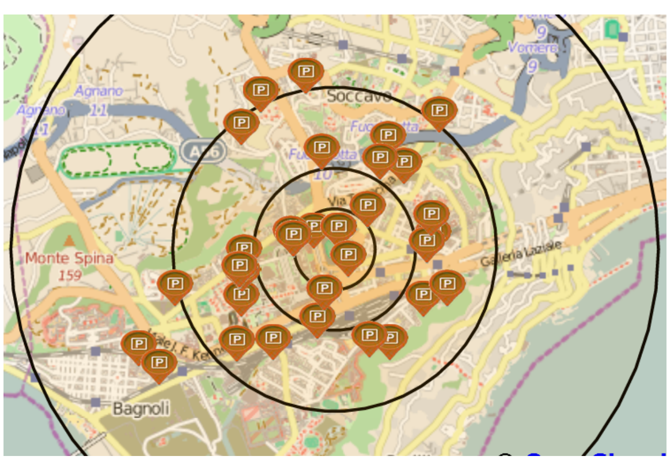

Figure 5. Distribution of UA_{best} parking space without negotiation.

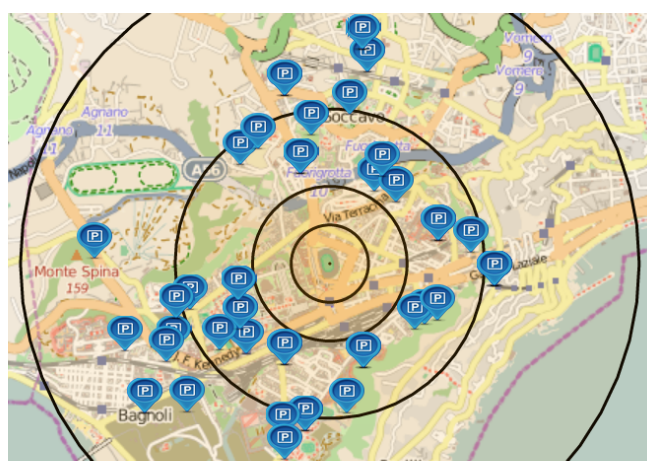

Figure 6. Distribution of PM_{best} parking space without negotiation.

from a maximization of such utility with all the information available. In our case, we showed that a negotiation process may be more effective, in terms of social welfare maximization, than a simple one-sided utility maximization. Dynamic price mechanisms were also explored in [5], where the objective was to set up prices for available parking spaces to prompt the most efficient allocation, in terms of social welfare, intended as the total utility value of all agents who are allocated to a parking space. Hence, while the social welfare in our approach is a result of a mediation of the conflicting needs of a user and the city management, in their work it consists in an optimal allocation of parking spaces to different users.

The optimal allocation of cars in car parks was also studied in [9], where the authors propose a semi-centralized approach for optimizing the parking space allocation, and improving the fairness among parking zones by balancing their occupancy-load. In this approach, parking coordinators process the user requests and may communicate with the neighbor coordinators. In [17] the parking space allocation strategy, implemented through the use of a Mixed Integer Linear Program, is based on the user's objective function that combines proximity to destination and parking cost, while ensuring that the overall parking capacity is efficiently utilized. In our work, a more efficient allocation of parking spaces is not the main goal. However, it may be obtained as a side effect of the negotiation because of the adopted dynamic price strategy.

VI. Conclusion

Smart parking applications should make it easier for motorist to find a parking space, and so help in reducing traffic congestion, carbon emission, and users frustrations and time wasting, leading to a benefit for the whole city as a side effect. But in order to really improve the living conditions of city life, Smart Cities should rely also on the contribution of local authorities providing information regarding city regulations and decisions that, if shared, could help to design smarter applications. Typically, this type of information is very dynamic depending also on unforeseen events. For these reasons, we proposed a smart parking application having as a main objective to reach a social benefit as well as helping users. The implemented mechanism aims to maximize the social welfare of users and city managers finding a compromise between their goals sometimes in conflict. The classical way to achieve such a compromise is through negotiation, that we propose as the underling mechanism of a smart parking application.

In this paper, we described a first prototype of the negotiation process in order to assess its suitability in the context of smart parking. The experimental results, obtained in testing the application, showed that negotiation may improve the social welfare mainly when the goals are conflicting. In future works we plan to extend the experimentation to evaluate the possibility of achieving optimal social welfare by varying the values of parameters that characterize the negotiation mechanism.

Acknowledgment

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