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Generic model for resource allocation in transportation. Application to urban parking management

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ABSTRACT

In this paper, we define the online localized resource allocation problem, especially relevant for modeling transportation applications. The problem modeling takes into account simultaneously the geographical location of consumers and resources together with their online nondeterministic appearance. We use urban parking management as an illustration of this problem. In fact, urban parking management is an online localized resource allocation problem, where the question is how to find an efficient allocation of parking spots to drivers, while they all have dynamic geographical positions and appear nondeterministically. We define this problem and propose a multiagent system to solve it. The objective of the system is to decrease, for private vehicles drivers, the parking spots search time. The drivers are organized in communities and share information about spots availability. We have defined two cooperative models and compared them: a fully cooperative model, where agents share all the available information, and a "coopetitive" model, where drivers do not share information about the spot that they have chosen. Results show the superiority of the first model.

1. Introduction

Transport activities have important financial consequences and serious ecological fallout. As a consequence, increasing number of researches optimizing these activities are being conducted in the recent years, especially concerning urban activities. Indeed, investment on infrastructure are limited by space and financial costs, while the fleet of vehicles is continuously increasing. As a consequence, optimizing urban traffic is vital, together with increasing the use of electric vehicles and encouraging vehicle sharing. To this end, intelligent transportation systems are designed to improve the use, safety and efficiency of the transport means and infrastructure with information and communication technologies. Indeed, researchers are more and more interested in problems such as the search of charging stations for electric cars (Acha et al., 2011), the sharing of vehicles (taxi, car, bike, etc.) (Katzev, 2003), and urban parking management (Delot et al., 2013).

A part of these problems can be seen as resource allocation problems, where the challenge is to find an optimal allocation of resources to consumers. In transportation applications, the drivers or the travelers are generally the consumers. The resources might be charging stations, parking spots, traffic information or vehicles. However, these resource allocation problems are recurrent in transport applications and should have a generic problem formulation representing them.

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This formulation would identify the common concepts and constraints of these applications. One of the main characteristics of these problems is that they require the simultaneous consideration of time and space. Indeed, in a transport application, there is always an explicit representation of the environment (i.e. the transport network). The actors (drivers, travelers, etc.) are localized in this environment where they dynamically move. A generic formulation of resource allocation that is specific to these problems is the first objective pursued in this paper.

In transportation applications, the time dimension has to be explicitly represented because the information about resources and/or consumers is not known at the beginning of the allocation. This kind of problem is generally modeled as an online resource allocation (ORA) problem (Tesauro, 2005). The space dimension has to be explicitly modeled because resources and consumers are situated and because the distance between them generally conditions the allocation: resources and consumers have to be geographically co-located or close enough for the allocation to take place. This kind of problem can be modeled as a localized resource allocation (LRA) problem (Golkar and Sousa, 2011). We present in this paper a generic model for both ORA and LRA problems called OLRA (for Online Localized Resource Allocation) problem. One main contribution is the introduction of a systematic, explicit and dynamic representation of the physical environment in the problem definition. Different instantiations of the problem specify different transport applications. Indeed, consumers might have only access to a sub-part of their physical environment at a certain time, resources might be volatile, especially in a shared environment, and can therefore be taken by any close consumer and resources might be uncontrollable because they are created and released in a nondeterministic way.

A lot of applications can be modeled as an OLRA problem. Actually, a resource allocation problem that involves moving entities (resources or consumers) can be seen as an OLRA problem. For instance, in the search of charging stations for electric cars (Acha et al., 2011), the consumers are mobile (the electric cars), while the charging stations are the resources. In the sharing of vehicles (car, bike, etc.) (Katzev, 2003), both the resources (the vehicles) and the consumers (the drivers or the passengers) are mobile. The scheduling of aircraft landings to multiple run-ways (Beasley et al., 2000) can also be seen as an OLRA problem, where the run-ways are the resources and the planes are the consumers. Among all the applications that can be modeled as an OLRA, we are more particularly interested in the search of urban parking spots, in which spots have to be assigned to drivers. This is one of the most challenging OLRA problems. Indeed, the resources in this problem appear and disappear non-deterministically. In addition, to consume a resource, a driver has to drive to the spot location, with uncertain arrival time due to traffic conditions. The management of urban parking is identified as an important issue to improve the quality of life in urban areas (Bayless and Neelakantan, 2012).

To formally model and analyze the problem of urban parking management, we propose to define it as an OLRA problem. Indeed, the solution to a particular urban configuration implies the assignment of a set of parking spots (the resources) to the drivers (the consumers). In addition to the problem specification, we are interested in proposing an efficient solution to the problem. In this paper, we propose a multiagent transport information system that helps finding parking spots in an urban agglomeration.

The multiagent paradigm facilitates an approach by analogy in the transportation domain where one of the objectives is the coordination of distributed entities. This is why the multiagent approach is often chosen to model, solve or simulate transportation problems. This approach is particularly relevant for the management of parking spots, since the problem is indeed to take into account human behaviors that interact in a complex, dynamic and open environment. We propose a multiagent system that facilitates the information sharing related to parking for a community of drivers. In our system, agents communicate to exchange information concerning the parking spots availability. The information come from the users, while remaining anonymous, and their collaboration ensures an information of good quality. Our agent-based approach is totally decentralized and we employ an inter-vehicular communication (using VANET[1]) to allow vehicles to receive and broadcast information to the other vehicles of the same community. VANETs provide a bottom-up discovery of parking places. One advantage of our proposal is that it can be developed without any additional infrastructure. Our solution is able to function without initial information and ensure drivers to have information that are the most up-to-date possible.

This article is organized as follows. Section 2 defines the OLRA problem as well as the urban parking management problem. Section 3 presents the multiagent system solving the problem. Section 4 details our experimental results. Section 5 discusses the related works. Finally, Section 6 concludes this paper and provides some perspectives.

2. Problem definition

In this section, we detail the formal model of Online Localized Resource Allocation (OLRA) (Bessghaier et al., 2012b).

2.1. Description

Consider a set of resources and a set of consumers. Both resources and consumers appear non-deterministically and can subsequently change their position at any moment. Each resource has a state and a set of properties. An allocation changes the state of the resource but the properties that define it remain the same (Topaloglu and Powell, 2005).

[1] Vehicle Ad Hoc Networks.