Towards a Decentralized Architecture for Information Dissemination in Inter-Vehicles Networks

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***Abstract*—Inter-Vehicles Networks (IVNs) have emerged as a new environment for intelligent transportation applications. The implementation of these applications requires dealing with many issues. The design and the implementation of an efficient and scalable architecture for information dissemination constitute one major issue. In this paper, a decentralized architecture inspired by stigmergy and direct communication between Ants is presented. The Ants colony has a set of organizing principles, such as scalability and adaptability that are useful for developing a decentralized architecture in highly dynamic networks. Simulations are conducted using Starlogo simulator and some metrics such as information relevance and drivers' awareness are evaluated. Preliminary results are reported to first show the effectiveness of the proposed information dissemination strategy.**

Keyword: Inter-vehicles network, Information dissemination, Ant colony, Stigmergy, Pervasive applications.

I. INTRODUCTION

With the growth and expansion of wireless communication technologies, considerable research efforts have done in the area of Inter-Vehicle Communications (IVC). The objective is to increase the vehicle safety or driver comfort by relaying required information from vehicle to vehicle. Two types of applications can be distinguished, comfort applications and safety applications [14]. The comfort applications can improve passengers comfort by updating them about route optimization and increase the traffic efficiency e.g., weather information, gas station or restaurant location, etc. Whereas safety applications increase the safety of passengers by exchanging safety data via inter vehicle communication. For example, a vehicle detecting an icy road could inform other vehicles intending to use the affected route.

By relying on the participation of vehicles' community and wireless communication, a high-quality Context-Aware Information System (CAIS) can be deployed. However, using CAIS, information coming from one vehicle may not be credible and reliable to take right action or trigger an alert. To develop a smart CAIS, vehicles within a particular geographical area should be involved in communicating their context to confirm or reject an emergency situation. Involving multiple vehicles in exchanging context information will increase the confidence about a global current context.

In addition, vehicles equipped with advanced sensors (e.g., ABS, ESP) and capable to become aware of specific abnormal conditions can share this information with other vehicles lacking this technology. For example, once the ABS (Automatic Braking System) within a vehicle is activated to indicate an icy road, strong rainfall or snow, the deriver will be notified by the CAIS module. This information will be sent to other surrounding vehicles in order to be informed and eventually take preventive actions before getting into same dangerous situation [6]. Another important scenario concerns exchanging information between vehicles to prevent traffic jams from growing too fast. For example, a vehicle having an embedded traffic detection sensor can send the traffic state to its following vehicles that can take preventive actions to avoid the congested areas.

Numerous research issues have recently been identified and should be tackled before real implementations of safety and comfort applications. The design and the implementation of efficient and scalable architecture for information dissemination constitute one major issue. This effort is a part of our work in the EU FP7 project, ASSET[1] (Advanced Safety and Driver Support for Essential Road Transport), with the main objective is to enable ASSET safety applications to propagate relevant information between vehicles. In this paper, we will emphasize more in data dissemination for road conditions e.g., bad road condition, traffic jam, road under construction, and unfortunate accident conditions, etc. More precisely, this paper proposes an approach that takes inspiration from the Ants' communication principles for information dissemination in inter-vehicles communication. We will mainly focus on critical emergency information dissemination with the goal is to describe the CAIS architecture and present a dissemination strategy by mimicking ants' pheromones spreading principles.

The remainder of this paper is organized as follows. Section 2 presents the related work. In section 3, the architecture of context-aware information system is presented. Section 4 presents our preliminary simulation results. Conclusions and future work are presented in section 5.

II. RELATED WORK

In recent years, due to the emergence of mobile telecommunication, increasing research efforts have been put into the area of inter-vehicles communication. Numerous applications have been proposed that require Vehicle to Vehicle (V2V) and Vehicle to Roadside unit (V2R)

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[1] http://www.project-asset.com/

communication in order to increase driver safety and comfort. Applications such as road condition monitoring, information on traffic jam/accident need safety data dissemination among concerned vehicles within suffering geo-graphic area. Unlike traditional centralized way of information dissemination, [3] proposed a highly decentralized and self-organizing approach for data dissemination for IVNs. However, they only considered data dissemination for comfort applications and not for safety applications' data, secondly, they consider only V2V communication and didn't mentioned V2R communication during their proposed dissemination scheme. Similarly, [9] presents a decentralized information dissemination approach for parking data through wireless LAN broadcasting. Communication protocols for data dissemination has been proposed and analyzed by [11] and [18]. A dynamic traffic view to driver and data dissemination using Car to Car (C2C) communication based on 802.11b is proposed in [8]. In [12] IVC is integrated with Vehicle-Roadside Communication (VRC) and flooding technique is proposed for messages delivery between moving vehicles and base stations.

The authors in [16] suggested an information dissemination technique based on swarming where 802.11 access points act as a gateway to the internet for passing vehicles. In [27], the ad-hoc networking is used to form clusters of communicating vehicles while cellular infrastructure provides reliable inter-cluster communication. A policy based strategy for data dissemination for cooperative vehicular system is presented in [17]. The UMTS network load and the estimated quality of the wireless LAN channel are used as input to the policy decision point and based on their values, an appropriate means of propagating the information is determined.

A study of one dimensional highway scenario is presented in [7]. However, the one dimensional situation in highway can't be directly compared with inner city environment where number of junctions and intersections is typically high. Moreover, the driving speed and traffic pattern are also largely different, which can severely influence the dissemination time. Other information dissemination approaches are described in [4, 10, 13, 15].

In this paper, being inspired from Ants direct and indirect communication to disseminate information about food source, we are proposing a self-organized approach to disseminate information about safety critical incidents on the roads.

III. THE CAIS ARCHITECTURE

We see social ants' colonies as the inspiration to developing self-organized, emergent, and decentralized CAIS system to propagate safety data among relevant vehicles. In this section, we will first provide a short description of the Ants colony principles. Then a mapping is made between Ants communication paradigm and the proposed dissemination strategy. To enable V2V and V2R communication, we introduce a CAIS module that would be the part of each vehicle or RSU. Finally, we propose an information dissemination strategy.

A. Ants' System (AS)

Biological principles have been exploited in a variety of computationally based learning systems such as artificial neural networks and genetic algorithms [22]. Also, the emergence of complex collective behaviour from the local interactions of simple agents is illustrated by many natural systems, like immune system [20] and Bee colony [21] that exhibit capabilities of complex distributed problem solving. Ant colony receives similar attention like other biological-inspired approaches [6]. They are a great source of inspiration in different areas e.g., route optimization, wireless network routing, scheduling problems, vehicles routing [5], and many others applications [23,25].

Ants are very simple insects but collectively they can perform complex tasks with good consistency. Examples of such complex problem solving behaviour include: building nests, co-operating in carrying large prey, and finding the shortest routes from the nest to the food [2]. In Ants' colony, two types of communication can be distinguished: ants' indirect and direct communication.

Ants use stigmergy to communicate indirectly. Two distinct types of stigmergy are observed within ants [2]. One is called sematectonic stigmergy that represents a change in the physical environment characteristics e.g., nest building wherein an Ant observes a structure developing and adds its ball of mud to the top of it. Another form of stigmergy is *sign-based,* which is used for indirect communication between Ants through chemical messages known as *pheromones*. Ants foraging for food lay down some pheromone which marks the path that they follow. An isolated Ant moves at random but an ant encountering a previously laid trail will detect it and decide to follow it with a high probability and thereby reinforce it with a further quantity of pheromone. Since the pheromone will evaporate, the lesser used paths will gradually vanish. Now if the shorter path is blocked or unavailable, then in this scenario the longer route may still be used and made the preferred route by repeated use. Hence, the pheromone concentration here gets stronger that leads to that path being used. This is how Ants develop a solution when a path is blocked. This illustrates how swarm intelligent systems adapt with changes in the environment. Ants' direct communication has also been observed when two ants come closer to each other; they exchange some information (e.g., food source). This is just like we say 'hello' when we meet each other.

These key points then in turn can be summed up for an AS as very simple rules: lay pheromone, and follow trails of other ants. Now we will describe about the design of our AS inspired solution.

B. AS and the proposed solution

Within our problem area, we are treating each vehicle like an Ant. When a vehicle perceives an abnormal environmental change on the road surface, it creates a safety message to inform other vehicles and roadside units along its way. This is similar to an Ant behaviour i.e., when an Ant observers a food source; it creates pheromone to convey indirectly to other Ants about route information of that food source. According to [5], it is also interesting to note that in some Ant species the amount of pheromone deposited is proportional to the quality of the food source found: path that lead to a better food sources receive a higher amount of pheromone. Similarly, in our Ants inspired information dissemination method, the relevance or significance of the safety messages will depend upon the severity and type of the event took place on the road.

Another important characteristic of Ant's pheromones is that these are evaporated with the passage of time. Taking the concept of pheromones decay from the AS, we defined the relevance of safety messages (similar to pheromone values) which evaporate by the function of time and distance, and finally be vanished from the system. Ants are also seen adaptable when they face obstacles in their current preferred route; they just select the next available path and will follow that path in the same fashion described previously. Similarly, vehicles can optimize their itineraries by receiving safety messages. In short, by following the swarm intelligence of AS, vehicles can build an intelligent cooperative vehicular network.

Table 1 presents the mapping between Ants' behaviour and the proposed decentralized system for information dissemination.

TABLE 1: Mapping AS and proposed system

Ants Behaviour	**Proposed dissemination method**
Ants use pheromones to communicate indirectly.	Vehicles use messages to update road side units (OBU to RSU communication).
Food sources	Event location (e.g., accident)
Ants' thrown pheromones evaporate with the passage of time and the distance to the food location.	The relevance of messages stored within RSUs and OBUs is automatically decreased based on the time and distance to the location of the emergency event. The message will be deleted when its relevance value reaches 0.
Ants communicate directly to exchange useful information.	Vehicles communicate directly (OBU to OBU communication) using DSRC/WAVE technology to exchange safety information about their routes.
Awareness to decide next actions : ants use alternate route when the current route is blocked	Drivers, by receiving information from CAIS module, take preventive actions.

C. *The structure of CAIS module*

To enable V2V and V2R communication we are proposing the special device named as CAIS module which is illustrated in figure 1. The detail of each CAIS module component is given below:

- *GPS receiver*: is available in modern cars and will be used to get position information.
- *Sensors*: different sensors will be used to monitor roadside conditions, vehicles' states, and drivers' behaviours. These sensors will be part of each vehicle and RSU taking part in dissemination process.
- *Knowledge base*: will be used to store messages received from other vehicles/RSUs. This knowledge base will also be used to store and transmit new safety messages:
- *Data Processing Unit*: will be used to analyze the data stored within knowledge base unit and will pick up useful data chunks for next transmission.
- *Generation of messages*: This module will generate complete messages along with timestamp, and spatial component.
- *Communication interface*: will be used to transmit and receive safety messages. We recommend DSRC/WAVE technology for this purpose that is specially designed for automotive use and supports mobility.

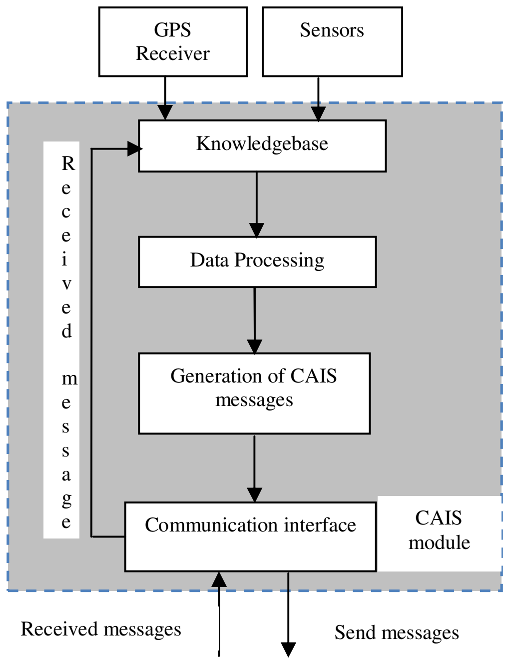

Figure 1. The Architecture of CAIS module

Hence, CAIS module will be the part of each vehicle and RSU involved in information dissemination process in this decentralized system. The following dissemination strategy will be used to spread information within the related geo-graphical area.

D. The Dessimination strategy

The dissemination protocol is composed of four phases: data generation, data dissemination, data reception, and data evaporation.

Data generation: When any vehicle or RSU[2] observes an event/phenomenon p_j that needs to be reported to other vehicles in order to increase their safety information about that particular event, it will generate a safety message m_{p_j}. This message should include the timestamp (t), spatial information (X_{p_j}, Y_{p_j}) about the event to be informed, the description of the event (d_{p_j}), and the relevance of the message R_{p_j}.

Data dissemination: two modes are distinguished: dissemination through V2R communication and dissemination through V2V communication. In the first mode, when a vehicle passes through a RSU and one/both have some new message(s) to exchange, they will update each other's knowledge base by using communication medium. This is just like an Ant throws pheromones alongside its route. A vehicle throws new message to RSU such that other vehicles could get this information. Similarly, vehicles can also get information from RSU that has been provided by previous vehicles or RSU itself. In the second mode, when two vehicles (moving in opposite direction or same direction) approach within the communication range of air interface and one/both have some new message(s) to exchange, they will update each other's knowledge base by exchanging new messages. This is quite similar to direct communication between Ants.

Data reception: when any message m_{p_j} is received from other node (i.e., vehicle or RSU), if receiving node doesn't have an entry of the message, it will simply store that message into its knowledge base. Otherwise, received message will be analyzed and compared with current available information. The old message will be replaced only if the new one is still relevant and more accurate. Suppose $m_{p_k}(t_2)$ is the new message received by vehicle v_i, that was generated for event p_k at time t_2, and its corresponding previously stored entry is $m_{p_k}(t_1)$, which was generated for the same event, p_k, but at time t_1, then $m_{p_k}(t_1)$ will be replaced by $m_{p_k}(t_2)$ if $R_{p_k}(t_1)$ is less than $R_{p_k}(t_2)$. This relevance value is described later in this section.

Data evaporation: Since the pheromone trials laid by Ants evaporate with the passage of time. The lifetime of these pheromones also depends upon the number of Ants that follow such trail and throws pheromones to further enhance the effect of pheromones [2]. Taking the concept of pheromones decay from the Ants system, we defined the relevance of safety messages similar to pheromone values which evaporate and finally be vanished from the system. Furthermore, using relevance value, vehicles can anticipate about phenomenon further up the road.

Similar to pheromone evaporation in Ant's colony, the relevance value of each message decreases as the distance increases from the current position of the vehicle to the phenomenon location. Let's consider $R_{p_i}(t)$ is the relevance of the received message m_{p_i} related to the phenomenon p_i received by a particular vehicle. The relevance value can be calculated at step $t+1$ as follows:

$$R_{p_i}(t+1) = R_{p_i}(t) - \Delta R_{p_i}(t) \qquad (1)$$

where the value of $\Delta R_{p_i}(t)$ cab be calculated with the following logistic function as follows: $\Delta R_{p_i}(t) = 1/(1+\exp(-\lambda\delta(t)))$, where λ is an adjusting factor and its value is between 0 and 1. The value of $\delta(t)$ is a function of the vehicle distance to the phenomenon (in meters) and the transmission range T_r, which can be calculated as follows: $\delta(t) = d(t)/T_r$.

It is worth noting here that the importance of safety related information to a vehicle is increased when the distance is decreased between the vehicle and the place where safety data was generated, and vice versa. This is quite similar to the pheromones, as pheromones life time is also decreased as the distance between nest and food sources is increased. Finally, the message will be deleted from knowledge base when its relevance is reaches 0.

To evaluate the performance of proposed solution, we introduced another important metric known as driver *awareness* which measures the driver knowledge about road conditions and is derived from relevance value. The driver awareness value at step t: $A_{v_i}^{p_i}(t)$ about a phenomenon p_i can be calculated using the phenomenon relevance value at step t $R_{p_i}(t)$ and the relevance value at time t_0, i.e., the time of message generation i.e.,

$$A_{p_i}(t) = \frac{R_{p_i}(t)}{R_{p_i}(t_0)} \times 100 \qquad (2)$$

The awareness value can help drivers to decide next actions such as decreasing/increasing speed, finding an efficient route, and avoiding traffic jam, etc.

[2] RSUs correspond to stationary vehicles

IV. SIMULATION RESULTS

Simulations have been conducted using Starlogo [26]. Starlogo is a programmable modelling environment for exploring the workings of decentralized systems such as biological and natural phenomena. Starlogo provides the ability to program a system that is composed of thousands of Pathes and Turtles. Turtles are agents that run in the environment composed by Pathes. Both Turtles and Pathes can execute commands and procedures. Turtles and Pathes can interact with each other, for example a Turtle can move and execute some commands or procedures to change the states of the Pathes it pass by. Starlogo provides a very simple language to describe the behaviors of Turtle and Pathes. It also provides a run-time environment to run thousands of Turtles and Pathes in parallel. Turtles simulate represent active elements such as vehicles and RSUs and the environment represents passive elements such as the road.

To evaluate the dissemination strategy presented above, we enhanced the traffic simulator developed using Starlogo in [26]. In this simulator, the vehicles follow two very simple rules: If there is a car ahead, then slowdown. if there is no car ahead, then speed up. In this evaluation, we consider information dissemination in a highway scenario. The scenario simulated is a straight section of a road with 50 vehicles moving in both directions as depicted in Figure 2. The scenario would just consist of two lanes of vehicles entering the road section at the one end, and leaving it at the other. At both ends of the road section, vehicles initialized them to behave as new vehicles, i.e., vehicles arrived to end of the first lane are treated as a new vehicles and vice versa. In addition to speedup and slow down rules, when introducing an accident, nearby vehicles to the accident location slowdown and start dissemination/evaporation process as described above. When a vehicle receives a message it first calculates it awareness value, if this value is greater than 0.5 (50%), the vehicle slowdown, otherwise speed up.

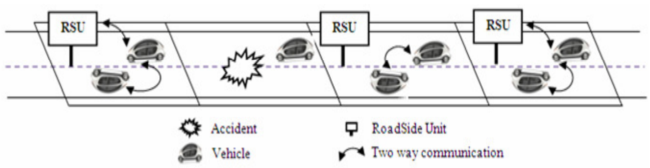

Figure 2. The simulated scenario

For a particular phenomenon, a given vehicle will receive messages from vehicles passing the location that have information about the location before getting to it. At each step, based on the awareness value, the driver can decrease or increase the speed. In the simulation, the speeds limit decreases 30% when the information relevance is below 0.5 and set to speed limit otherwise. Figure 3 illustrates the average awareness vs average speed. As shown in this figure, the protocol achieves better information awareness of the accident introduced at time 50. As the information awareness increases (i.e., relevance increases) vehicles drivers become aware of the accident and therefore decrease the speed. Furthermore, as the information becomes not relevant, the drivers increase the speed to the speed limit. For example, at time 250, the accident effects are removed from the road and its information is cleared from vehicles knowledge and therefore the speed increases to be the speed limit.

As we can see in Figure 4, the average value of drivers' awareness decreases when the distance increases between the accident (phenomenon) location and the current position of his vehicle. The darker an area is, the more awareness about the phenomenon, and white areas indicate that no knowledge is available.

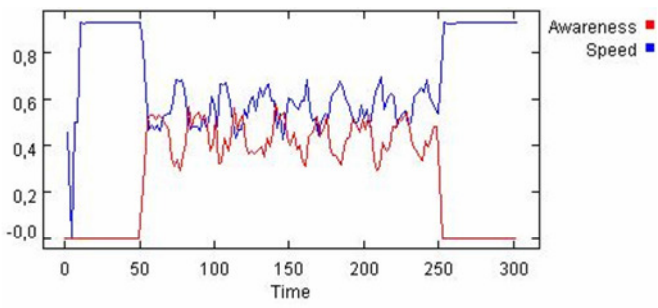

Figure 3. Awareness vs. Speed

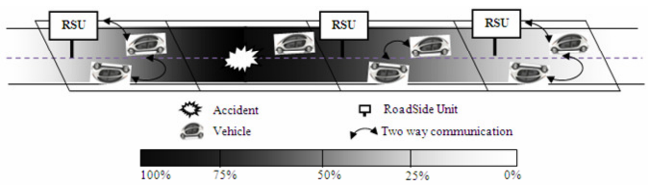

Figure 4. Awareness during information dissemination process

The main advantage of using this dissemination strategy is that the geographical area is not defined in advance. When a vehicle detects a danger (e.g., accident) it will issue an emergency message. The message will have a relevance value specified according to the corresponding safety application reliability requirement (by analogy to Ants' this value corresponds to the quantity of the food). Vehicles stop disseminating a message when its relevance value reaches 0. To enable drivers to decide next actions more efficiently, the awareness value can be computed (eq. 2) using the message relevance. This value is used by CAIS to help drivers make an appropriate decision which is best suited to a particular context.

V. CONCLUSIONS AND FUTURE WORK

In this paper, a self-organized and decentralized information dissemination method inspired from Ants' colony behaviour exploiting signed based stigmergy and direct communication is proposed. The architecture of the context aware information system, CAIS, was presented to facilitate each vehicle with the necessary information about its surrounding and to assist drivers to be aware of undesirable road conditions. Simulations are conducted and preliminary results are reported to show the benefits of using Ants' principles for information dissemination in IVNs.

Simulations with NS2 to evaluate the robustness and performance of the proposed approach, such as the network load, latency, and the percentage of messages received is an ongoing work. Future work addresses the comparison of the proposed dissemination strategy with other work from the literature.

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