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An Architecture for a Mobility Recommender System in Smart Cities

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Abstract

To date, there is a wide availability of academic and commercial ICT proposals to improve urban mobility. Nevertheless, in the literature, there is still a lack of suitable solutions for door-to-door routing supporting users from their origins to destinations and including the suggestion on where to park. On the other hand, in an Internet-of-Things (IoT) scenario, a lot of novel information sources could be exploited to compute more efficient mobility solutions to be proposed to the user. As an example, parking availability data could be easily collected and exploited to provide multimodal routes (i.e. routes with at least two different means of transportation) that include suggestions on where to park and how to reach the final destination. In this paper, we describe a distributed IoT architecture towards the definition of a Mobility Recommender System. In particular, we focus on a car-based multimodality, where the user always starts a trip with his/her private vehicle, but he/she can also leave the car in Park-and-Ride infrastructures and reach the destination with public transportation. This type of routing on a wider search area will result to be more costly, and thus, it will particularly benefit from a parallel computational architectural solution.

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1. Introduction

A lot of research in the field of Intelligent Transportation Systems, or ITSs, is devoted to mitigate mobility problems, also by exploiting in novel ways information about the state of the road infrastructure [1,2]. Many commercial and academic ITSs provide optimal door-to-door routing exploiting multiple means of transport (i.e. a synergistic use of bus, rail, and/or taxi). Nevertheless, up to now, very few investigations have been conducted on routing including parking [3]. Finding a parking space is a key issue in the field of mobility. A study conducted by the University of California-Los Angeles in 2006, in the small district of Westwood (only 3 blocks by 4), shown that, during rush hour, up to 30% of the traffic is due to drivers looking for a parking space [4]. The main cause of these problems is that drivers

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do not know where there could be free parking spaces matching their expectations and so they have to roam. These problems have not only strong socio-economic implications, since the time spent in finding free parking spaces is a cause of stress and frustration for drivers, but there is also a dramatic ecological impact: just in that small district of Westwood, about 500 tons of CO2 are wasted per year only to search for free parking spaces[4]. Another crucial problem is that this roaming behavior is dangerous. Drivers looking for parking spaces are distracted drivers, making lots of right and left turns, thus being more likely to hit a cyclist, or another vehicle crossing the street.

Park Guidance and Information (PGI) solutions are designed to increase the probability of finding a parking space[5,6], but without considering the possibility to find a better solution for the driver (e.g., a solution that is not near the destination, but cheaper)[7,8]. Moreover, PGI solutions leave the burden of making the parking decision on the drivers[9] by evaluating all the available information in the destination area. Drivers may not be aware of available alternatives that are not in the destination area, but are easily connected with it, for example by using public transportation, and none of them exploits the available Park-and-Ride infrastructures, i.e. the car parks with nearby public transport connections. Such solutions are useful for travelers living beyond the practical walking distance from railway stations or bus stops, willing to leave their private vehicles along the route and transfer to a bus or rail system for the remainder of the journey to a city center.

From a technological stand, it is easy to envision a near future scenario of urban mobility, where it will be possible to know in real-time the availability of parking spaces for each off-street parking lot and on-street parking stall, thanks to Internet-of-Things (IoT) techniques[10,11]. By leveraging these new and potentially huge data sources, novel mobility applications become possible. Within this scenario, in this paper, we propose a distributed architecture for a Mobility Recommender System (MRS) that helps drivers in their mobility needs, by providing efficient door-to-door route solutions, matching the users' preferences as well as city regulations, and including the identification of suitable parking spaces, either in a Parking Garage or on-street. Indeed, we also consider the phase of leaving the vehicle somewhere (a phase that is usually neglected in most of the routing solutions) and reach the destination with a different mode of transport, like walking or mass transit, thus being *multimodal*. This new feature has a deep impact on the computational requirements of the Route Calculation Planner (RCP), which has now to deal with a much wider space of solutions (e.g.: parking close to the destination and walk, or exploiting a farther Park-and-Ride infrastructure). To solve this issue, we propose an architecture encompassing a back-end based RCP, where the evaluation of multiple paths is performed in the Cloud. By gathering information from this specifically developed RCP, the MRS will reason on the available data and offer to the drivers different alternative routes.

The overall goal of the present work is to present the high-level scalable architecture of the system to be developed able to integrate multiple IoT data sources, where the core modules that will require a deep scientific investigation are a multimodal RCP and an MRS. The remainder of this paper is structured as follows: In Section 2, we describe the scalable architecture we propose to tackle the requirements posed by the massive datasets and the use cases. In Section 2.1, we provide a description of the IoT data sources to be employed in the proposed solution. In Section 2.2, we describe a possible implementation of the distributed RCP. Then, in Section 2.3, we present the envisioned MRS. Finally, in Section 3, some concluding remarks and future research directions are pointed out.

2. The Proposed Architecture

A Multimodal route choice is a much more complex task with respect to a simple car route. Indeed, with a private vehicle, the choice among routes usually falls on those able to optimize the estimated time of arrival or the shortest path. On the other hand, the definition of a multimodal route requires a complex search process, whereas a traveler has to make a number of linked decisions based on updated knowledge gained from experience[12]. However, the user may suffer from choice overload since too many options have to be evaluated[13]. The potential availability of real-time information on parking spaces could help this process, by discarding some unfeasible routes, but still the search space is too vast.

A Mobility Recommender System could help the travelers in their decision-making process, by providing suggestions about relevant routes for users. The objective of the proposed MRS is to generate different ranked lists of possible multimodal door-to-door routes that include also parking spaces (either on- or off-street) by querying multiple times the RCP with different parameters, in order to find the relevant alternative to propose to the drivers. Some previous research has been devoted to propose data-driven architectures for mobility[14]. Moreover, in the literature on

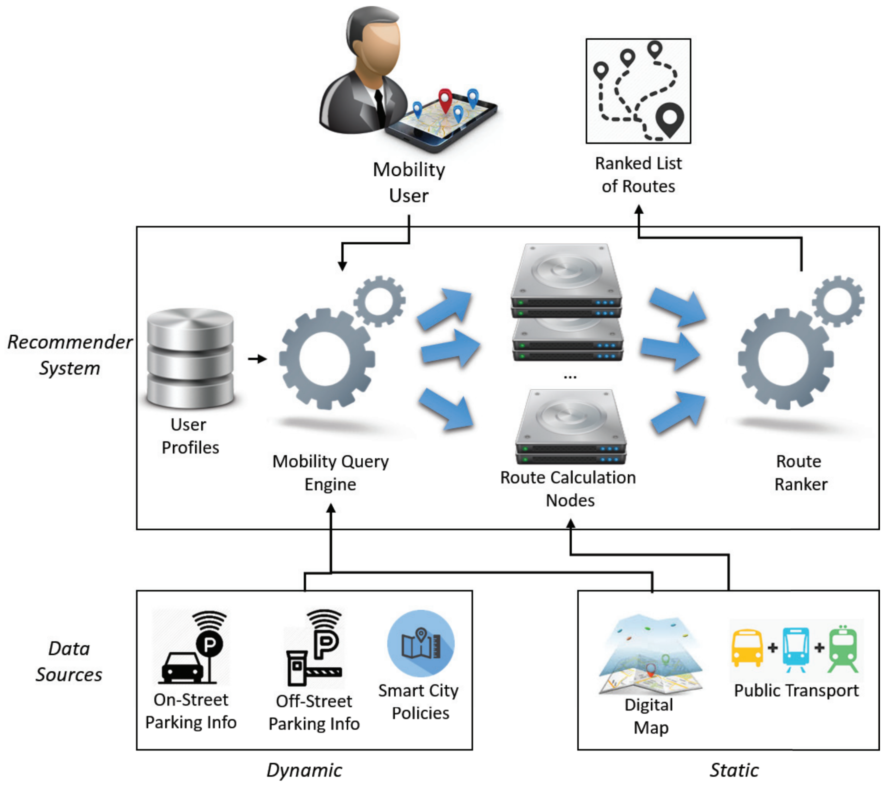

Fig. 1: The Architecture of the Proposed Mobility Recommender System.

decision support systems for traffic and transportation optimization, there are some solutions whereas the proposed mobility suggestions contain information on their impact on the city congestion [15]. Nevertheless, also in these cases, these applications do not deal with the parking selection problem.

The architecture we propose in this work, shown in Figure 1, is meant to exploit heterogeneous data sources about the road infrastructure, mainly from 3rd party data providers, such as the digital map of the road network and the parking information. Fundamental data are the one obtained by the public transportation network, and smart city policies and regulations. Starting from a user's query, which is composed by a starting location (typically the current location) and his/her destination, the Mobility Query Engine will reason on the available data to generate different queries for the RCP. More in detail, the query engine will generate n queries each by adding a different way-point in between the couple source/destination. Each of the n way-point represents a possible parking area selected by reasoning on city policies and estimated parking availability information and then evaluated according to the user parking preferences (a user profile). The RCP will provide, for each route request, a list of potential door-to-door routes, each of them intended as the sequence of road segments, the Estimated Time of Arrival, and optional information about public transportation to be used to reach the destination. To obtain this result, the RCP will require the definition of a novel cost function looking for the best multimodal route, able to minimize the total travel time for the user. After the RCP computation, a Route Ranker will order the multimodal route results with respect to the user preferences and the highest rank results will be suggested to the user.

2.1. Data Modeling and Provisioning

In this work, we propose to develop a system that relies on heterogeneous information sources, gathered by external stakeholders, to provide different suggestions to the user. This process requires the development of an integrated software module suited to model, collect, and provide the information needed by the system, mainly gathered from 3rd party data providers.

In particular, we can distinguish two classes of data sources: the static and the dynamic ones. More in detail, the **Static Data Sources** are:

- *The Digital Map*, containing the geographical information needed to calculate routes. The information can be regarded as a graph of road segments with corresponding attributes, like historical speed profiles, provided per day of the week and time of the day. The map contains also additional information about the static attributes of car parks, like the location and the total number of parking stalls. The digital map has to be provided in a standardized format, like OpenStreetMap[1].
- *Public Transportation Network*, including information about the location of the bus and rail stations, as well as their timetables.

It is reasonable to estimate that this kind of data may present a slow update rate. A new release of a map or of a timetable may happen once a month or even less frequently. However, in the presence of roadworks or any other kind of disruption, updates may be sent to the system.

As for the **Dynamic Data Sources**, we consider:

- *On- and Off-Street Parking Information*: As for dynamic attributes of car parks, either on- or off-street, we will use the real-time number of available parking spaces that can be provided by the Public Transportation Authority, but also by distributed sensors on streets and cars. Many proposals have been done in the literature to acquire knowledge about the availability of parking spaces. Examples include the use of special sensors in the asphalt [10], cameras mounted on the light poles or high locations [11], up to the use of mobile phones to track trajectories. The hourly price for a parking space could be either static or dynamic, depending on the policies of the site. Parking information should be updated every 5-10 minutes.
- *Smart city policies and city regulations*, adopted by public administration to improve the quality of life of citizens and to help the city management, such as car-free places, pedestrian areas, park-and-ride facilities, and policies with the aim of avoiding congestion in strategic areas, discourage the use of cars and promote public transport. This information should be updated once a day.

Hence, a module that periodically queries according to multiple scheduling the different information's owners and populates the internal state of the system has to be defined, with the proper API to access the modeled information from the RCP and the MRS.

2.2. The Multimodal Route Calculation Planner

The Multimodal Route Planner should be able to propose a set of efficient routes, given origin, destination, and a car park. In particular, such MRP is intended to be a multi-objective optimization engine, looking for the best multimodal route, that is able to minimize the travel time for the user by taking into account the different data sources defined in Section 2.1.

The problems posed by the new domain, in terms of multimodality and inclusion of a parking phase, will require developing new routing strategies and heuristics, able to reduce in a smart way the search space. Most likely these new strategies will be intended as evolutions of the well-known A* (A star) one. The A* algorithm [16], an extension of Dijkstra's algorithm, uses a heuristic to estimate the minimum costs from each node to the destination. This results in a reduced search tree that "grows" in the direction of the destination, and so the suitability of strategies like the bidirectional search for time-dependent route calculations [17] can be explored. The MRP will produce, besides the list of road segment composing the route, as a secondary result, the Estimated Time of Arrival (ETA). Since the precision of the ETA is a key factor for a proper synchronization with public transportation solutions, multiple sources of information are required to its estimation, including historical speed profiles, for each road segment.

[1] https://www.openstreetmap.org

For each query, the RCP will provide a list of potential door-to-door routes, each of them intended as the sequence of road segments, plus the parking location received as input, the ETA at the final destination, and optional information about public transportation to be used, after parking, to reach the destination, and information about segments to cover on foot. This list will be fed to the MRS for a subsequent ranking.

2.3. The Mobility Recommender System

The proposed Mobility Query Engine (MQE) is designed as a multi-agent system, following an agent-oriented system engineering approach[18,19]. The application domain, in fact, considered in the present work, is characterized by a dynamic heterogeneous nature of the required information and by different levels of complexity in the reasoning process. The rationale for this choice is to guarantee the autonomy of the different components of the system, the possibility to communicate and exchange data among them, and to clearly distinguish the different functionalities. Hence, a multi-agent approach allows designing a modular and distributed approach to the problem. Moreover, a multi-agent approach is particularly suited for such an Internet-of-Things scenario since it makes it possible to distribute the management of information sources according to their type, complexity, and location, and to add new agents to the system in order to include both new functionalities and new sources of information, when they become available.

As an example, consider the case of a query starting from the user current location by car towards a destination. The MQE queries will be composed of a starting point, a destination, and one or more different intermediate points. Such points, selected according to the user preferences, can include a parking space. Hence, the goal of the different agents is to select parking spaces for composing the queries with respect to different cost models and by reasoning on different input data. The first, typical, solution would be to search for parking spaces directly in the destination area, selected by considering a cost model based on parameters such as successful parking probability and the dynamic availability of parking spaces. However, since the door-to-door routes may include also public transportation, such selected area cannot be restricted to the one connected to the destination by a walking distance[7]. Another agent, which is aware of city policies (as, for example, of park-and-ride infrastructure), may generate a different set of queries that includes such regulations. Finally, an agent that is aware of the user parking preferences may generate different queries for the RCP, with the aim to offer to the users different route alternatives evaluated according to his/her preferences. A user (citizens, commuters, tourists, businessmen, etc...) may be modeled with respect to his/her preferences on a parking spot, for example, whether or not he/she is willing to park far from the destination, an hourly cost he/she is willing to pay for the space, and so on. In literature, these preferences are aggregated by using utility functions composed of several factors that affect the decision-making[20].

After querying the RCP, the results will be collected and aggregated in a ranked list of route recommendations. Such list is the result of a process that aims to take into account, again, the user preferences in order to suggest relevant routes to the user while filtering irrelevant ones. In this context, utility-based recommender systems suggest items starting from the user's preferences on multi-attribute products. As introduced in Section 2.1, parking spaces and routes can be described in terms of attributes that depend on static information (e.g.: their locations and hourly price for parking space, and so on), on predicted values (e.g.: predicted occupancy values), and on dynamical information that depends on the specific route query (e.g.: the distance from the selected final destination). User preferences may be modeled with utility functions depending entirely on the values of these attributes so that two items are identically preferred if they have the same value for the considered attributes. By defining the proper utility functions, the results of the RCP can be numerically evaluated taking into account the different attributes. Routes with the highest ranks will be proposed to the user.

3. Conclusion

In this paper, we presented a high-level distributed architecture of a multimodal door-to-door routing system, aimed at tackling the challenges of urban mobility. In particular, we envision a near future scenario of urban mobility, where, thanks to Internet-of-Things techniques, it will be possible to know in real time the availability of parking spaces for each off-street parking lot and on-street parking stall. By leveraging this new potentially huge data sources, novel mobility applications will be possible. In particular, we propose a Mobility Recommender System for ITS that helps drivers in their mobility needs, by providing efficient door-to-door route proposals, matching the user preferences, and including the identification of suitable parking spaces, either in a Parking Garage or on-street. Indeed, we also consider the phase of leaving the vehicle somewhere (a phase that is usually neglected in most of the routing solutions) and reach the destination with different a different mode of transport, including walking or mass transit, thus being *multimodal*. This new feature has a deep impact on the computational requirements of the Route Calculation Planner, which has now to deal with a much wider space of solutions, and on the search areas for selecting park spaces (e.g.: parking close to the destination and walk, or exploiting a farther Park-and-ride infrastructure). To solve this issue, we propose an architecture encompassing an RCP, whose evaluation of multiple paths is performed in the Cloud, and a multi-agent system to select car parks. By gathering information from the specifically developed RCP, the MRS will reason on the available data and offer to the drivers different alternatives routes evaluated according to their preferences as well as city regulations.

As future work, we would like to provide an analysis of the execution time of the proposed architecture. Moreover, we would also like to take into consideration real-time information about traffic. This new data source has a strong impact on the Multimodal Route Planner, that will thus become time-dependent.

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