Journal of Network and Computer Applications 46 (2014) 154–165

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

journal homepage: www.elsevier.com/locate/jnca

# A decentralized approach for information dissemination in Vehicular Ad hoc Networks

Seytkamal Medetov[a], Mohamed Bakhouya[b], Jaafar Gaber[a], Khalid Zinedine[c],
Maxime Wack[a], Pascal Lorenz[d,*]

[a] University of Technology Belfort-Montbeliard, 90010 Belfort Cedex, France
[b] International University of Rabat Parc Technopolis, 11 100 Sala el Jadida, Morocco
[c] Chouaib Doukkali University, El Jadida, Morocco
[d] University of Haute Alsace, 68008 Colmar, France

ARTICLE INFO

*Article history:*
Received 3 November 2013
Received in revised form
28 June 2014
Accepted 30 July 2014
Available online 10 August 2014

*Keywords:*
VANETs
MANETS
Information dissemination
Broadcasting protocols
Ant colony
Swarm computing

ABSTRACT

Substantial research efforts on Ad hoc networks have been devoted recently to Vehicular Ad hoc NETworks (VANETs) to target Vehicle to Vehicle (V2V) and Vehicle to Roadside unit (V2R) communications in order to increase driver/vehicle safety, transport efficiency and driver comfort. VANETs are special subclass of Mobile Ad hoc NETworks (MANETs) for inter-vehicle communication and have relatively more dynamic nature compared to MANETs due to the rapid network topology changes. The development and implementation of efficient and scalable algorithms for information dissemination in VANETs is a major issue which has taken enormous attention in the last years. In this paper, an efficient distributed information dissemination approach is proposed, inspired by Ant-colony communication principles, such as scalability and adaptability that are useful for developing a decentralized architecture in highly dynamic networks. The main objective is to provide each vehicle with relevant information about its surrounding to allow drivers to be aware of undesirable events and road conditions. A "relevance" value into emergency messages is defined as an analog to pheromone throwing in Ant colony, to take an appropriate action. Simulations are conducted using NS2 network simulator and relevant metrics are evaluated under different node speeds and densities to show the effectiveness of the proposed approach.

## 1. Introduction

VANETs appeared as a subclass of MANETs for inter-vehicle communication. However, VANETs have relatively more dynamic nature as compared to MANETs with respect to network topology. The design and implementation of an efficient and scalable architecture for information dissemination in VANETs constitutes a major issue that should be tackled. Indeed, in this dynamic environment, increasing number of redundant broadcast messages will increase resource utilization, which would indirectly affect the network performance (Bakhouya et al., 2011). By relying on the participation of vehicles' community and wireless communication, information coming from one vehicle may not be credible and reliable to take right action or trigger an alert. Therefore, 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 (Hartenstein and Laberteaux, 2010). For example, once the Automatic Braking System (ABS) within a vehicle is activated to indicate an icy road, strong rainfall or snow, the driver will be notified (Dar et al., 2010a). This information could be disseminated to other surrounding vehicles in order to be informed and eventually take preventive actions before getting into same dangerous situation. Another important scenario concerns exchanging information between vehicles to prevent traffic jams from growing too fast. For example, a vehicle having embedded traffic detection sensors can send traffic information to its following vehicles that can take preventive actions to avoid the congested areas (Dar et al., 2010a; Fuchs et al., 2007).

This paper proposes a decentralized Context Aware Information Dissemination (CAID) approach using two strategies (G1 and G2) that takes inspiration from the Ants' pheromones spreading

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* Corresponding author.
*E-mail addresses:* seytkamal.medetov@utbm.fr (S. Medetov), mohamed.bakhouya@uir.ac.ma (M. Bakhouya), jaafar.gaber@utbm.fr (J. Gaber), zinedine@ucd.ac.ma (K. Zinedine), maxime.wack@utbm.fr (M. Wack), pascal.lorenz@uha.fr (P. Lorenz).

http://dx.doi.org/10.1016/j.jnca.2014.07.037
1084-8045/

principles for information dissemination in VANETs. The main focus is on critical emergency information dissemination in safety related applications. Ants' communication principles are used to develop new approaches of problem solving in different areas of research and development (Mullen et al., 2009; Rizzoli et al., 2007). In Ant colony, when Ants observe a food source they create pheromone to inform other Ants about route information to that food source (Chu et al., 2004); Detrain and Deneubourg, 2006). In some Ant species, the amount of pheromone deposited is proportional to the quality of the food source found, i.e., paths that lead to better food sources receive higher amount of pheromone (Dorigo et al., 2000). In the proposed Ant inspired information dissemination method, when an abnormal environmental event is noticed on the road surface, a safety message is created to inform other vehicles and roadside units (RSUs) along its way. Similar to the pheromone values, we defined the relevance value of safety messages, which depend upon the severity and event types. Furthermore, as pheromones are evaporated with the passage of time, the lesser used Ant paths are gradually vanished (Dorigo et al., 2000, 2006). Similarly, the relevance value decreases over time, with distance, till the corresponding safety message is vanished and dropped from the system.

The remainder of this paper is organized as follows. Section 2 presents the related work. The proposed dissemination strategy is described in Section 3 with an overview of Ant system. Simulation results are presented in Section 4. Conclusions and future work are given in Section 5.

## 2. Related work

VANET is a type of wireless network where nodes that communicate with each other are vehicles and RSUs. Unlike MANETs where nodes can freely move in a certain area, the movements of vehicles in VANETs could be predicted, because it is dependent on streets, traffic and specific rules. Communication between nodes in VANETs is less reliable due to the high mobility and different traffic patterns compared to MANETs. In addition, in VANETs, the safety information should be disseminated to other surrounding vehicles in order to be informed and eventually take preventive actions. For example, a vehicle having an embedded traffic detection sensor can disseminate current traffic state to its following vehicles that can take preventive actions to avoid the congested areas (Hartenstein and Laberteaux, 2010).

Various information dissemination approaches were proposed in the literature (Nadeem et al., 2004; Brickley et al., 2007). Flooding is the simplest technique for information dissemination in Ad hoc based networks, in which nodes disseminate a received message to all their neighbors. This algorithm can lead to the broadcast storm problem that severely affects the resources consumption due to redundant message rebroadcasts (Ni et al., 1999). Several techniques have been proposed to solve this problem by preventing certain nodes from rebroadcasting received messages or by differentiating the timing of rebroadcasts, e.g., using strategies based on a broadcasting probability, or according to the number of same received messages, the distance between receivers and senders, or the location (i.e., position) in an appropriate cluster of nodes (Bakhouya, 2013; Ye et al., 2012). However, it should be noted that these methods used various static threshold parameters which are not appropriate for dynamic networks, such as VANETs, wherein adaptability is an important issue to consider (Bakhouya and Gaber 2014). In Bakhouya et al. (2011), an adaptive approach for information dissemination is proposed where each node can dynamically adjust the values of its local parameters using information from neighboring nodes. It is worth noting that broadcasting and dissemination are two different issues: broadcasting protocols can be tackled at the routing layer, while dissemination algorithms deal with the application layer.

Applications in VANETs can be classified into two main categories, i.e., comfort and safety applications (Dar et al., 2010b; Nadeem et al., 2006). In general comfort related applications are aimed to improve passenger comfort and traffic efficiency, e.g., traffic-information, weather information, gas station or restaurant location, advertisements and other Internet services (Caliskan and Graupner, 2006). In safety-related applications, high reliability and short delays are required for information dissemination. In other words, safety messages are time-critical; vehicles are required to disseminate warnings immediately to avoid probable accidents and traffic congestions (Zhuang et al., 2011). However, safety and comfort applications are not completely separated from each other. For example, a message generated for accident can be seen as a safety urgent message from the perspective of nearby vehicles. The same message can be seen by farther vehicles as an informative message to choose an alternative optimal route with low traffic jams (Hartenstein and Laberteaux, 2010).

The role of RSU is important in urban areas where density of vehicles is commonly very high, since vehicles cannot always verify all received messages from neighbors in a timely manner, which can cause message loss. Several works are devoted to RSUs location, coverage area extension, and its effective use in information dissemination process. For example, two different optimization methods for placement of a limited number of RSUs in urban areas are proposed in Mullen et al. (2009), namely Binary integer programming and Balloon expansion heuristic methods. These methods were used to tackle the optimization problem of minimizing an average reporting time. Indeed, a RSU typically can reach with a single hop only a fraction of the interested vehicles. Three algorithms to extend RSU's coverage area using multi-hop inter-vehicle communications are proposed by Bakhouya and Gaber (2014). These algorithms apply a set of geometrical rules based on the position of sending nodes. In Nadeem et al. (2004), inter vehicle communication is integrated with vehicle to infrastructure communication as an extension of the IEEE 802.11p MAC standard to increase driver's awareness in safety-critical cases. In Dar et al. (2010b), a hybrid network architecture is proposed, that consists of multiple Ad hoc clusters, connected through proxy servers and cellular links to target the delivery of emergency messages to all intended vehicles in a short time interval. A RSU-aided message authentication scheme (RAISE), where RSUs are responsible for verifying the authenticity of the messages sent from vehicles and notifying the results back to all the associated vehicles, is proposed by Nadeem et al. (2006).

Since vehicles can receive safety messages, that can be more or less critical, from the infrastructure and other vehicles, selecting useful and reliable information is one of the most important issues in the context of VANET safety applications (Huang et al., 2010). In the absence of a central authority monitoring in VANETs, application of an accurate trust and reputation mechanism might be extremely helpful in that context. For example, a TRIP model, to decide whether to accept, disseminate or discard traffic warnings coming from other vehicles is proposed by Marmol and Perez (2012), by assessing the trustworthiness/reliability of the issuer of such message. The priorities are assigned to messages based on their urgency level (Suthaputchakun and Ganz, 2007). Higher priority messages are transmitted more times than lower priority messages to provide higher reliability for higher priority messages. Disseminating emergency messages to different distances according to their importance is proposed by Zhuang et al. (2011). In Moreno et al. (2009), a distributed power control method is proposed to control the load of periodic messages on a channel. It is based on a strict fairness criterion, i.e., a distributed fair power adjustment that copes with vehicular environments. A WAVE-enhanced safety message delivery scheme to minimize the delivery delay of safety messages in multi-channel VANETs is proposed by Felice et al. (2012).

In this work, a self-organized approach to disseminate information about safety critical incidents on roads is presented, which is inspired by Ants' direct and indirect communications to exchange information about food source locations. Ants are simple insects that can collectively perform complex tasks with remarkable consistency. Examples of such complex problem solving behavior include building nests, co-operating in carrying preys, and finding the shortest routes from the nest to food locations (Dorigo et al., 2000). Ants adapt their foraging behavior when environmental conditions are suddenly changed, e.g., when a path towards a food source is obstructed or when new and shorter routes are discovered (Vittori et al., 2004). Number of applications published so far implemented ants' communication principles in different areas of research, e.g., route optimization, wireless network routing, scheduling problems, vehicles routing (Bakhouya and Gaber, 2007; Grasse, 1960; Trivedi, 2008). For example, a self-organizing approach for routing in MANETs, called distributed ant routing, is proposed by Rosati et al. (2008); routing is stochastic, i.e., a next hop is selected according to weighted probabilities that are calculated on the basis of the pheromone trails left by ants. Routes not recently used are purged by means of pheromone evaporation.

The ant colony optimization (ACO) algorithm is one of the most studied and successful optimization techniques (Mullen et al., 2009). Several applications of ACO have been used to solve optimization problems in different area of research. For example, a delay-sensitive vehicular routing protocol derived from the ACO is proposed by Li and Boukhatem (2013). A route setup process is achieved by reactive forward ants and backward ants, which are in charge of network exploration and pheromone dissemination respectively. The pheromone dissemination is declared with respect to the relaying delay of the visited road segments. Based on the pheromone routing tables at each intersection, routing decision is made by opportunistically selecting next optimal intersection. Similar work presented by Jabbarpour et al. (2014) used ACO to alleviate the vehicle congestion problem using intelligent traffic lights. The algorithm is based on streets traffic load condition; road network is divided into different cells and each vehicle guided through the less traffic path to its destination using ACO in each cell. A hybrid Ant colony system is proposed to target dynamic vehicle routing problem (VRP) using heuristics to reconstruct routes and update pheromone by Rashidi and Farahani (2012). In this time window-based approach, requests arriving during a slice time are listed and posted to the next closest time slice. During each time slice, a problem similar to a static VRP is traced, but with vehicles having different capacities and starting locations.

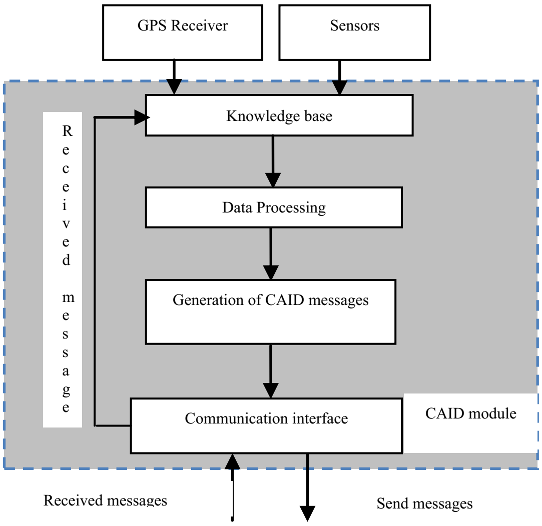

**Fig. 1.** The CAID module architecture.

Aforementioned and many other Ant-based algorithms were proposed due to their superior ability in solving dynamic problems (Peinado and Ortiz-Garcia Munilla, 2013). In this paper, information dissemination approaches taking inspiration from swarm communication principles are proposed.

## 3. The dissemination strategy

In this section, mapping rules of Ant-colony communication system to Vehicular Ad hoc Networks are presented. Two analogous information dissemination strategies are presented.

### 3.1. Ant communication principles in VANETs

In the proposed dissemination strategy, each vehicle is considered as an Ant. When an abnormal environmental event is noticed on the road, a safety message is created and disseminated to inform other vehicles and roadside units along its way. This is similar to Ant behavior i.e., when an Ant observes a food source it leaves pheromone traces to convey indirectly to other Ants about route information of that food source. Research published by Wilson (1962) demonstrated that Ant pheromone trails provide positive and negative feedbacks to organize foraging at the colony level. A colony forms a trail when successful foragers deposit pheromone on their return to the nest, with the trail gaining in strength as more and more workers add pheromone to it, so providing positive feedback (Bakhouya and Gaber, 2014). Moreover, according to Dorigo et al. (2000), in some Ant species the amount of pheromone deposited is proportional to the quality of the food source found, i.e., path that leads to a better food sources receive a higher amount of pheromone.

Similarly, in the proposed Ant inspired information dissemination method, we define the *relevance of safety messages* depending upon the severity and type of events that took place on the road. Furthermore, as pheromones evaporate with the passage of time, the lesser used Ant paths are gradually vanished (Dorigo et al., 2000, 2006). In fact, when the food runs out, foragers refrain from reinforcing it on their return, so providing negative feedback (Bakhouya and Gaber, 2014; Jackson and Ratnieks, 2006). Taking the concept of pheromones decay from the Ant system, the relevance of safety messages, similar to pheromone values, evaporates over time and with distance, and finally be vanished from the system. Ants also adapt when they face obstacles in their current preferred route by selecting next available paths. Similarly, drivers take preventive appropriate actions (e.g., choose alternative route, slow down speed, or immediate stop) according to the relevance value of received emergency messages from the Context Aware Information Dissemination (CAID) module (see Fig. 1). Table 1 presents the mapping between Ants' foraging behavior and the proposed decentralized system for information dissemination in VANETs.

### 3.2. Context aware information dissemination module

Figure 1 depicts the different components of the CAID module as follows:

- *GPS receiver*: available in modern cars and will be used to get position information (GPS, 2007).

**Table 1**
Mapping rules.

| **Ants communication behavior** | **Proposed dissemination approach** |
|---|---|
| Ants use pheromones to communicate indirectly | Vehicles use messages to update road side units (V2R communication) |
| Food sources | Event location (e.g., accident) |
| Pheromones thrown by Ants evaporate with the passage of time and the distance to the food location | The relevance of stored messages is automatically decreased based on the time and distance to the event location. The message will be deleted when its relevance value reaches 0 |
| Ants communicate directly to exchange useful information | Vehicles communicate directly (V2V 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 context-aware information dissemination module, take preventive actions |

- *Sensors*: different sensors will be used to monitor roadside conditions, vehicles' states, and drivers' behaviors. These sensors will be part of each vehicle and RSU taking part in dissemination process, e.g., ABS, ESP (Karpinski et al., 2006; Segata and Cigno, 2013).
- *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 the 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, spatial data and the relevance value.
- *Communication interface*: will be used to transmit and receive safety messages. We recommend DSRC/WAVE technology for this purpose, which is specially designed for automotive use and supports mobility (Dar et al., 2010b).

Hence, CAID module will be integrated as a part of each vehicle and RSU that are involved in information dissemination process.

### 3.3. *Information dissemination protocol in VANETs*

As stated above, we use Ants communication principles for information dissemination by focusing mainly on safety-critical reason. In practice, providing such a service i.e., safety-critical services only take a short period of time and consume a small fraction of bandwidth (Liu and Lee, 2010). The objective of the proposed approach is to provide each vehicle with the relevant information about its surrounding to allow drivers to be aware of undesirable events and road conditions. The dissemination protocol is composed of four phases: *data generation, data dissemination, data reception, and data evaporation*. For *data generation*, when a vehicle (or RSU) $v_i$ observes an event $p_j$ that needs to be reported to other vehicles, it generates a safety message $m_{p_j}$. This message includes the timestamp ($t_0$),location information, and the initial relevance value ($R^{(0)}_{v_i,p_j}(t_0)$) generated at time $t_0$. Alarm triggered by the event $p_j$ will be generated and *disseminated* periodically up to a time $T$, which represents the maximum time required to handle $p_j$ by road and security authorities (i.e., the lifetime of the emergency, defined as the time needed to return to regular traffic conditions after the emergency situation). Subsequently, an initial relevance value ($R^{(0)}_{v_i,p_j}(t)$) associated to a generated message at time $t$, by a source node, is expressed by the following equation:

$$R^{(0)}_{v_i,p_j}(t) = \begin{cases} R^{(0)}_{v_i,p_j}(t_0)\cdot\frac{T-(t-t_0)}{T}, & t_0 \le t < T \\ 0 & t \ge T \end{cases} \tag{1}$$

In *data dissemination* process, 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 or both have some new messages to exchange, they will update each other's knowledge base by using the communication medium. This is just like an Ant throws pheromones alongside its route. A vehicle throws a new message to RSU such that other vehicles could get this information. Similarly, vehicles can get information from RSU that has been provided by other vehicles or RSUs. In the second mode, when two vehicles (moving in opposite or in same direction) are located 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.

For *data reception* and *dissemination* process, we considered the two following strategies: strategy G1 and strategy G2. In G1, when a message $m_{p_j}$ is received by the node $v_k$ (i.e., vehicle or RSU), its relevance value is computed according to the following logistic function:

$$R_{v_k,p_j}(t+\tau) = \frac{2\cdot R^{(0)}_{v_i,p_j}(t)}{1+e^{(d+\lambda\cdot\tau\cdot s/D)}} \tag{2}$$

where $R^{(0)}_{v_i,p_j}(t)$ is the relevance of the message $m_{p_j}$ disseminated by the source vehicle $v_i$; $d$ is the distance between the current location of receiver vehicle $v_k$ and the location where the event appeared (source), which can be calculated as $d=\sqrt{(X_{v_k}-X_{p_j})^2+(Y_{v_k}-Y_{p_j})^2}$; $\tau$ is the assessment delay needed to compute message relevance before re-disseminating it to other surrounding vehicles; $s$ is the current speed of $v_k$; $\lambda$ is a sign, representing vehicles direction: if it is moving toward the accident location its value will be $(-1)$, otherwise its value will be $(+1)$; $D$ is the radius for the relative geographical area, and the quantity of $\lambda\cdot\tau\cdot s$ represents the influence of distance variation during the assessment delay $\tau$.

It is worth noting that data, such as the initial relevance value, the generation time, location of the event and the relative geographical area, which are used for computing received messages' relevance, are stored in the header of each message together with the description of the event. In the strategy G1, information in the header, which is generated by the source node, will not be changed by receivers. After computing the new relevance value, receiver nodes should take appropriate actions depending on the relevance value. For instance, according to the relevance the CAID module could suggest drivers either to choose alternative road, or to decrease the speed, or to stop vehicle immediately if the value of message relevance is positive or higher than certain threshold value.

If there are many vehicles within a relative geographical area, several redundant messages could be issued. Therefore, in order to decrease redundancy, for messages generated by the same source, which has entry for the same event, their generated time (timestamp of new and previous received messages) will be compared; the latest generated message will be processed, i.e., its relevance will be computed by Eq. (2); the early generated messages will be dropped. This process is necessary since the emergency messages are generated periodically; if the generation interval is very small, some nodes could receive redundant messages generated earlier traveling in communication area among neighbor nodes while newer messages have already been received. However, short interval in periodic message generation is also important in the concept of safety applications due to some specific characteristics of VANETs, i.e., high mobility, very short communication duration, and highly dynamic topology.

For messages generated by different sources for same or different events, their relevance values will be computed and the highest one will be disseminated first (immediately), messages with lower relevance value will wait in the queue or will be dropped if their relevance value is lower than a given threshold.

Unlike G1, in G2, when a node $v_k$ receives a message $m_{p_j}$ from another node $v_x$, it computes its relevance value using node-$v_x$'s information. More precisely, the difference between strategies G1 and G2 is that the receiver node uses intermediate nodes' (sender/forwarder) relevance value (i.e., $R_{v_x,p_j}(t)$) instead of the source generated relevance value (i.e., $R^{(0)}_{v_i,p_j}(t)$) in the computation of the new relevance value. Thus, Eq. (2) is re-formulated for strategy G2 as follows:

$$R_{v_k,p_j}(t+\tau)=\frac{2\cdot R^{(0)}_{v_i,p_j}(t)}{1+e^{(d+\lambda\cdot\tau\cdot s/D)}}\overset{R^{(0)}_{v_i,p_j}(t)\to R_{v_x,p_j}(t)}{\Longrightarrow}R_{v_k,p_j}(t+\tau)=\frac{2\cdot R_{v_x,p_j}(t)}{1+e^{(d+\lambda\cdot\tau\cdot s/D)}} \tag{3}$$

Similar to G1, in order to reduce redundancy, early generated messages will be ignored if the received node has already the same entry in its knowledge base for the same event, which is generated by the same source. In addition, less relevant messages with same generation time are ignored, while more recent messages should be processed because, nodes in strategy G2 can receive messages with different relevance values that are computed by intermediate nodes.

The importance of safety related information received by a vehicle depends mainly on the distance between the current location of the vehicle and the place where safety data was generated. The distance decreases when vehicles move in the direction of the accident/event, and increases when the vehicle goes away from the event/dissemination area. As depicted in Fig. 2, the average relevance value decreases when the distance from the event location increases. The darker area denotes, the area being aware of the event, and white areas indicate that no knowledge is available. Receiving such message when approaching this place can help drivers to decide next actions, such as decreasing/increasing speed, finding an alternative route avoiding traffic jam, etc.

This is quite similar to the pheromones, as pheromones life time also decreases as the distance between nest and food sources increases. Taking the concept of pheromones decay from the Ants system, as described above, we defined the relevance of safety messages similar to pheromone values, which evaporate and finally be vanished from the system. The relevance value of each message decreases as the distance increases from the current position of the vehicle to the event location. The message will be deleted from knowledge base when its relevance is below than 0 (or a given minimal value). The algorithm of the proposed information dissemination approach is given in Fig. 3.

## 4. Performance evaluation

In this section, parameters related to mobility and traffic scenarios are first described. Performance metrics together with simulation results are then reported and analyzed. The performance evaluation of the proposed scheme is studied using the network simulator ns2 (Network Simulator NS 2.34, 2011). The objective is to evaluate the influence of relevance values on information dissemination process within related geographical areas. Because, drivers far away from the event location (outside of the related geographical area) may not be interested since no actions are needed from them to avoid such a dangerous situation. Similar to Ant's communication principles (i.e., the amount of deposited pheromone is proportional to the quality of the food source found (Dorigo et al., 2000)) the source node initializes the relevance value of emergency messages according to the event severity (significance). In fact, the relevance value increases for approaching vehicles, and decreases for going away vehicles.

### 4.1. Simulation parameters

In this study, a realistic mobility scenario is used to conduct simulations. This scenario is generated by Traffic and Network Simulation Environment (TRaNS) (Piorkowski et al., 2008), which are built on top of SUMO, an open source micro-traffic simulator (Simulation of Urban Mobility). The scenario generated, using these tools, is a grid topology of 800 × 800 $m^2$ with a block size of 200 m × 200 m as depicted in Fig. 4.

The maximum speed of vehicles is fixed to 1, 5, 15, 25 m/s and the number of vehicles is fixed to 25, 50, 75, 100 for each simulation, respectively. These scenarios are randomly generated and each of them contains six roads, nine intersections, and 12 crossover points at the border. Vehicles move along the grid of horizontal and vertical streets on the map. Each line representing a single-lane road and vehicular movement occurs on the directions shown by arrows. At a crossover, vehicles choose to turn left or right with equal probability, 0.5. At the intersections of the horizontal and vertical streets, each vehicle chooses to keep moving in the same direction with probability 1/2 and to turn left or right with probability 1/4.

The simulation time is fixed to 100 s, which is long enough to evaluate the dissemination strategies with different nodes' speed and densities. Each node uses IEEE 802.11 MAC protocol, operating at 2 Mbps, to send/broadcast and receive messages. We used two-ray ground model for radio propagation and 200 m for the transmission range. The simulation parameters are described in Table 2.

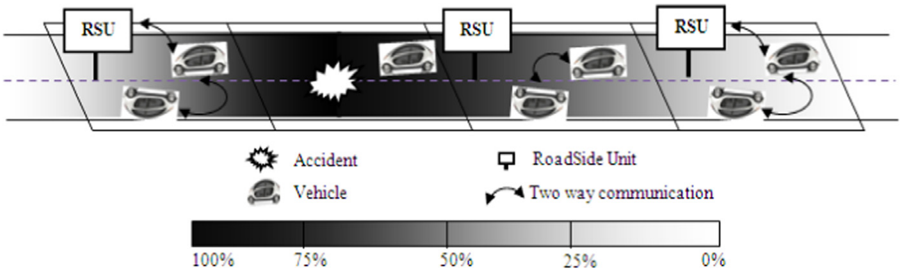

**Fig. 2.** The information dissemination process.

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When a vehicle receives the message $m_{p_j}$ do:
    queue (message $m_{p_j}$);
    generate a random value $\tau$ for $m_{p_j}$ dissemination;
    compute its relevance by eq.(2) or eq.(2') (based on the selected strategy G1 or G2);
    wait until the dissemination actually starts, i.e., until $\tau$ has expired, then do
        if the relevance value is positive
            disseminate $m_{p_j}$ to neighbouring nodes
        else discard $m_{p_j}$
    de-queue (message);
done.
```

**Fig. 3.** The message relevance and information dissemination algorithm.

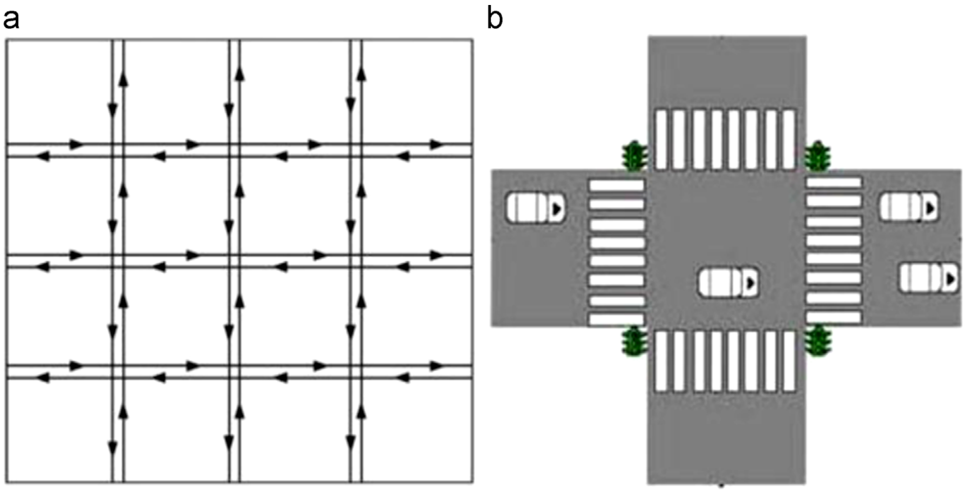

**Fig. 4.** (a) Mobility scenario and (b) structure of each intersection.

**Table 2**
Simulation parameters.

| Simulation parameter | Value |
|---|---|
| Network range ($m^2$) | 800 × 800 |
| Transmission range (m) | 200 |
| Number of nodes | 25, 50, 75, 100 |
| Nodes speed (m/s) | 1, 5, 15, 25 |
| Radius of geographical area (m) | 100, 200, 400, 600 |
| Alarm time (s) | 60, 120, 300, 1800 |
| Initial relevance value | 0.1, 0.5, 1.0 |
| Bandwidth (Mbps) | 2 |
| Message size (bytes) | 1000 |
| Simulation time (s) | 100 |

### 4.2. Simulation results

For both strategies G1 and G2, we have evaluated the average relevance value for different geographical area – *D* (Fig. 5), alarm time – *T* (Figs. 6 and 8), initial relevance value – $R^{(0)}$ (Figs. 7 and 9) and, network density (Fig. 10), and vehicles' speed (Fig. 11) variations.

Figure 5 presents average relevance value comparison according to different geographical areas (*D*, 100 m, 200 m, 400 m, and 600 m) for both strategies G1 and G2 (with $R^{(0)}=1$, $T=300$ s), for vehicles moving with maximum 15 m/s speed. The *x*-axis represents an average distance between receiving vehicles and the source location; it is decreasing or increasing based on the direction of vehicles, i.e., coming or going away from the event's location. It can be seen from the figure, the average relevance value increases for coming vehicles and decreases for going away vehicles. Significant influence of geographical area is depicted in the figure to the average relevance value of messages. For example, the average relevance value of received messages for larger defined geographical areas (*D*) is higher compared to small geographical areas for both strategies G1 and G2. For the strategy G1, as illustrated in Fig. 5a and b, the average relevance value for vehicles that are located at 400–500 m far away from the event location is greater than 0.6 for $D=600$ m and about 0.2 for $D=200$ m. However, when using the strategy G2, this data is slightly different; the average relevance value is small for short geographical area and high for long geographical area.

It is also noticed that, since strategy G2 uses intermediate nodes' information, the average relevance value for vehicles located far away from the event location is lower compared to the strategy G1. For example, when using G2, the average relevance value for vehicles located at 400–500 m far from the event location (Fig. 5c and d) is almost two times less than G1 (e.g., average relevance value is about 0.3 for $D=600$ m, about 0.2 for $D=400$ m, less than 0.1 for $D=200$ m, while they are more than 0.6, 0.4 and 0.2 for strategy G1, respectively). Furthermore, messages generated for short geographical areas (i.e., $D=100$ m) may not be interesting for vehicles located far away from the event location (i.e., far than 400 m), because its relevance value is almost 0 for both strategies G1 and G2. As the distance becomes shorter, the average relevance value is slightly similar when using either G2 or G1.

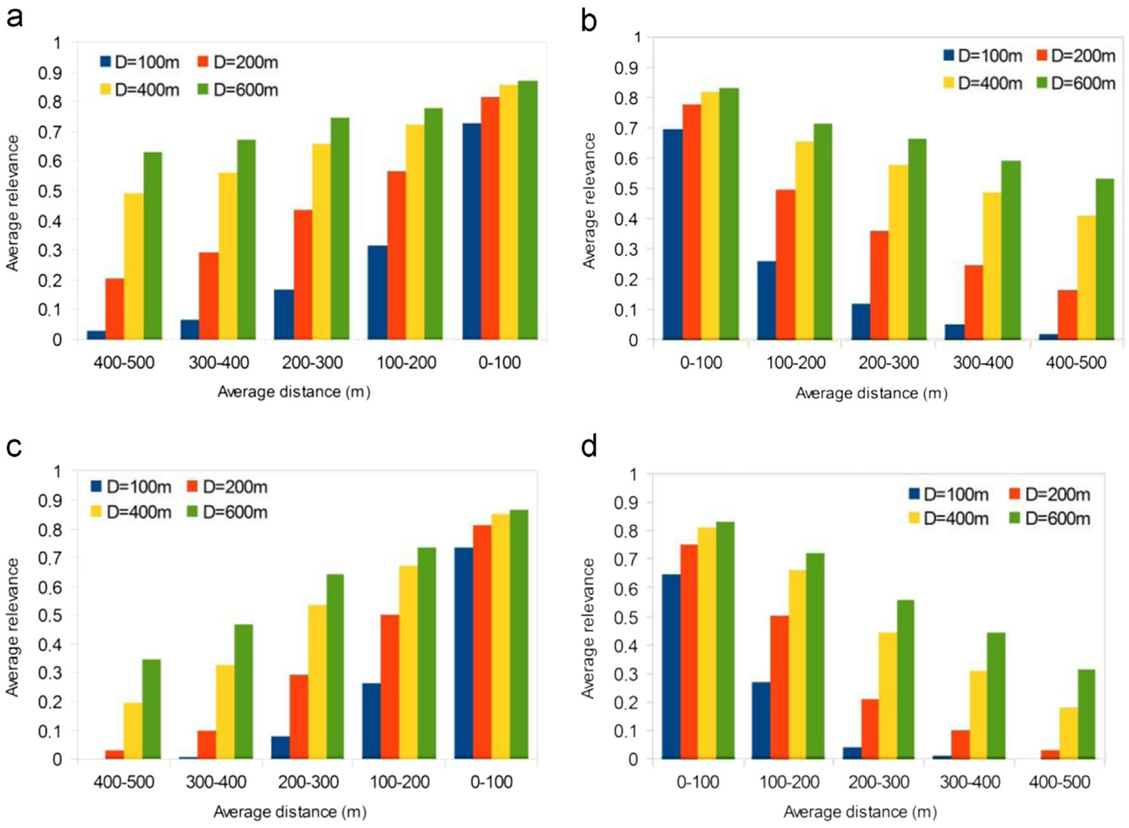

**Fig. 5.** Comparison of average relevance value according to determined geographical area ($D$) for both strategies G1 and G2 (with $R^{(0)}=1$, $T=300$ s).

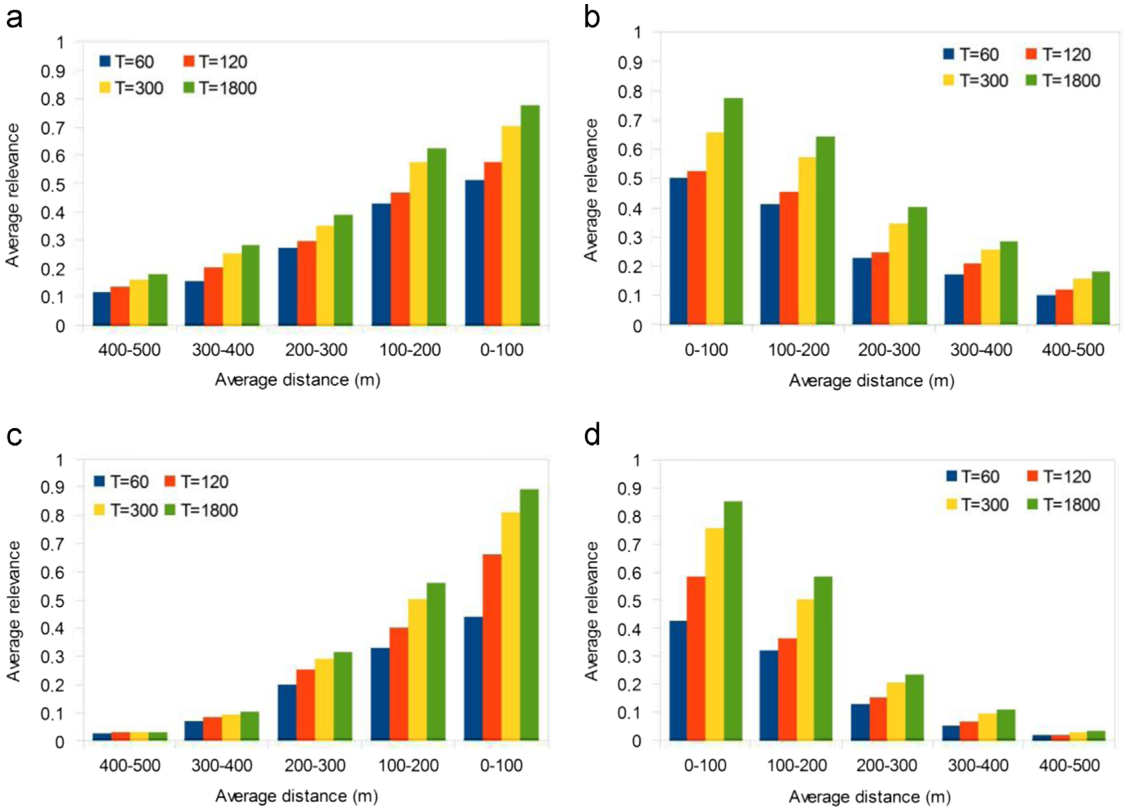

**Fig. 6.** Comparison of average relevance value according to alarm time ($T$) variation in 200 m geographical area with $R^{(0)}=1$

Figure 6 shows the average relevance values according to time $T$ required to solve the problem caused by the event on the road (e.g., time needed for extrication in case of accident). In these graphs, the relevance value is initialized to 1 and the geographical area is fixed to 200 m (equal to transmission range). As shown in these figures, the average relevance value is lower when $T$ is small.

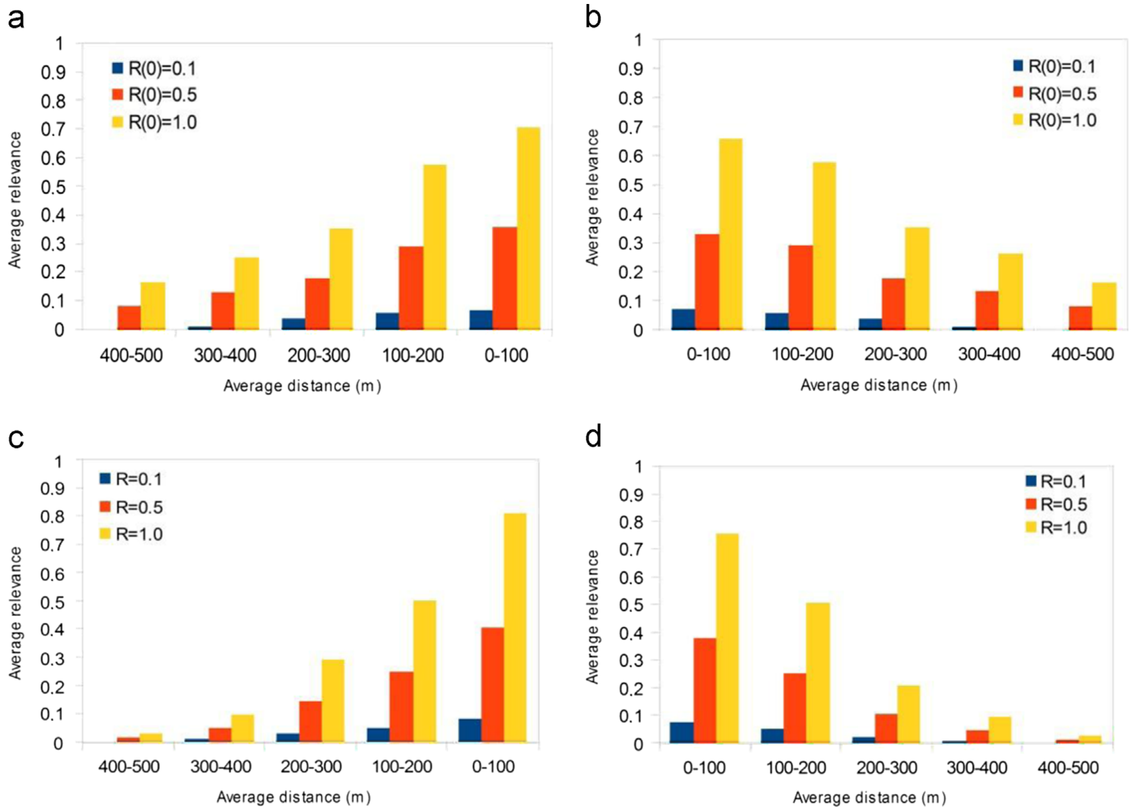

**Fig. 7.** Comparison of average relevance value according to initial relevance value ($R^{(0)}$) variation in 200 m geographical area with 300 s alarm time.

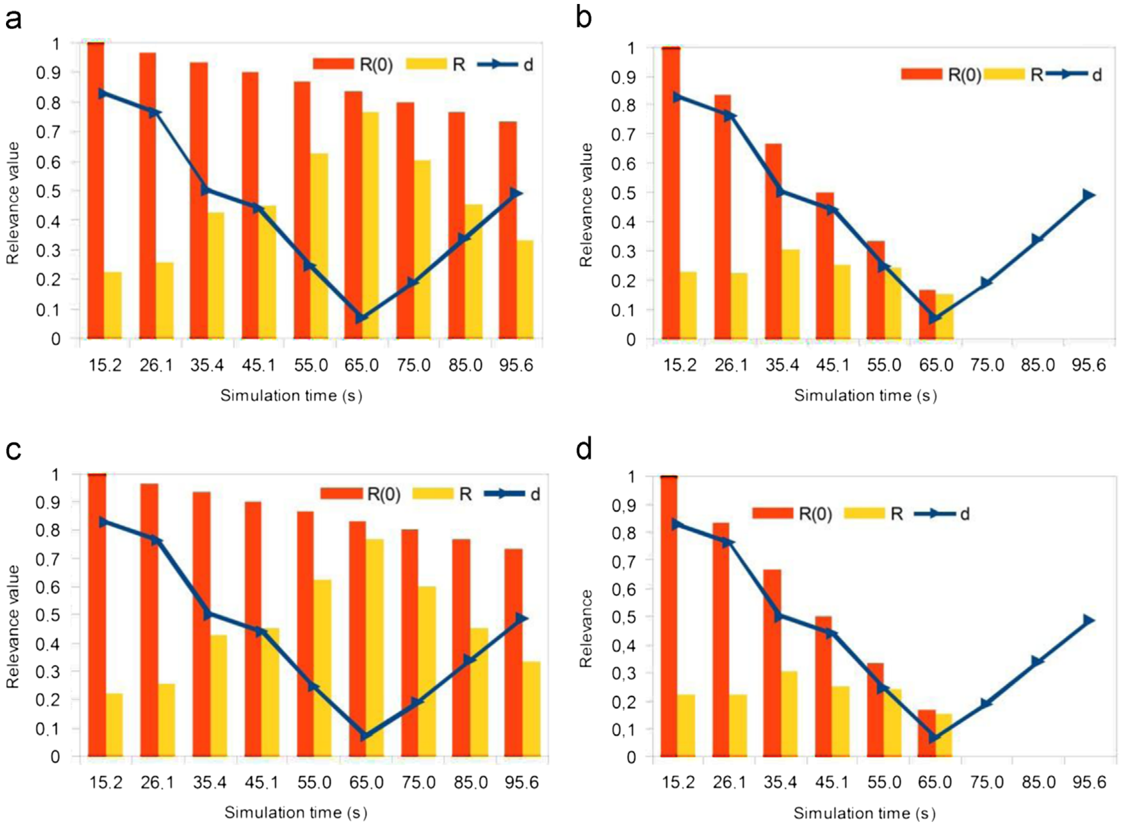

**Fig. 8.** Comparison of relevance value according to alarm time ($T$) variation for individual given node ($D$=200 m, $R^{(0)}=1$). (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

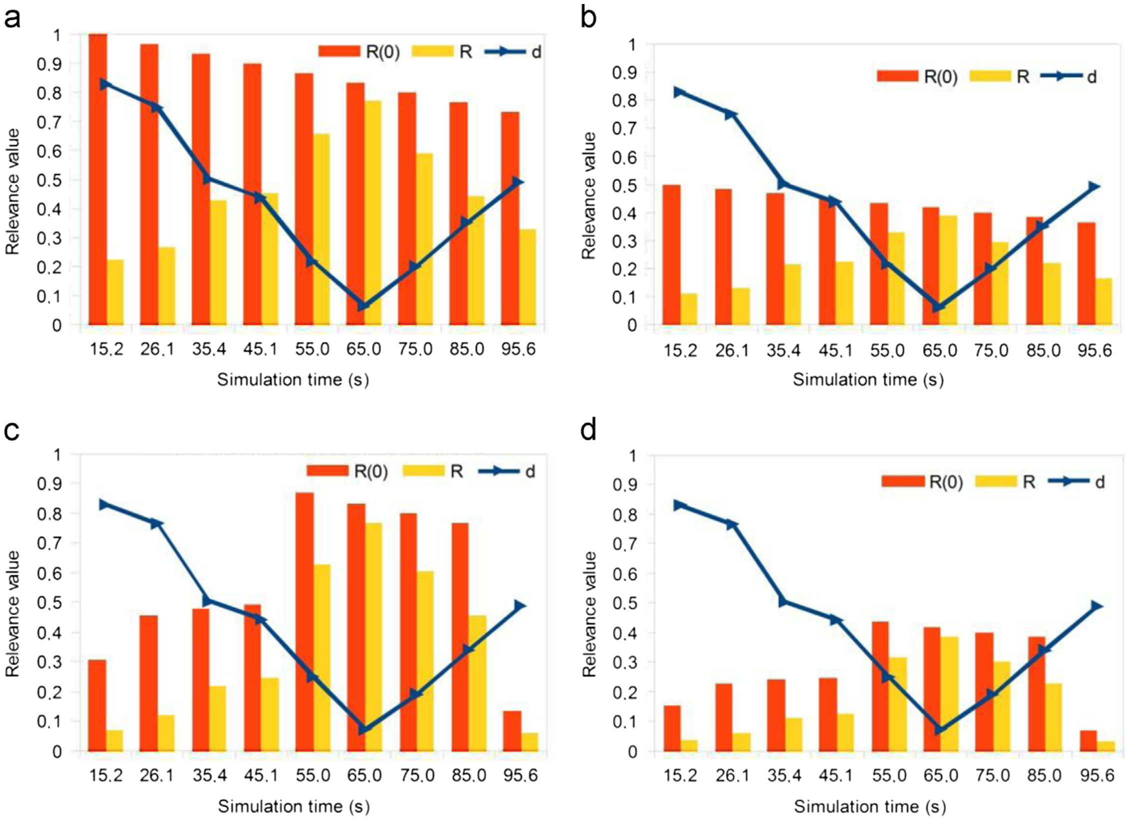

**Fig. 9.** Comparison of relevance value according to initial relevance value ($R^{(0)}$) variation for individual given node ($D = 200$ m, $T = 300$ s).

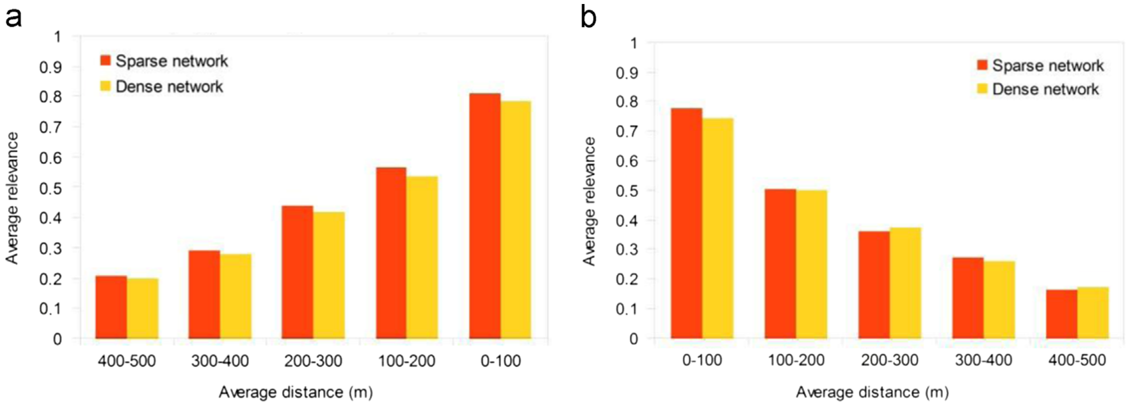

**Fig. 10.** Comparison of relevance value according to network density variation ($D = 200$ m, $T = 300$ s, $R^{(0)} = 1$).

As time required to warn is long about the event, the average relevance value will be high. This is due to the influence of time $T$ during message generation process at the source node. For vehicles located within the same distance from the event location, the average relevance value is high for long warning/alarming time. For example, for vehicles located at 100–200 m distance, the average relevance value is more than 0.5 with 300 s alarm time while this value is about 0.3 for vehicles located within the same distance with $T = 60$ s for both strategies, G1 and G2. The average relevance value for the strategy G2 is lower than G1 (except for vehicles that are located within the transmission range), because in G2 receivers use intermediate node's relevance values to compute the new message relevance values. While in strategy G1, receivers use only the relevance value that is generated by the source node. Vehicles that are located far away from the event location can receive messages mostly from intermediate nodes (with lowered relevance value) rather than directly from the source node (which has original relevance value). For example, as illustrated in Fig. 6c and d, the average relevance value, when using the strategy G2, is less than those values obtained when using G1 mainly for vehicles farther than 200–300 m from the event location. Moreover, vehicles located at 400–500 m far from the event location have almost the same average relevance value for all values of $T$ for both strategies G1 and G2. As the distance is decreasing, the average relevance value is increasing for all $T$, but, with slight increase for higher $T$. For example, in G2, the average relevance value is near to 0 for all $T$ for those vehicles located at 400–500 m distance from the event location, and there is minor difference among average relevance values for different $T$ at 300–400 m distance, which has significant difference for 0–100 m distance.

Figure 7 compares the average relevance value when using different initial relevance values (i.e., generated by the source node). Warning time $T$ is fixed to 300 s and the relative geographical area $D$ is fixed to 200 m. As discussed above, based on the event significance/severity, the source node sets the initial relevance value $R^{(0)}$ and disseminates an emergency message to neighboring vehicles. Afterwards, when vehicles receive this message the new relevance value will be computed. If the message is relevant it will be re-disseminated with a new relevance value.

As mentioned in the previous section, the main difference between strategies G1 and G2 is related to the message relevance value. When using G1, the relevance value of messages will not change by receiver nodes; i.e., messages are disseminated with the original relevance value. However, when using G2, receiver nodes disseminate messages with a new computed relevance value. It can be seen from the graphs that the average relevance value for vehicles located around transmission range (200 m) of the source node is almost same for both strategies G1 and G2. For example, the average relevance value for vehicles located within 0–100 m distance from the event location is about 0.82 for $R^{(0)}=1$, 0.4 for $R^{(0)}=0.5$, 0.08 for $R^{(0)}=0.1$ for both strategies G1 and G2.

The average relevance value decreases as the distance between a receiver node and the event location increases. Unlike G1, when using G2, the average relevance value decreases faster because vehicles those are located far away from the event location receive messages most often by the participation of intermediate vehicles. For example, the average relevance value when $R^{(0)}$ is fixed to 1 (original relevance value) is about 0.5 for both strategies G1 and G2 for vehicles going away and are within 100–200 m distance from the event. This value decreases slowly to reach 0.18 for strategy G1 (Fig. 7b), while it decreases faster to become almost 0 for strategy G2 (Fig. 7d) when vehicles are situated within 400–500 m.

It is worth noting that the values of $T\,R^{(0)}$ are directly dependent on each other. More precisely, let us consider that an event is detected based on its severity, an initial relevance value and a warning time are initialized. Afterwards, periodically, emergency messages are generated and the relevance value of these messages is gradually decreased (by Eq. (1)) according to the initialized warning time $T$. At the end of the period $t=T+t_0$ the relevance value becomes 0, i.e., end of generation process of messages. Therefore, neighboring vehicles will receive messages every time but with a decreased relevance value. Figures 7 and 8 show the variation of relevance values over time based on different initial relevance values and warning time for individual nodes.

Figure 8 shows the relevance value for different warning times $T$ ($T$ is fixed to 300 s for long warning and 60 s for short warning) for both strategies G1 and G2. Emergency messages are periodically disseminated with 10 s time interval during $T$. Every time the original relevance value (set as $R^{(0)}=1$ in the beginning) is decreased according to Eq. (1). It is similar, as time elapses, to Ant's pheromone evaporation process, i.e., the relevance value is decreased constantly and disappeared after $T$ is expired. For both strategies, long original warning time (Fig. 7a and c) keeps high proportionality of relevance value during simulation (it will continue until $T$ is expired), while the relevance value decreases very fast when using a short original warning time (Fig. 8b and d).

As illustrated in Fig. 8b and d, because vehicles are receiving the original and decreasing relevance value from the source node, the relevance value continues decreasing while vehicles are coming to the event location. This can be explained by the fact that as time elapses the severity of the event is decreasing, i.e., the risk caused by the event (e.g., accident) will disappear within $T$, and vehicles are warned when they reach the place of the event. For example, in the simulation, after 75th second the relevance value reaches 0 and the dissemination process is terminated. It is worth noting that, the relevance value was low (less than 0.2) for our selected vehicle even it was very near to event location (in 65th second), because the dissemination process was terminated before it reaches the event location.

When using the strategy G1, the relevance value $R^{(0)}$ (red lines) generated by the source node decreases linearly as illustrated in Fig. 8a and b. However, when using the strategy G2, the relevance value $R^{(0)}$ increases and decreases because it is changed frequently by intermediate nodes during the dissemination process. For example, as shown in Fig. 8c and d the new computed relevance values are lower when compared to those obtained when using strategy G1 (Fig. 8a and b) for long distances. This is due to the fact that intermediate nodes, which are not within the transmission range of the source node, compute the new values of received messages. However, messages received by vehicles that are near to the event location have the same relevance value for both strategies G1 and G2.

When an event is detected, a relevance value is generated based on the event severity. For example, the original relevance value will be initialized higher ($R^{(0)}=1$, Fig. 9a and c) for very critical events, and lower (Fig. 9b and d) for less important events. Consequently, when messages are received by neighboring vehicles, the relevance value will be decreased or increased based on the direction of the vehicle, but, the highest value will be upper bounded by the initial relevance value being generated periodically by the source node (which is decreasing as time elapses) as shown in Fig. 8. When using the strategy G2, received relevance value is decreased by intermediate nodes for vehicles located far away from the event location. Accordingly, the new computed relevance values will be lower when compared with those obtained when using the strategy G1. But, for vehicles moving around the event location (within the transmission range) they are almost equal for both strategies (because they receive the same relevance value from the source node).

The impact of network density on the average relevance computation is illustrated in Fig. 10. We have simulated 100 nodes for dense network and 50 nodes for sparse network. Parameters used are fixed as follows: 200 m for geographical area, 300 s for alarm time, and 1 for initial relevance value. Values obtained for sparse network are in the same order of magnitude as values obtained when using dense networks, i.e., the difference is almost negligible. We can also see, as already stated above, that the relevance value increases and decreases linearly for vehicles coming or going away from the event location respectively. More precisely, the relevance value is not reacting very much to the network density. Only slight difference can be seen for coming vehicles in sparse network compared to dense networks (Fig. 10a). The relevance value of received messages depends on the distance between the current locations of vehicles and the event's location. In dense networks, intermediate nodes help in informing other neighbor vehicles if the geographical area is higher than the transmission range. However, in sparse networks, there are very few vehicles in the network, but messages can be received directly from the source since it is generated periodically. Similar results were produced for G2 with other parameters and show similar behavior as depicted in Fig. 10.

Figure 11 shows the average relevance value at various vehicles' speed, 1 m/s for low speed and 15 m/s for high speed. Other parameters are fixed as follows: $R(0)=1$, $D=200$ m, and $T=300$ s. As it can be seen from the graphs, vehicles' speed does not influence the average relevance value very much, instead they are interchangeable in some cases. It can be observed that the average relevance value is slightly higher for coming vehicles in high speed (for 500–200 m distance in Fig. 11a). Because, high speed vehicles can reach

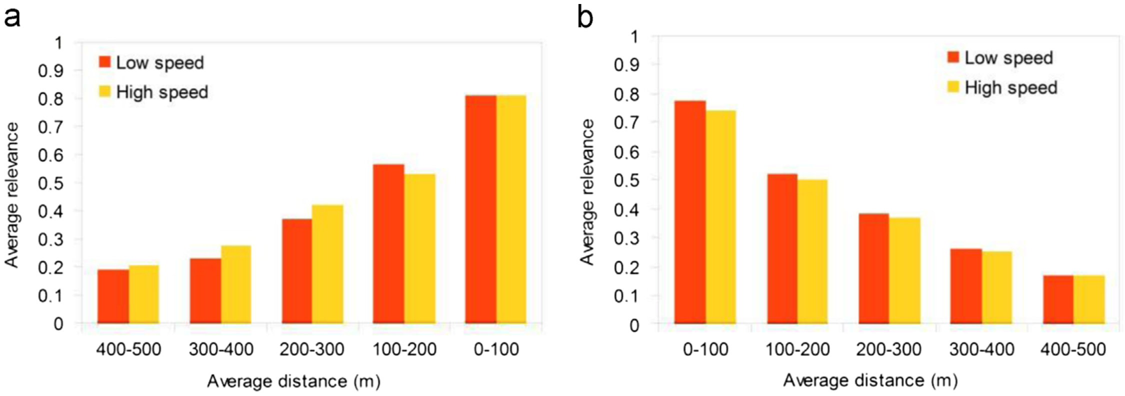

**Fig. 11.** Comparison of relevance value according to speed variation in 200 m geographical area.

event location faster/earlier comparing to low speed vehicles, and the risk is higher. However, the average relevance value is lower for high speed for going away vehicles (Fig. 11b).

It is worth noting that, according to Eq. (2) and Eq. (3) the value of $\lambda$, which represents the vehicle direction ($-1$ or $+1$), influences the relevance value of received messages; the relevance value decreases when the vehicle became increasingly remote rather than nearer to the accident location.

As shown in Figs. 5–11, for both strategies G1 and G2, new computed relevance value $R$ mostly depends on distance $d$, direction $\lambda = \pm 1$, geographical area $D$ as well as initialized relevance value $R^{(0)}$ and warning time $T$. As the relevance value is decreasing as time elapses, especially for vehicles going away from the event's location, it is also possible to limit dissemination process by fixing the minimum relevance value (by introducing a threshold for relevance, by default 0). For instance, for messages generated for 200 m geographical area, with enough long warning time and high initial relevance value, the minimum relevance value can be fixed to 0.2. Afterwards, vehicles will/may not take any action (simply discard) because the received message could be considered not important/relevant. But, there is a relationship between $D$, $T$, $R^{(0)}$ based on the event severity/level, $D$ should not be very short with long $T$ or with high $R^{(0)}$.

From the results presented above, it is shown that for vehicles far away from the event location the average relevance value is lower when using the strategy G2 compared to the strategy G1. Because in strategy G2, the new relevance value of messages is computed using relevance value received from intermediate nodes, while in strategy G1 only the original relevance value is used. It is worth noting that, the strategy G1 is more suitable, because, the relevance value is proportionally distributed within geographical area according to distance between current locations of vehicles and the event location.

## 5. Conclusions and future work

In this paper, a decentralized information dissemination method inspired from Ants' colony behavior exploiting stigmergy and direct communication is proposed. The main goal is to provide each vehicle with the required information about its surrounding and assist drivers to be aware of undesirable road conditions. Simulations are conducted and results are reported to show the benefit of using Ants' principles for information dissemination in inter-vehicle networks. The main advantage of using proposed dissemination strategies is that the geographical area is not defined in advance. When a danger is detected (i.e., accident/icy road) an emergency message will be generated and disseminated in order to inform its surrounding vehicles. 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 becomes below 0 or a given threshold value. This value will be used to help driver making an appropriate decision, which is best suited to a particular context. Future work will include VSimRTI with ns2 in order to develop applications, such as rerouting and congestion avoidance, using this dissemination scheme.

## Acknowledgment

This work is supported by the EU EACEA Erasmus Mundus project TARGET-I (2011–2014) Grant agreement 2011-2569/001-001-EMA2. Authors wish to thank the reviewers and the editors who greatly helped us improving the paper.

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