Intelligent Transportation Systems – Maybe, But Where Are My Agents?

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Abstract. Significant advances in wireless communication technologies and mobile devices have led to their widespread use. For example, the so-called Intelligent Transportation Systems (ITS), which encompass a wide range of advanced applications for transportation, have attracted a lot of attention. In this context, one could think that software agents, which can have properties such as intelligence and autonomy, are expected to play a key role. But is this the case? Are they being used in work related to ITS and/or vehicular networks? Could they really provide benefits? In this paper, we analyze the state of the art and draw some conclusions about the potential interest of mixing these two fields.

Keywords: Intelligent Transportation Systems · Vehicular networks · VANETs · Software agents · Mobile agents

1 Introduction

Today, the car is indisputably the most heavily used mode of transportation. Unfortunately, its popularity has been accompanied by numerous problems, for example, in the areas of safety and the environment. Despite significant efforts to reduce the number of persons dying on the road, this number remains quite high, mainly due to the human factor (e.g., accident-prone behavior or impaired reaction time). To reduce the number of accidents, a variety of programs, generally involving *Intelligent Transportation Systems* (ITS) [1,2], have been initiated in Japan, Europe, and the United States, attracting the interest of researchers both in academia and in industry.

On the other hand, in the field of Artificial Intelligence (AI), *software agents* [3,9,10] represent a fundamental major effort to provide intelligence in the form of software programs that somehow mimic the behavior of people and act as their virtual representatives in the computer world. They exhibit features such as autonomy, social ability, reactivity, and pro-activeness. In other words, they are not merely passive objects but active pieces of software that pursue their own goals and behave in an intelligent way.

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Apparently, the aforementioned capabilities of agents make them a good fit to bring the intelligence that Intelligent Transportation Systems need. The interest of applying agents in the field of transportation is also highlighted in other papers. For example, [4] indicates that many problems in traffic management and control are inherently distributed and that many actors in transportation (drivers, pedestrians, traffic experts, and even intersection and traffic light controllers) could be considered as autonomous agents, and [5] indicates that the "autonomous and distributed nature of multi-agent systems is well-suited to the transportation domain which is dynamic and geographically distributed".

But what is the real impact of software agents on ITS? Are they really made for each other? In this paper, we try to explore this question and provide some insights that could help to understand the current state of the art. The structure of the rest of the paper is as follows. In Section 2 we provide an overview of the technological context that is relevant in this work, that is, ITS and agents. In Section 3 we describe the analysis of the literature that we have carried out to discover the existing relation between agents and ITS. In Section 4, we briefly describe some proposals that are based on the use of mobile agents. Finally, in Section 5, we provide some conclusions.

2 Technological Context

In this section, we provide a basic overview of the two topics whose relation we try to analyze. First we will focus on ITS (including vehicular networks), and then we will consider software agents (including mobile agents).

2.1 Intelligent Transportation Systems

ITS have attracted significant research attention. Independently of the specific technology used, the key point is that ITS tries to provide "intelligence" to improve the efficiency of transportation, the safety of the passengers, and the convenience of travelers.

Thanks to the resulting research, Advanced Driver Assistance Systems (ADAS) and Advanced Traveler Information Systems (ATIS) were born. Some of them are already available on the market (e.g., navigation systems, warning systems to alert the driver when he/she is about to fall asleep), and many others are under development. Nevertheless, ITS continues to be a hot spot of research and a major focus in initiatives and projects around the world, also as an important element of the so-called *smart cities*.

Within the context of ITS, *vehicular ad hoc networks* (*VANETs*) [6], where vehicles dynamically set up a network using short-range wireless communication technologies (e.g., WiFi, Bluetooth, or WAVE) to exchange different types of data, are expected to play a key role. Thanks to short-range wireless communication devices, the vehicles can quickly exchange data with others and even to transmit queries (i.e., requests of data) in a peer-to-peer way (i.e., without the need to deploy a costly support communication infrastructure and without incurring the economic cost derived from the use of technologies such as mobile telephony networks). Whereas this scenario opens up a number of opportunities for the development of interesting applications and services, several difficulties also arise, as this is a highly-dynamic network subject to frequent changes in its topology (e.g., two vehicles driving in opposite directions at high speeds will be within range of each other only during a short period, and therefore they should exchange data very quickly).

2.2 Software Agents

In this section, we first describe the general concept of *software agent* [3,9,10]. Then, we present a specific type of software agents that have the movement capability, which are called *mobile agents* [7,8].

Generic (Static) Software Agents. Wooldridge defines an agent as a software-based computer system that exhibits certain properties (which conform what he calls the *weak notion of agency*) [3]: autonomy (agents have control over their internal state and behavior), social ability (they interact with each other, using a certain agent communication language, and potentially also with humans), reactivity (they perceive their environment and are able to react to changes), and pro-activeness (they are not only reactive, but they can also act to pursue their own goals, even in the absence of changes in the environment). Moreover, a *stronger notion of agency* would imply attributing agents other features usually applied only to humans, such as their ability to have knowledge, beliefs, intentions, and desires.

Despite the existing controversy regarding the right definition of agent [9], most authors agree that autonomy is a required feature of an agent whereas other capabilities could be absent in some cases, and this autonomy requires some form of intelligence [10]. Although it is difficult to establish a precise definition of intelligence in this context, it is usually assumed that it should involve learning from past experiences to improve the behavior along time. There is also a strong emphasis on the cooperation aspects of agents, as they can accomplish complex task when composing *multi-agent systems* (MAS) [11]. For the development of agent-based applications, many *agent platforms* have been developed (e.g., see [12,13]), being JADE [14] one of the most popular ones nowadays.

Agents and multi-agent systems have been around for more than 20 years [15] and provide a nice abstraction suitable for the development of certain software systems, which gave rise to the emergence of the *Agent-Oriented Software Engineering* (AOSE) paradigm [16].

Mobile Agents. Mobile agents are software agents that have the capability to move from one execution environment (hosted in a certain computer or device) to another [7,8]. Thus, a mobile agent can stop its execution at a device, move to another device, and resume its execution at the destination. Thus, they are not bound to the computer where they were created; instead, they can move freely across different computers and devices along their lifetime. Only a specific middleware, called *mobile agent platform* [8], which is a server process that supports the execution of agents and provides them specific services (e.g., communication with other agents, security, a movement facility to support their mobility, a naming or directory service to search for agents, a persistence service, etc.), is required in the involved computer/devices.

The mobility capability makes mobile agent technology an ideal solution to design solutions for distributed and mobile computing environments [17]. Thanks to their mobility, mobile agents offer many interesting benefits [18], such as: *encapsulation* (they encapsulate tasks and can dynamically carry the required functionality to any device with a mobile agent platform, by moving there), *minimization of the network load* (they can move the computation to the data instead of the other way around, and therefore they can filter the data at the source in order to communicate only the data that are really relevant), *minimization of the network connections* (as they can perform their processing without accessing remote data, they minimize the amount of time during which network connections need to be kept active), *minimization of network latency* (they can move closer to a resource –e.g., a service, another agent, or a data source– in order to access it without much network delay), *asynchrony and autonomy* (a mobile agent does not need to keep contact with its source computer while performing its tasks, as it can live independently, and therefore for example the originating device can be turned off or go offline without any problem), *higher adaptability* (a mobile agent can adapt its execution, for example, by traveling to other computers/devices, due to different reasons such as to achieve load balancing).

Thanks to these features, they have also been considered as a very promising technology for mobile, wireless, and pervasive computing environments (e.g., see [19]). Therefore, they should be expected to play an important role in ITS.

3 Study of the Literature on Agents and ITS

We have analyzed several journals and international events related to both agents and intelligent transportation in order to see the relation between these two fields. Specifically, we have considered the following representative venues:

- J1: *Autonomous Agents and Multi-Agent Systems* journal (Springer).
- J2: *Transportation Research Part C: Emerging Technologies* journal (Elsevier).
- J3: *IEEE Intelligent Transportation Systems Magazine* (IEEE).
- J4: *IEEE Transactions on Intelligent Transportation Systems* journal (IEEE).
- J5: *Expert Systems with Applications* journal (Elsevier).
- C1: *IEEE Intelligent Vehicles Symposium (IV).*
- C2: *IEEE Conference on Intelligent Transportation Systems (ITSC).*
- C3: *Autonomous Agents and Multiagent Systems (AAMAS)* conference.
- C4: *IEEE Vehicular Technology Conference (VTC).*
- W1: *ACM International Workshop on Vehicular Inter-Networking, Systems, and Applications (ACM VANET).*

In Table 1 we show the number of papers that concern some aspect of ITS and agents at the same time, for each journal and conference/workshop, per year; for simplicity, we do not distinguish between different types of papers (e.g., full papers vs. posters or short papers). The symbol "–" is used for a conference/journal that did not exist yet that year or for a conference that has not been held yet (in the case of the year 2014); it should be noted that most journals will continue publishing papers in the remaining of 2014.

Table 1. Numbers of papers applying agents in transportation (sources considered)

Year	**Total**	**J1**	**J2**	**J3**	**J4**	**J5**	**C1**	**C2**	**C3**	**C4**	**W1**
2002	4	0	3	–	0	0	0	0	1	0	–
2003	3	0	0	–	0	0	0	1	2	0	–
2004	2	0	0	–	0	0	0	0	2	0	0
2005	13	1	2	–	0	1	0	0	9	0	0
2006	1	0	0	–	0	0	0	0	1	0	0
2007	2	0	0	–	1	0	0	0	1	0	0
2008	1	0	0	–	0	0	1	0	0	0	0
2009	5	1	1	1	0	0	0	0	1	1	0
2010	11	0	3	0	2	0	1	0	5	0	0
2011	11	0	0	0	3	0	1	0	7	0	0
2012	2	1	0	0	0	0	0	0	1	0	0
2013	5	0	1	0	2	1	0	0	1	0	0
2014	3	0	1	0	0	1	–	–	1	–	–
Total:	63	3	11	1	8	3	3	1	32	1	0

If we consider the total number of papers published in the journals and international events considered per year, we can reach the conclusion that the actual percentage of papers applying agent technology in the context of ITS is quite low.

In the following, we will show in more detail some of the different papers identified as relevant (i.e., dealing with both agents and transportation) in our study (due to the lack of space, we only select a subset of such papers). In Table 2 we show some data for the relevant papers found in the journals, conferences, and workshops selected in our study. In column "Reference" we indicate the reference to the work (a value *MA* in brackets next to the reference indicates that mobile agents are considered in that work). In column "Focus" we indicate the main concern of the work mentioned: traffic signal control and coordination, such as the coordination of traffic lights to optimize the traffic flow (value *TSC*); intelligent traffic management and coordination, such as route guidance to solve local traffic problems such as traffic congestion (value *TM*); intelligent transportation systems in general (value *ITS*); traffic information systems (value *TIS*); road safety (value *RS*); and design and planning of transportation systems (value *DTS*); it should be noted that we are not covering all the possible topics in the table, as we also identified some papers focused on simulation. In column "Infrastructure" we indicate the basic underlying infrastructure considered, such as *road*, *water*, and *air*; although we are mainly interested in terrestrial transportation, for completeness we also consider other scenarios. Finally, in column "A few key ideas" we collect some basic ideas of the proposal.

As shown in the tables, many identified proposals deal with traffic management, which basically tries to distribute traffic in the network (based on the demand, supply, and capacity at different locations) through information broadcast (to influence the route choice), control (e.g., traffic signals, variable message signs), and optimization (e.g., operational parameters of traffic lights, route planning) [4].

Table 2. Relevant papers in the journals, conferences and workshops considered

Reference	Focus	Infrastructure	A few key ideas
Journals			
[4]	TSC, ITS	road	Agentification in transportation. Survey of methods and problems.
[20]	TSC	road	Centralized vs. agent-based control. Evolutionary game theory.
[21]	TSC	air	Agent-based air traffic management. Learning. Reward structure.
[22]	TM	road	Adaptive vehicle route guidance. Ant colony behavior. Fuzzy model.
[23]	TM	road	Centralized vs. agent-based control (integrated TRYS, TRYS agents).
[24]	TM	road	Agent-based DSS (Decision Support Systems). Transport prototypes.
[25]	TM	urban roads	Generic model of a traffic regulation support system.
[26] (MA)	TM	road	Integration of mobile agents (FIPA-compliant Mobile-C) and MAS.
[28]	TM	air, road, water, rail	Survey of agent-based approaches for transportation. Logistics.
[29]	TM	air	Efficiency of communication, delays of flights.
[30]	TSC	urban roads	Linear dynamic systems. Graceful extension, localized reconfiguration.
[31]	TM	air	Air Traffic Management. Reinforcement Learning (RL). Rewards.
[32]	TM	freeway roads, streets	Distributed cooperative problem solving. Cartesius.
[33]	TM	road	Cooperative traffic management instruments, modeled as agents.
[34]	TM	road	Traffic guidance using VMS (Variable Message Signs). Based on SWARM.
[35] (MA)	ITS	road, rail and air	Survey. Modeling and simulation vs. real-world applications. Interest of MAs.
[36]	TSC	road	Multi-agent reinforcement learning. Agents as controllers of traffic lights.
[37]	TM	road	Coordination for anticipatory vehicle routing (avoid congestion). Ant behavior.
[38]	TSC	urban roads	Geometric fuzzy multi-agent system. Simulation models in PARAMICS.
[39]	TM	road	Integration of agent organizations and services for transportation management.
[40]	TM	road	Congestion Avoidance and Route Allocation using Virtual Agent Negotiation (CARAVAN).
[41]	TM	urban roads	Competitive market. Driver agents negotiate the use of intersections.
[42]	TM	air	Conflict resolution for intersecting flows. Planar space partition.
[43]	TIS	road	Architecture-centric method to develop MAS. Applied to ITS.
[44]	RS	road	Exchange info between vehicles and road nodes. Detect vehicles driving in the opposite direction.
[45]	DTS	urban roads	Demand Responsive Transport systems (DRT). Flexible optimized routes.
Conferences and Workshops			
[5] (MA)	TM	road	Classification of multi-agent techniques. Suitability for congestion management.
[46]	TSC	urban roads	Intelligent agents for coordination of traffic lights. Hierarchical architecture.
[47]	TM	urban roads	Demand Responsive Transport (DRT). Multilayer distributed hybrid planning.
[48] (MA)	ITS	road	Overview of ITS applications where multi-agent systems may impact.
[49]	TSC	urban roads	Multi-agent history-based traffic light controllers. Global fairness.
[50]	TM	air	Agents associated to specific locations set the separation required among airplanes traveling nearby. NASA's FACET simulator.
[51]	TM, RS	urban roads	Reserve space and time at intersections for safe crossing. Driver agents trade with infrastructure agents in a virtual marketplace.
[52]	TM	road	Coordinated look-ahead scheduling. Optimize traffic approaching intersection. Consider non-local impacts from indirect neighbors.
[53]	TM	air	Managing delay in airports. Autonomous partitioning of agents using system features.
[54]	TM, TSC	road	Pheromone-based traffic management model. Optimize vehicle re-routing and traffic light control. Forecast traffic conditions.
[55]	TSC	urban roads	Cooperative multi-agent fuzzy system. Decentralized traffic signal control to minimize traffic congestion. NetLogo-based traffic simulator.

It is worth mentioning that from all the papers identified as relevant, only [40] considers the use of ad hoc wireless communication technologies explicitly; other papers either do not consider it or do not mention the details of the communication infrastructure used. This scarce impact of agent technology on vehicular ad hoc networks can also be noticed if we observe the absence of relevant papers identified in W1 (see Table 1), which is a workshop focused on VANETs. It is also a bit surprising that, even though all the papers indicated consider the use of multi-agent systems, only a few of them actually mentions the use of a specific agent platform, such as:

– *MadKit* (*Multiagent Development Kit*, http://www.madkit.org/) is used in [22] for simulation purposes.
– *Mobile-C* (http://www.mobilec.org/) [56] is used in [26].
– *JADE* (*Java Agent DEvelopment Framework*) [14] is used in [24,36,40,43,44].

The reason is that in many occasions a specific platform does not seem necessary, as the proposal focuses on the application (or at least consideration) of techniques and methodologies from multi-agent systems in a real environment where the agents are the real entities involved (drivers, pedestrians, traffic lights, etc.). According to [35], most agent-based applications in the context of transportation focus on modeling and simulation.

Moreover, as can be observed in the tables, only a very reduced number of papers published in the journals and venues considered use mobile agents [5,26, 48], despite their potential interest in the context of ITS. Interestingly, the review presented in [35] emphasizes that "mobile agents can enhance the ability of traffic-control and management systems to handle the uncertainty introduced in a dynamic environment"; in particular, it indicates the interest of encapsulating functionalities within mobile agents to facilitate their dynamic deployment on remote machines. Notice also that some proposals (e.g., [42]) may also use the term "mobile agent" to refer to physical entities that move rather than to the concept of software agent that has the capability to change from one execution environment (computer or device) to another.

4 Mobile Agents in Transportation

In this section, we briefly describe some work that illustrates interesting approaches regarding the application of agents in the field of ITS. We focus on the application of mobile agents in the context of transportation because, as indicated in Section 2.2, mobile agents are software agents with the mobility capability, which in principle makes them ideal candidates to develop applications for the dynamic scenarios found in transportation. However, according to what was mentioned in Section 3, mobile agent technology has not achieved a significant impact on transportation research so far.

The work presented in [26] proposes the integration of mobile agents with multi-agent systems to improve the ability of traffic management systems to deal with the inherent uncertainty that arises in dynamic environments that are continuously changing. So, it basically uses mobile agents as a way to encapsulate updated code and algorithms that can be delivered dynamically to the intended systems as needed. The authors indicate that "to the best of our knowledge, the mobile agent technology has not been applied to this field" before. The work presented in [27] proposes the use of *context-aware migratory services* that migrate transparently due to context changes (similar to the concept of mobile agents); the authors present TJam as a proof-of-concept example that predicts traffic jams in a highway.

The proposal in [57] motivates the interest of using mobile agents in vehicular networks for environment monitoring. The idea is to exploit sensors available in conventional cars to flexibly monitor the environment. So, it tries to benefit from the fact that the number of sensors available in cars is continuously increasing: according to [58], "Today's luxury cars have more than 100 sensors per vehicle". Instead of manually deploying a set of static sensors in the area that has to be monitored, which would be expensive and time-consuming, agents travel to cars moving through the interesting area and exploit their sensors dynamically.

The proposal in [59] attempts to generalize the ideas presented in [57] by considering general query processing tasks in vehicular networks. The goal is to exploit information available on the vehicles, which are considered as data sources that can provide interesting information about events and other elements relevant for drivers (e.g., the surrounding traffic and the environment, the available parking spaces, etc.). To make this a reality, significant challenges arise from the point of view of data management: it is necessary to communicate a query to the relevant vehicles, retrieve the relevant data from such a distributed and highly-dynamic network, and bring back those data to the vehicle that originated the query. Although mobile agent technology could provide significant benefits to accomplish these tasks (thanks to the adaptability of mobile agents to mobile environments, their mobility, autonomy, and intelligence), its potential and the associated difficulties should be researched in more depth.

As short-range ad hoc wireless communications are exploited in these last proposals, mobile agents must hop from car to car until they arrive in the target area, collect measures, and then come back to the monitoring station with the data collected. A mobile agent could keep itself in a certain car while the car is within the area to monitor, but if the car gets out of the area it will have to find a way to come back to the area (again, by jumping from car to car). So, mobile agents move both thanks to the locomotion of the vehicles (by staying in a car that moves) and thanks to the wireless communications (by jumping to another car nearby). They use vehicles as "taxis" and as monitoring instruments when they have the required sensors and the vehicles are within the area to monitor.

Therefore, a key issue is the need of appropriate *jumping policies* for agents, that is, suitable mechanisms that allow agents to decide between jumping and staying, and in the case of jumping select a promising target.

5 Conclusions

In this paper, we have studied the relation between software agents and transportation. Based on our study, we agree with the conclusions from [28,35] that indicate that agent-based approaches seem suitable in the transportation domain but there are very few real deployed systems. It is also worth noticing that mobile agents have had for the moment a limited impact on the transportation field. The same can be said about the use of (generic) agents in VANETs.

The analysis presented in this paper should be regarded with certain caution, due to its limited scope (we mainly focused on a fixed set of journals and venues related to the transportation and agent fields). Moreover, it is complementary to other surveys published. For example, [35] reviews the application of agent technology in traffic and transportation systems, considering several issues affecting traffic and transportation systems (modeling and simulation, routing and congestion management, intelligent traffic control), and covers different modes of transportation (roads, railways, air). Another interesting overview of the applications where multi-agent systems could be useful is presented in [48].

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