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AGENT-BASED APPROACH FOR CONNECTED VEHICLES AND SMART ROAD SIGNS COLLABORATION

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Abstract. Road traffic is drastically increasing in big cities around the world. In order to enable a flexible management of this traffic, Intelligent Transportation System (ITS) solutions are relying on emergent ubiquitous, mobile, and communication technologies, particularly to intelligently deal with the limited capacities of the existing road infrastructures. While intelligence is left to the autonomous and connected vehicles as well as to the ITS, the road infrastructure has been mostly playing a passive role (as a source of data). Road signage, in particular, are in best cases dynamic but do not play an active role in monitoring traffic and incidents. We propose in this paper to build Smart Road Signs (SRS) that can collaborate with Connected Vehicles in order to monitor traffic and warn drivers about any incident or danger. Our SRSs are meant to operate autonomously in order to detect road traffic problems, share appropriate information with vehicles in the vicinity, and display relevant messages based on the ongoing contextual situation. To meet our goals, we rely on Multi-Agent Systems to design SRSs as proactive components in the ITS landscape. We also rely on agent mobility in order to strengthen the collaboration with the connected vehicles.

Keywords: Connected vehicle, multi-agent system, mobile agent, intelligent transportation system, smart road sign

1 INTRODUCTION

The transportation sector has always been at the heart of the economic and social development of countries, whether through infrastructure, modes of transport or services offered to customers. With the ongoing trend towards smart cities around the world, transportation is attracting an increasing interest from researchers and decision-makers alike to make it even smarter. As a result, new generations of Intelligent Transportation Systems (ITSs) are being deployed, particularly based on emergent technologies like the Internet of Things (IoT), Big Data, and Artificial Intelligence. ITS can be defined, according to Perallos et al. [1], as a term which "encompasses the set of applications that make use of information and communication technologies in the field of transport with the aim of obtaining economic social and energy benefits". An ITS, which can be applied to all transportation means, may involve vehicles, drivers, passengers, and infrastructure [1]. ITS has even gained more importance with all the technological innovations that the automotive industry has witnessed over the last few years. In particular, new vehicles are more and more equipped with communicating systems, which has introduced the notion of connectivity into the traditional transportation ecosystem, hence the term Connected Vehicles (CV). The CV concept is allowing vehicles to wirelessly communicate with objects from the surrounding environment (V2X), such as other vehicles (V2V), the infrastructure (V2I), and pedestrians (V2P) [2, 3]. Thanks to the ongoing advances in communications, sensing, and computing, vehicles are expected to serve as data/service production platforms in the future, capable of generating rich data, operating through inference, and driving significant changes in mobility, human-vehicle dynamics, climate, and the economy [4]. However, although connected and autonomous vehicles would ultimately transform the transportation sector [5], this may take some time as the diffusion of intelligent cars is still limited.

The abovementioned technological developments have not been limited to vehicles only. In fact, the road infrastructure has seen massive advances brought by new technologies such as IoT. These advances have particularly enabled to partially overcome the limited capacities of the existing infrastructures as well as the embodiment of some intelligence within its components. Initially, wired sensors were used to monitor and/or manage road traffic, but because of the relatively high cost of the installation [6], wireless equipment has been introduced. However, a major constraint of wireless sensors is the limited battery life and the high cost of replacement, which makes these systems often cost prohibitive [7, 8]. Besides, while modern roads/highways are equipped with such sensors, there is still a need to monitor traffic and incidents in the road network sections where IoT devices are unavailable. To meet this goal, we argue in this paper that road signage can play an important role. More specifically, road signs may support ITS operations by providing dynamic alerts to drivers about changing events and situations. The effectiveness of Dynamic Message Signs (DMS) in the management, safety, and monitoring of road traffic has been highlighted by several studies (e.g. [9, 10, 11]). While most scientific studies focus on bringing intelligence to the vehicle, road signs are considered as passive elements that can be decoded and interpreted by intelligent vehicles by using, for example, deep learning and neural network algorithms (e.g. [12, 13, 14]). In this paper, we therefore propose to bring intelligence to road signs and enable them to become active components in the ITS. Our vision is supported by some recent works ([15, 16]) where a number of intelligent road signs systems have been proposed. However, the intelligence of these signs remains very limited, particularly in terms of autonomy, proactivity, and decision-making. In order to enhance these aspects, we will rely on the Multi-Agent System (MAS) paradigm that has already proven its efficiency in bringing intelligence to ITS and its applications (e.g., [17]). For instance, static and mobile agents were used in [17] to manage data routing between cars (V2V) to determine the shortest travel time. Agents, based on the BDI (Beliefs, Desires, Intentions) architecture [18], are also known to be effective in controlling traffic light systems. In the present paper, we propose to use software agents and agent mobility to enable collaboration between Connected Vehicles and Smart Road Signs in order to monitor traffic and incidents in parts of the network which are not covered by sensors/cameras.

In the reminder of this paper, Section 2 discusses some related works. Section 6 presents the internal architecture of the proposed Smart Road Sign (SRS). Section 4 explains how agents are using to support the collaboration between CV and SRS. Section 5 concludes the paper and presents our future works.

2 RELATED WORKS

Several works have proposed an architecture for "smart" or "intelligent" traffic signs. Czyżewski et al. [15] have recently described a system based on intelligent road signs that can exchange data collected by dedicated sensors (using LTE and LoRa WAN technologies) in order to help managing the road traffic. The system is composed of communicative modules and a microcomputer that ensures the execution of each step of data processing received from external electronic sensors. A similar system was proposed in [16] where intelligent road signs, which are equipped with a variety of sensors and adaptive LED Display, can communicate with each other. In [19], the authors proposed an architecture consisting of four modules which aim at providing drivers with relevant data about temperature and humidity. Although the label "intelligent" has been used to describe these new road signs, most of these road signs are still playing a passive role and do not implement any autonomy, proactivity, or decision making, which may make them intelligent.

As Multi-Agent Systems (MASs) have brought intelligence to many other research fields, they have been also used to improve many aspects and components of ITS. In [20], a multi-agent driving simulation methodology was proposed to assess the safety benefits of providing alert information by examining vehicle encounters, which are described as the behavioral changes between the subject vehicle and the vehicle ahead of it. In [21], a multi-agent system was used to address traffic at intersections. An Internet of Agents (IoA) framework for connected vehicles was then proposed and where each connected vehicle behaves as a collaborative and communicative agent to improve V2V communication. In [22], a MAS based approach was used to improve the driving experience by minimizing the traffic congestion after analyzing the forecasts in a more direct and efficient way. In [23], an architecture based on a MAS and big data analysis was proposed to exploit, analyze and process the data accumulated by sensors in a smart city, including those provided by connected vehicles and/or those equipped with integrated sensors. MASs have been also integrated into the architecture of real-time autonomous vehicle infrastructure simulation plat-forms [24, 25] and used to evaluate the impact of V2V and V2I technologies on the mobility performance [26].

Moreover, when agents are also capable of physically moving between nodes, they may offer even more advantages. Thanks to their mobility, autonomy, and flexibility, mobile agents have been used to support ITS in general, and connected and autonomous vehicles in particular. In an early research work [27], the authors showed how mobile agents can be used by vehicular networks to process data that needs to be collected from different nodes. Later, the same authors proposed a new approach [28] where they use mobile agents to process queries in vehicular ad hoc networks. Typically, a mobile agent associated to a certain vehicle will move between nodes to collect and process any relevant data to the considered query (e.g., get the pollution rate or find a parking space). In [27], autonomous vehicles make decisions partially based on information they are sharing between each other and by using mobile agents. These agents collect and process data over the Edge Computing. In [30], a combination of mobile and static agents is used in order to establish trust in vehicular networks. Mobile agents were even used to control traffic congestions under a VANET scenario [31].

In the next two sections, we propose to use mobile agents and Smart Road Signs and make them collaborate with connected vehicles in order to collect data and monitor roads.

3 SMART ROAD SIGN ARCHITECTURE

As mentioned in Section 2, the existing "Smart" Road Sign architectures, intelligence has not been supported adequately. For this reason, we propose in this paper the architecture depicted in Figure 1.

The core of our architecture is the Intelligent Management Module (IMM) which represents the "brain" of the Smart Sign. The architecture includes the following modules.

Display Module (DM): In the sign panel it displays the information received by the IMM which is destined to the drivers.

Power Module (PM): It provides power to all the physical parts of the road sign. This module may rely on conventional power or solar power.

Multi-Agent System Module (MASM): It hosts and manages the incoming and outgoing mobile agents. More details will be provided in the Section 4.2.

Communication Module (CM): It allows the road sign to communicate with external entities such as other road signs to exchange information. In particular, it facilitates the migration of the agents of the MASM.

Data Accumulation Module (DAM): It reassembles data collected by the road sign sensors as well as data obtained from different APIs (e.g., Traffic API, Weather API) that provides the road sign with relevant data when available.

Data Organization Module (DOM): It transforms data collected by the DAM into supported formats and then stores it in a local database.

Intelligent Management Module (IMM): It takes input from the DAM/DOM (data collected by sensors and external APIs) and the MASM (data collected by mobile agents) in order to take decisions about what to display in the road sign panel (to the drivers) and what tasks to delegate to the MASM in order to collaborate with the CVs as well as the other road signs in its vicinity. Decisions are also made based on the current context (timing, location, weather conditions, etc). As data displayed to the drivers is critical, the IMM has to make sure that the received data is trusted and all data exchanges are secure. The IMM is thus composed of 4 units, namely, Processing Unit, Context Awareness Unit, Collaboration Unit, and Security Unit.

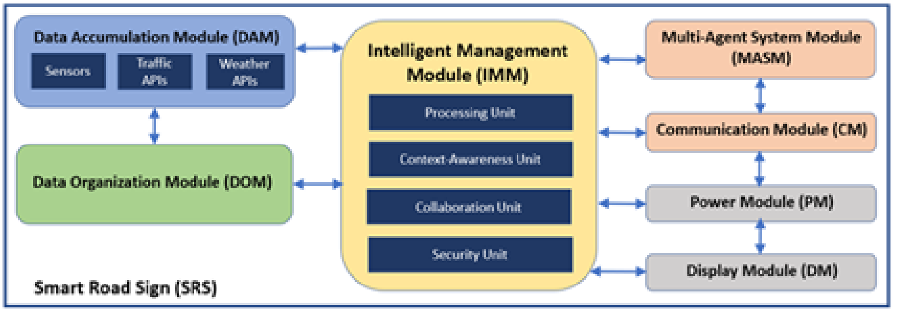

Figure 1. Smart Road Sign (SRS) architecture

The next section describes our approach on how to use Smart Road Signs in conjunction with Connected Vehicles (CVs) in order to monitor roads, detect incidents, and warn drivers. Regarding the functioning of the Smart Road Sign, we mainly focus on the Multi-Agent System Module (MASM) though. Details about the other modules will be presented in future publications.

4 PROPOSED APPROACH

4.1 Motivating Scenario and Hypotheses

In most V2V existing systems, when for example a car suddenly detects an incident (e.g., an obstacle on the road), the car sends a message to all the other cars of its vicinity. The road signs are thus not actively involved. Indeed, current "smart" panels are mostly passive and are not yet able to make decisions on their own; they only display data collected by external sensors.

Nevertheless, involving further the road signs by making them more autonomous and allowing them to be an active part of the process, can be very effective in many cases and scenarios. For instance, regarding the scenario mentioned above, the car may also send a message to a smart road sign. The Road Sign may then analyze the message (check its relevance, its trustworthiness, etc.) and display a warning message to all drivers heading to the obstacle while taking into account all contextual constraints. This also gives more reachability to the warning message as it can also reach cars which are not connected. Another plausible scenario involving smart road sign could be the automatic enforcement of unlawful cars. For instance, if a truck or bus is not in the correct lane, the Smart Road Sign may display the specifics and a personalized message to the errant vehicle. To illustrate our approach, we will rather use the first scenario, where a connected vehicle detected an obstacle on the road. The hypotheses are as follows.

1. The considered road section (between one to few kms) is not monitored by any sensors/cameras.
2. The road section is bi-directional and delimited by one Smart Road Sign (Section 6) at each extremity. Smart Road Signs are within the communication range of each other and can thus communicate with each other or send mobile agents to each other.
3. Vehicles using the road section are both connected and not connected vehicles. Some of the connected vehicles allow the mobile agents coming from the Smart Road Signs to access their data.

4.2 Agent-Based Collaboration Phases

In this section, we demonstrate how software agents are utilized by Smart Road Signs and connected vehicles in order to collaborate through different phases. The idea

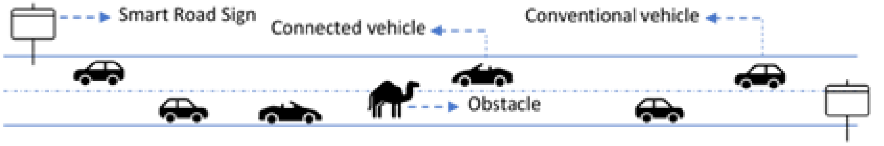

Figure 2. Illustrative scenario

is that the SRS creates mobile agents (SRS_agents) which will be sent to different CVs in order to collect data and monitor the road section. These mobile agents are able to physically move between CVs and ultimately return back to their SRSs. For the sake of simplicity, we describe our approach by using one SRS_agent. Figure 3 illustrates all the operational phases that SRS_agent has to go through in order to accomplish its task. These phases are detailed below.

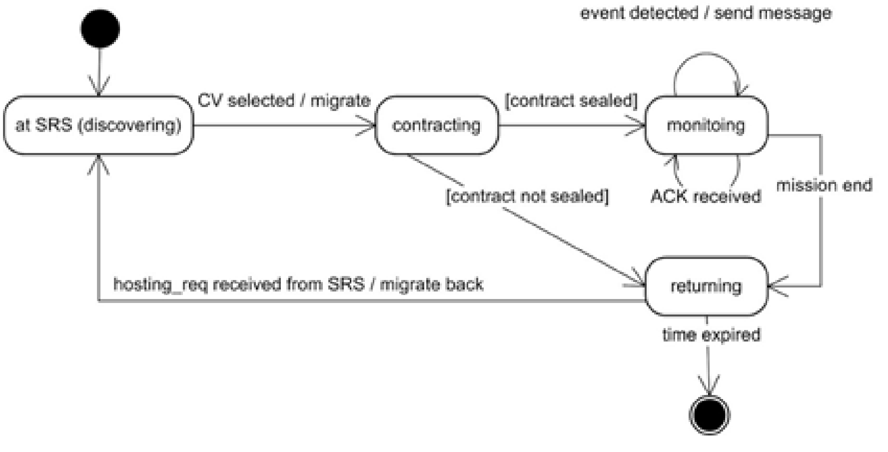

Figure 3. State diagram of SRS_agent showcasing phases 1_4

Phase 0: Joining

We here suppose that the owner of a connected vehicle CVi, who is willing to cooperate with Smart Road Signs (SRSs), has to install a piece of software issued by the concerned authorities (owner of the SRSs). This software is basically a software agent CV_agent which will be the interface between the connected vehicle and the SRSs. The car owner has to configure CV_agent by setting up his preferences and in particular data (e.g., car identity, driving history) and resources (e.g., car's sensors) to which CV_agent would have access to. For the sake of simplicity, we represent them by a list of services Si.

Phase 1: Discovering

We suppose here that some connected vehicles have already agreed to cooperate with SRSs (see phase 0). In this first operational phase (illustrated in Figure 4), the SRS has to find a connected vehicle which is able to host its mobile agent (SRS_agent). First, the SRS, represented here by its Multi-Agent System Module (MASM), broadcasts a hosting request message (hosting_req(srs_source, srs_priv_key)) to cars in its vicinity. When a connected vehicle CVi, represented by its agent CVi_agent, receives the request, it may ignore it or accept it depending on its registered preferences. In this latter case, and after making sure that the private key srs_priv_key is really coming from a Smart Road Sign, CVi_agent has to send a hosting acceptance message hosting_accept(id_cvi, cvi_agent, Si, Ki) to the SRS. This message contains a unique key Ki which has been generated by CVi_agent as well as the list of services Si that the car may help the SRS with.

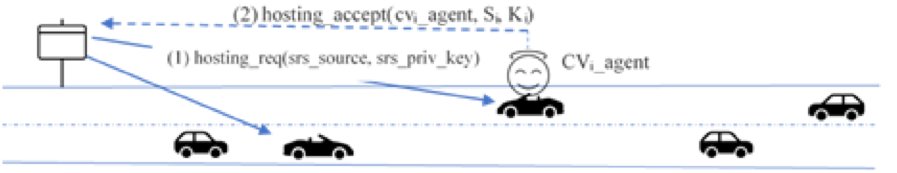

Figure 4. Illustration of the Discovery phase

Phase 2: Contracting

The SRS may receive many hosting_accept messages from different connected vehicles. The MASM module will have then to choose which connected vehicles it wants to collaborate with depending on the services they are willing to offer (expressed by respective Si). For the sake of simplicity, we describe the Contracting mechanism with one selected connected vehicle CVi. MASM creates then a mobile agent SRS_agent and the Communication Module (CM) takes in charge the task of securing the agent (encrypting its code) and physically sending it to the hosting vehicle CVi. The SRS_agent, once physically in the hosting vehicle, has to prove that it is really coming from the claimed SRS by presenting the key Ki to the vehicle's agent CVi_agent. If the key is authentic, CVi_agent provides SRS_agent with access to the promised services Si. The connected vehicle will get in return some rewards which will be discussed in Section 4.3. A contract is thus sealed between the SRS and CVi via their representatives SRS_agent and CVi_agent, respectively. SRS_agent sends a message contract(id_CVi, Si) to its SRS to confirm that the contract is sealed. This will be used by the SRS to reward the collaborative CVi (see Section 4.3). As this message may not reach its destination (e.g., if SRS is out of communication range), SRS_agent keeps a copy of the message and will deliver it once it migrates back to its parent SRS. Figure 5 illustrates the Contracting phase.

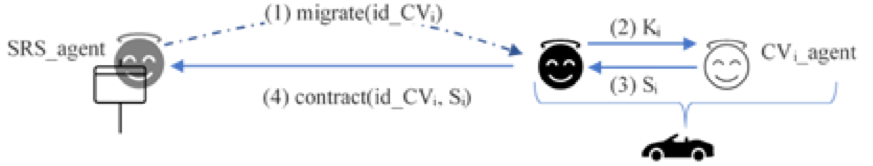

Figure 5. Illustration of the Contracting phase

Phase 3: Monitoring and Reporting

While the hosting connected vehicle is moving, SRS_agent collects relevant data from CVi_agent. Depending on the agreed contract, data may include current vehicle speed, braking behavior, detected obstacles, vehicle identity and properties, etc. When SRS_agent detects critical data (e.g., presence of an obstacle or traffic jam), it broadcasts, using the hosting vehicle communication infrastructure, a message to_srs_msg(id_msg, id_CVi, SRS, type, content, expiry_time) where it specifies the source (hosting CV) and the destination (here the parent SRS) as well as the type of message (e.g., obstacle) and the message content (e.g., location) (see Figure 6). Depending on the communication range, this message may directly reach its final destination (the parent SRS) or another SRS. In the latter case, the SRS analyses the message to see if the content is relevant to its own context, and then forwards it to the SRS destination. However, the hosting CV may not be within the communication range of any SRS and may not be in the near future (e.g., the vehicle has stopped). For this reason, any connected vehicle in the road which receives this message (to_srs_msg()), will try to forward it to any SRS as soon as it is within any SRS range.

Being within a certain SRS range is known once the connected vehicle receives a hosting_req message from that SRS. In order to avoid flooding the network with forwarded and redundant messages, each connected vehicle will destroy any stored to_srs_msg() message of which the expiry_date is over. In addition, when an SRS receives the message, it broadcasts an acknowledgement msg_ack(id_msg). Any connected vehicle or SRS_agent which receives this acknowledgement will then know that the message was received by the SRS network and will then stop forwarding the message. Finally, the IMM module of the SRS processes the received message in order to decide whether an action is required (e.g., displaying a warning to incoming drivers and/or notifying other SRSs) or not.

Phase 4: Returning

Even if no incidents were detected, the SRS_agent will still have to report collected data to its SRS, which would end its mission. Then, SRS_agent will have to run the algorithm return_to() (see Figure 7) in order to return back to its parent SRS or, in the worst case, to another connected vehicle which is coming

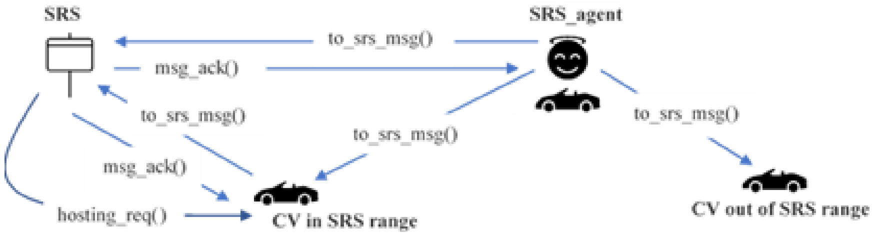

Figure 6. Illustration of the incident reporting (messages parameters omitted for simplicity)

from the opposite direction (this will increase the chances of SRS_agent to reach its SRS). In this latter case, the agent may decide to collect data from the new host or to return back to its SRS if it enters its communication range. In case it fails within a certain period of time to reach its initial SRS, the SRS_agent destroys itself in order to avoid overloading the network with infinite messaging and agent migrations.

```
Function return_to (SRS, expiry_time) {
   While expiry  time not over and new msg received
      //the SRS_agent is still within the communication range of its SRS
      if (msg == hosting  req(srs_source, srs_priv_key) and srs_source == SRS) {
            migrate_to(SRS);
            deliver collected data to SRS;
            return;}
      //the SRS_agent is within the communication range of another SRS
      else if (msg == hosting  req(srs  source, srs  priv  key) and srs  source != SRS) {
            migrate_to(srs_source); //migrate to another SRS without sharing collected data
            wait to be sent by srs_source to SRS;
            return; }
      //another CV accepts to host the SRS_agent
      else if (msg== hosting_accept(cvi_agent, Si, Ki) and CV coming from opposite direction ){
            migrate_to(cvi_agent);
            return;
      } else { wait for a new message msg for max t seconds;
            hosting_req(srs_source, srs_priv_key); //send a request to move to another CV}
   }//end while loop
   Self destroy //if time expires and agent was not able to reach destination
}
```

Figure 7. Algorithm used by SRS_{agent} to migrate back to its SRS

4.3 Rewarding System

The whole idea of collaboration between the SRS and the CVs depends on whether CVs accept to host SRS_agents or not (joining phase). To encourage drivers to enrol their vehicles, a rewarding system is then needed. This system should keep track of the number of SRS_agents hosted as well as the services that the CV is providing to these agents. Practically, SRS_agent confirms, via contract(id_CVi, Si), to its SRS that a contract has been sealed with a given CVi (either by sending a message from he hosting CV or once returning back to its SRS). The MASM module transfers the information to the IMM module (see Figure 1) which processes a score score(Si) depending on the services that the CVi is willing to offer to the SRS_agent. The score is then stored in the SRS' database as a pair (id_CVi, score(Si)). If the CVi has already an entry in the database, the score is accumulated. CVs can also be rewarded (with a different scoring scheme) for sending/forwarding to_srs_msg() messages (see phase 3). Periodically (e.g., once per day), SRSs sends (id_CVi, score) entries to a central unit (e.g., police system) which aggregates the scores per vehicle and adds them to the previous entries. SRSs, after transferring their data, have to delete all their local entries.

To be more specific, let us assume that the overall traffic ecosystem between two SRS is offering n services $(S_1, S_2, \ldots, S_n)$. Let us also assume that the contribution of a given vehicle V_j in a given service S_i is c_{ji}. We are assuming in this paper that for every service S_i, the maximum reward is R_i. This maximum reflects the fact that rewards could be translated into financial benefits (e.g., discounts on insurance cost), and, thus, must be capped. The reward R_i is calculated as the tradeoff between the supply and the demand for the service S_i as well as the cost of the service and any related overhead:

$$R_i = f(supply_i, demand_i, cost_i, overhead_i).$$

The specific reward that will be obtained by V_j for its contribution in service Si will be calculated as follows:

$$r_{ji} = C_{ij} * R_i.$$

An advanced rewarding scheme could be designed in order to allow an agent of a given vehicle to provide services during unexpected events and/or emergencies (e.g., road accident, vehicle willing to drop its contract as specified in Section 4.2).

4.4 Collaborative Context-Awareness

Several definitions have been given to the concept of context. One of the earliest ones was proposed by Giunchiglia [37] who defined it as the partial and approximate representation of the world. Other definitions presented the context as "any information that can be used to characterize the situation of an entity, where an entity can be a person, place, or physical or computational object" [38]. More recent definitions have included additional features that reflect, for example, a set of observable real world parameters (e.g., temperature, velocity, location, etc.) as well as user's preferences, emotions, behaviours, and goals [39]. These features have been classified by Schmidt et al. [40] into six high-level categories. The first three categories, which relate to the user, are information about the user (e.g., habits, biophysical conditions), his/her tasks (e.g., goals, current actions), and his/her social environment (e.g., co-location with other users). The other three categories are about the physical environment. More precisely, they concern the location, the infrastructure (e.g., resources), and the physical conditions (e.g., light, weather, noise). We define in this paper the context as $C = (C1, C2, \ldots, Cn)$, where Ci is a context type, such as location, time, speed, etc. It will be mainly used by the context-awareness unit, which is responsible of assessing the ongoing road traffic conditions. To this end, this unit receives frequent updates from the onboard sensors of the SRS, the agents sent to the different vehicles, as well as from neighbouring SRSs. Updates are then compiled and the necessary changes will be shared with the relevant agents, vehicles, and SRSs.

Let us assume that an agent x will provide a tuple $\langle i_t, x_t \rangle$ to its SRS about a context type t, where i_t denote the information about t and x_t denote the agent's rating (or assessment) of this information. We assume that all the ratings are normalized. The rational behind sending the ratings to SRS is that every agent is in a better position to assess the ongoing information than the SRS. In order to cross-check the information reported by the agents, the SRS will compare the data reported by the agents in order to assess its accuracy. More specifically, the SRS will use the Pearson correlation coefficient. This approach, which measures the degree of a linear relationship between two variables, is commonly used to weight user similarity. The Pearson coefficient for the rating of a given context type t by two agents x and y will be:

$$r(x, y) = \frac{m(\sum_t x) - (\sum_t x)(|sum_t y)}{\sqrt{[m \sum_t x^2 - (\sum_t x)^2][m \sum_t y^2 - (\sum_t y)^2]}}$$

where $\alpha_(d(C_x, C_y))$ reflect the impact of the distance $d(C_x, C_y)$ in space and time between the context of x and the context of y.

Based on the Pearson coefficients calculated for the ratings of the agents, the context-awareness unit will process the information received and generate a better idea on the ongoing road traffic context. It will then send any relevant updates to the agents via the collaboration unit.

5 OPPORTUNITIES AND CHALLENGES

In order to demonstrate the performance of our solution, we created a proof-of-concept where the data accumulation module is using the Heltec board. This board contains an ESP32 module that can provide a wireless connection to the Internet. The access to available API services (mainly here Mapbox) is achieved through the HTTPS protocol. HTTPS ensures the security of transactions by encrypting the entire communication with the SSL protocol. The communication module is relying on a LoRa network to ensure lightweight, long-range, secure communications between the SRSs. The undergoing implementation of the intelligent capabilities of the proposed solution is being performed with the GAMA multi-agent system platform, based on the survey presented in [41]. In spite of its limited capabilities, our current prototype is showing promising initial results. We argue that its complete implementation would lead to several opportunities. These opportunities would face a number of challenges that need thorough investigations. We outline in what follows some of these opportunities and challenges.

5.1 Opportunities

Participatory context-awareness. Our solution enables different intelligent software agents to dynamically contribute to the identification of precise details about the road traffic context. Our context-aware unit on a given SRS will not only take into consideration to information reported by the agents. It will also compare the ratings of the agents while taking into consideration the distance between their respective contexts in space and time. The SRS can provide the active agents (and, therefore, the vehicles) with appropriate instructions based on ongoing scenarios.

Personalized road traffic services on-the-move. Every vehicle has its own road traffic context. While some parameters in this context are shared with neighbouring vehicles, other parameters are private. It is, therefore, important to address these latter parameters in a specific way in order to ultimately provide personalized services to each individual vehicle. This objective is achieved through the use of software agents, which are capable of bringing valuable information to their vehicles from other vehicles as well as SRSs. These information will be processed in order to improve the road traffic safety environment and optimize commutes. More precisely, these agents could, for example, provide personalized warning massages to drivers based on their speeds and locations. For this reason, we argue that the idea of personalized road traffic services would be very attractive to drivers as well as to insurance companies that would be particularly interested in implementing a pay-as-you-drive approach.

Mobile SRS. The concept of smart road sign is an interesting paradigm since it will dynamically provide the right information to the right vehicles. We believe that extending this paradigm to Mobile SRS (MSRS) would lead to multiple road traffic benefits. We define a MSRS (Figure 8) here as a virtual smart sign that will be running on vehicles. More precisely, the SRS will create an agent with specific capabilities similar to the SRS. This agent will migrate into a hosting vehicle in the same way described in Section 4.2. Based on the data collected from the host as well as from agents on other vehicles, it will generate messages to all vehicles in a specific range. This range is determined based on the road traffic flow as well as on the ongoing events. More details about the concept of MSRS will be available is a future publication.

Seamless integration with Digital Twins (DT). Recent advances on the digital twins paradigm are offering new approaches in simulating the operation of physical systems. Our solution can integrate DT capabilities in order to sim-

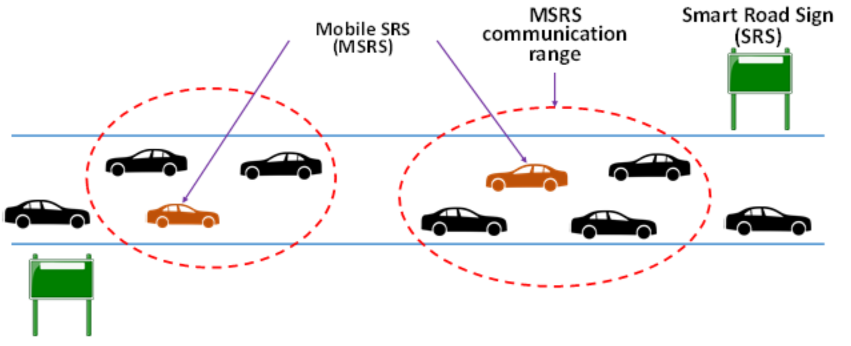

Figure 8. Illustration of the Mobile SRS concept

ulate the behaviors of vehicles as well as the behaviors of SRSs before making decisions into the real road traffic environment. With the help of our multi-agent system, the decision-making process would be more flexible, autonomous, and intelligent.

Adoption of Deep Learning (DL). DL is enabling super-human accuracy in a wide range of tasks, particularly object detection and classification. It is being used across all industries, from medical devices to autonomous vehicles. In this latter field, it is allowing remarkable performance in the automatic detection of traffic lights, stop signs, road infrastructure defects, and pedestrians. Our solution can be extended with DL capabilities in order to improve the identification and assessment of contextual parameters by the agents hosted by the vehicles. It can also be used for the prediction of traffic flow. These predictions can be enhanced with the proven capability of DL in forecasting weather time series that may affect road traffic.

5.2 Challenges

In order to reach out some of the opportunities that would be generated by our solution, we list below some of the challenges that require special attentions.

Management of huge volumes of data. The road traffic environment is by nature dynamic. When traffic is dense and multiple road-related events are happening, data acquisition and exchange streams become intense. In order to deal with such situations, important storage and processing resources as well as stable, secure communications are needed. These resources are not always available, particularly when the number of vehicles that volunteered to collaborate is limited. Machine learning tools could, in this case, be a relevant mean to identify and deal with the ongoing situations based on their priorities. An effective mechanism is needed here for the identification of these priorities.

Implementing an appropriate rewarding system. The number of vehicles that are needed to deal with the ongoing traffic conditions will depend on several parameters, including the traffic flow and the complexity of current events. In order to guarantee enough vehicles, we are proposing the use of a rewarding system. However, to make sure that this approach will work, a commitment from some main road traffic stakeholders (e.g., police, insurance companies, etc.) is necessary. This commitment must be translated into appropriate rewards to attract high number of participant vehicles. Higher number of vehicles will allow for a better selection of the right vehicle to deliver the right service at the right time. This is particularly important when specific services are requested from special road users, like police patrols.

Maintaining stable and secure communications. We are relying in solution on a LoRa network to enable long-range, secure communications between SRSs. However, inter-vehicle communications as well as communications between SRSs and vehicles will depend on onboard capabilities. When these capabilities are not able to convey messages within appropriate ranges and/or guarantee secure data exchange, the efficiency of the solution may drop. In this case, it is important to identify relevant communication alternatives. As the road traffic environment is highly dynamic, these alternatives must be screened at appropriate frequencies.

Collaboration between SRSs. Vehicles could be competitively used by more than one SRS at the same time. In order to prevent redundant processing and data storage, the coordination between SRSs is important. To this end, SRSs may exchange their current use of vehicle resources. Alternatively, their agents hosted by the same vehicles could be endowed with appropriate mechanisms to coordinate their operations.

Validation of the final system. The operation of the proposed solution can be relatively easy to validate via simulations. However, running this solution in a real-environment may be challenging. Indeed, the collaboration of the road traffic authority will be needed. In addition, allowing mobile agents to be hosted on private vehicles and carry out some processing while accessing to local data may not be easily approved by drivers.

6 CONCLUSION AND FUTURE WORKS

In this paper, and with regards to Intelligent Transportation Systems, we showed the importance of delegating some autonomy and intelligence to the infrastructure and in particular to the road signs. We then proposed an architecture of what a Smart Road Sign (SRS) will look like. This architecture will bring autonomy and intelligence to the road signage and would then allow them to play a more important role in the ITS by supporting more intelligent processes.

In this paper, we focused on only one module of the architecture, namely, the Multi-Agent System Module (MASM). We explained how agents can support the collaboration between SRSs and Connected Vehicles (CVs) in order to monitor traffic and report incidents so that road signs can warn drivers as soon as possible.

We are building a hardware prototype of the SRS. Data Accumulation Module (DAM), Data Organization Module (DOM), Communication Module (CM), Power Module (PM), and Display module (DM) have already been developed. We are currently working on the different units of the Intelligent Management Module (IMM) as well as the implementation of the Multi-Agent System Module (MASM). An agent-based simulation environment will be used in order to validate our agent-based approach and in particular to test and measure the overhead generated by agents migration and communication.

REFERENCES

[1] Perallos, A.—Hernandz-Jayo, U.—Onieva, E.—Zuazola, I. J. G.: Intelligent Transportation Systems: Technologies and Applications. Part 1: Intelligent Transportation Systems. Wiley, 2015.

[2] Lu, N.—Cheng, N.—Zhang, N.—Shen, X.—Mark, J. W.: Connected Vehicles: Solutions and Challenges. IEEE Internet of Things Journal, Vol. 1, 2014, No. 4, pp. 289–299, doi: 10.1109/JIOT.2014.2327587.

[3] Mahmood, Z.: Connected Vehicles in the IoV: Concepts, Technologies and Architectures. In: Mahmood, Z. (Ed.): Connected Vehicles in the Internet of Things. Springer, Cham, 2020, pp. 3–18, doi: 10.1007/978-3-030-36167-9_1.

[4] Siegel, J. E.—Erb, D. C.—Sarma, S. E.: A Survey of the Connected Vehicle Landscape – Architectures, Enabling Technologies, Applications, and Development Areas. IEEE Transactions on Intelligent Transportation Systems, Vol. 19, 2018, No. 8, pp. 2391–2406, doi: 10.1109/TITS.2017.2749459.

[5] Uhlemann, E.: Connected-Vehicles Applications Are Emerging [Connected Vehicles]. IEEE Vehicular Technology Magazine, Vol. 11, 2016, No. 1, pp. 25–96, doi: 10.1109/MVT.2015.2508322.

[6] Lynch, J. P.—Sundararajan, A.—Law, K. H.—Kiremidjian, A. S.—Carryer, E.—Sohn, H.—Farrar, C. R.: Field Validation of a Wireless Structural Monitoring System on the Alamosa Canyon Bridge. In: Liu, S. C. (Ed.): Smart Structures and Materials 2003: Smart Systems and Nondestructive Evaluation for Civil Infrastructures. Proceedings of SPIE, Vol. 5057, 2003, doi: 10.1117/12.482712.

[7] Sazonov, E.—Li, H.—Curry, D.—Pillay, P.: Self-Powered Sensors for Monitoring of Highway Bridges. IEEE Sensors Journal, Vol. 9, 2009, No. 11, pp. 1422–1429, doi: 10.1109/JSEN.2009.2019333.

[8] Huang, D. Y.—Chen, C. H.—Chen, T. Y.—Hu, W. C.—Feng, K. W.: Vehicle Detection and Inter-Vehicle Distance Estimation Using Single-Lens Video Camera on Urban/Suburb Roads. Journal of Visual Communication and Image Representation, 2017, Vol. 46, pp. 250–259, doi: 10.1016/j.jvcir.2017.04.006.

[9] Shi, W.—Wu, J.—Zhou, S.—Zhang, L.—Tang, Z.—Yin, Y.—Kuang, L.—Wu, Z.: Variable Message Sign and Dynamic Regional Traffic Guidance. IEEE Intelligent Transportation Systems Magazine, Vol. 1, 2009, No. 3, pp. 15–21, doi: 10.1109/MITS.2009.934642.

[10] Erke, A.—Sagberg, F.—Hagman, R.: Effects of Route Guidance Variable Message Signs (VMS) on Driver Behaviour. Transportation Research Part F: Traffic Psychology and Behaviour, Vol. 10, 2007, No. 6, pp. 447–457, doi: 10.1016/j.trf.2007.03.003.

[11] Esawey, M. E.—Walker, S.—Sowers, C.—Sengupta, J.: Safety Assessment of the Integration of Road Weather Information Systems and Variable Message Signs in British Columbia. Transportation Research Record: Journal of the Transportation Research Board, Vol. 2673, 2019, No. 4, pp. 305–313, doi: 10.1177/0361198119840335.

[12] Cao, J.—Song, C.—Peng, S.—Xiao, F.—Song, S.: Improved Traffic Sign Detection and Recognition Algorithm for Intelligent Vehicles. Sensors, Vol. 19, 2019, No. 18, Art. No. 4021, doi: 10.3390/s19184021.

[13] Jose, A.—Thodupunoori, H.—Nair, B. B.: A Novel Traffic Sign Recognition System Combining Viola-Jones Framework and Deep Learning. In: Wang, J., Reddy, G., Prasad, V., Reddy, V. (Eds.): Soft Computing and Signal Processing. Springer, Singapore, Advances in Intelligent Systems and Computing, Vol. 900, 2019, pp. 507–517, doi: 10.1007/978-981-13-3600-3_48.

[14] Tabernik, D.—Skočaj, D.: Deep Learning for Large-Scale Traffic-Sign Detection and Recognition. IEEE Transactions on Intelligent Transportation Systems, Vol. 21, 2020, No. 4, pp. 1427–1440, doi: 10.1109/TITS.2019.2913588.

[15] Czyżewski, A.—Sroczyński, A.—Śmiałkowski, T.—Hoffmann, P.: Development of Intelligent Road Signs with V2X Interface for Adaptive Traffic Controlling. 2019 6th International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS), 2019, doi: 10.1109/MTITS.2019.8883369.

[16] Gozdecki, J.—Łoziak, K.—Dziech, A.—Chmiel, W.—Kwiecień, J.—Derkacz, J.—Kadłuczka, P.: Communication System for Intelligent Road Signs Network. 6th International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS), Cracow, Poland, 2019, doi: 10.1109/MTITS.2019.8883382.

[17] Djahel, S.—Jabeur, N.—Nait-Abdesselam, F.—Wolstencroft, T.: A WAVE Based and Collaboration Driven Framework for Reduced Traffic Congestion in Smart Cities. IEEE Intelligent Transportation Systems Magazine, Vol. 13, 2021, No. 4, pp. 251–261, doi: 10.1109/MITS.2019.2953487.

[18] Kakkasageri, M. S.—Sataraddi, M. J.—Chanal, P. M.—Kori, G. S.: BDI Agent Based Routing Scheme in VANETs. 2017 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET), 2017, pp. 129–133, doi: 10.1109/WiSPNET.2017.8299733.

[19] Djahel, S.—Jabeur, N.—Barrett, R.—Murphy, J.: Toward V2I Communication Technology-Based Solution for Reducing Road Traffic Congestion in Smart Cities. 2015 International Symposium on Networks, Computers and Communications (ISNCC), Hammamet, Tunisia, 2015, doi: 10.1109/ISNCC.2015.7238584.

[20] Shaout, A.—Hassani, A.: An Intelligent Real Time Road Sign System. 2019 International Arab Conference on Information Technology (ACIT), 2019, pp. 8–13, doi: 10.1109/ACIT47987.2019.8991065.

[21] Ko, J.—Jang, J.—Oh, C.: A Multi-Agent Driving Simulation Approach for Evaluating the Safety Benefits of Connected Vehicles. IEEE Transactions on Intelligent Transportation Systems, 2021, pp. 1–13, doi: 10.1109/TITS.2020.3045675.

[22] Bui, K. H. N.—Jung, J. J.: Internet of Agents Framework for Connected Vehicles: A Case Study on Distributed Traffic Control System. Journal of Parallel and Distributed Computing, Vol. 116, 2018, pp. 89–95, doi: 10.1016/j.jpdc.2017.10.019.

[23] Krishnan, V. G.—Ram, N. S.: Analyze Traffic Forecast for Decentralized Multi Agent System Using I-ACO Routing Algorithm. Journal of Ambient Intelligence and Humanized Computing, 2018, doi: 10.1007/s12652-018-0981-2.

[24] Laport, F.—Serrano, E.—Bajo, J.: A Multi Agent Architecture for Mobile Sensing Systems. Journal of Ambient Intelligence and Humanized Computing, Vol. 11, 2020, No. 11, pp. 4439–4451, doi: 10.1007/s12652-019-01608-4.

[25] Davoust, A.—Gavigan, P.—Ruiz-Martin, C.—Trabes, G.—Esfandiari, B.—Wainer, G.—James, J.: An Architecture for Integrating BDI Agents with a Simulation Environment. In: Dennis, L., Bordini, R., Lespérance, Y. (Eds.): Engineering Multi-Agent Systems (EMAS 2019). Springer, Cham, Lecture Notes in Computer Science, Vol. 12058, 2020, pp. 67–84, doi: 10.1007/978-3-030-51417-4_4.

[26] Kesting, A.—Treiber, M.—Helbing, D.: Agents for Traffic Simulation. Chapter 11. In: Uhrmacher, A. M., Weyns, D. (Eds.): Multi-Agent Systems: Simulation and Applications. CRC Press, Computational Analysis, Synthesis and Design of Dynamic Models Series, 2009, pp. 325–356.

[27] Abdulsattar, H.—Mostafizi, A.—Siam, M. R. K.—Wang, H.: Measuring the Impacts of Connected Vehicles on Travel Time Reliability in a Work Zone Environment: An Agent-Based Approach. Journal of Intelligent Transportation Systems, Vol. 24, 2020, No. 5, pp. 421–436, doi: 10.1080/15472450.2019.1573351.

[28] Urra, O.—Ilarri, S.: Using Mobile Agents in Vehicular Networks for Data Processing. 2013 IEEE 14$^{\text{th}}$ International Conference on Mobile Data Management, Milan, Italy, 2013, pp. 11–14, doi: 10.1109/MDM.2013.57.

[29] Urra, O.—Ilarri, S.—Trillo-Lado, R.: An Approach Driven by Mobile Agents for Data Management in Vehicular Networks. Information Sciences, Vol. 381, 2017, pp. 55–77, doi: 10.1016/j.ins.2016.11.007.

[30] Yamamoto, G.—Aoki, Y.—Yarita, K.—Okamoto, S.—Yamanaka, N.: Result of Autonomous Driving Vehicle Control Using US-Japan Reconfigurable Resource Pool Networking. Graduate School of Science and Technology, Keio University, 2019.

[31] Mudengudi, S. S.—Kakkasageri, M. S.: Establishing Trust Between Vehicles in Vehicular Clouds: An Agent Based Approach. 2017 International Conference on Smart Technologies for Smart Nation (SmartTechCon), Bengaluru, India, 2017, pp. 529–533, doi: 10.1109/SmartTechCon.2017.8358428.

[32] Rath, M.: Smart Traffic Management System for Traffic Control Using Automated Mechanical and Electronic Devices. International Conference on Mechanical, Mate-

rials and Renewable Energy, Sikkim, India, 2017. IOP Conference Series: Materials Science and Engineering, Vol. 377, 2018, Art. No. 012201, doi: 10.1088/1757-899X/377/1/012201.

[33] Yuan, Q.—Li, J.—Zhou, H.—Lin, T.—Luo, G.—Shen, X.: A Joint Service Migration and Mobility Optimization Approach for Vehicular Edge Computing. IEEE Transactions on Vehicular Technology, Vol. 69, 2020, No. 8, pp. 9041–9052, doi: 10.1109/TVT.2020.2999617.

[34] Zhang, H.—Li, J.—Yuan, Q.: Edge Service Migration for Vehicular Networks Based on Multi-Agent Deep Reinforcement Learning In: Hsu, C. H., Kallel, S., Lan, K. C., Zheng, Z. (Eds.): Internet of Vehicles. Technologies and Services Toward Smart Cities (IOV 2019). Springer, Cham, Lecture Notes in Computer Science, Vol. 11894, 2020, pp. 344–352, doi: 10.1007/978-3-030-38651-1_27.

[35] Yamanaka, N.—Yamamoto, G.—Okamoto, S.—Muranaka, T.—Fumagalli, A.: Autonomous Driving Vehicle Controlling Network Using Dynamic Migrated Edge Computer Function. 2019 21st International Conference on Transparent Optical Networks (ICTON), Angers, France, 2019, doi: 10.1109/ICTON.2019.8840520.

[36] Tao, M.—Wei, W.—Huang, S.: Location-Based Trustworthy Services Recommendation in Cooperative-Communication-Enabled Internet of Vehicles. Journal of Network and Computer Applications, Vol. 126, 2019, pp. 1–11, doi: 10.1016/j.jnca.2018.10.023.

[37] Giunchiglia, F.: Contextual Reasoning. Epistemologia, Vol. 16, 1993, pp. 345–364.

[38] Abowd, G. D.—Dey, A. K.—Brown, P. J.—Davies, N.—Smith, M.—Steggles, P.: Towards a Better Understanding of Context and Context-Awareness. In: Gellersen, H. W. (Ed.): Handheld and Ubiquitous Computing (HUC 1999). Springer, Berlin, Heidelberg, Lecture Notes in Computer Science, Vol. 1707, 1999, pp. 304–307, doi: 10.1007/3-540-48157-5_29.

[39] Hofer, T.—Schwinger, W.—Pichler, M.—Leonhartsberger, G.—Altmann, J.—Retschitzegger, W.: Context-Awareness on Mobile Devices – The Hydrogen Approach. Proceedings of 36th Annual Hawaii International Conference on System Sciences (HICSS), 2003, pp. 1–10, doi: 10.1109/HICSS.2003.1174831.

[40] Schmidt, A.—Beigl, M.—Gellersen, H.-W.: There Is More to Context Than Location. Computers and Graphics, Vol. 23, 1999, No. 6, pp. 893–901, doi: 10.1016/S0097-8493(99)00120-X.

[41] Feraud, M.—Galland, S.: First Comparison of SARL to Other Agent-Programming Languages and Frameworks. Procedia Computer Science, Vol. 109, 2017, pp. 1080–1085, doi: 10.1016/j.procs.2017.05.389.

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