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SPIM

Thèse de Doctorat



école doctorale sciences pour l'ingénieur et microtechniques
UNIVERSITÉ DE TECHNOLOGIE BELFORT-MONTBÉLIARD

BIO-INSPIRED APPROACHES FOR INFORMATION DISSEMINATION IN AD HOC NETWORKS

■ **Seytkamal MEDETOV**

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Thèse de Doctorat



école doctorale sciences pour l'ingénieur et microtechniques
UNIVERSITÉ DE TECHNOLOGIE BELFORT-MONTBÉLIARD

Thèse présentée par

Seytkamal MEDETOV

pour obtenir le

Grade de Docteur de

l'Université de Technologie de Belfort-Montbéliard

Spécialité : **Informatique**

BIO-INSPIRED APPROACHES FOR INFORMATION DISSEMINATION IN AD HOC NETWORKS

Soutenue le 19 décembre 2014 devant le Jury :

Mr. Tarek El-GHAZAWI	Rapporteur	George Washington University
Mr. Thierry DIVOUX	Rapporteur	Université de Lorraine
Mr. Maxime WACK	Directeur de thèse	Université de Technologie de Belfort Montbéliard
Mr. Pascal LORENZ	Examineur	Université de Haute Alsace
Mr. Mohamed BAKHOUYA	Examineur	Université Internationale de Rabat
Mr. Jaafar GABER	Examineur	Université de Technologie de Belfort Montbéliard

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1.1 The research domain

General context: Information dissemination in Ad hoc networks

Specific context: Adaptive approaches for information dissemination in Ad-hoc networks inspired by swarm intelligence. Applications to safety in Vehicular Ad hoc Networks (VANETs).

1.2 Background

A wireless ad hoc network is a decentralized type of wireless network, where communication does not rely on a pre-existing infrastructure, such as routers in wired networks or access points in infrastructure-based wireless networks. Instead, each node participates in routing by forwarding data to the other nodes, and the determination of which nodes forward that data is made dynamically, “on the fly”, according to the network connectivity [1].

Ad hoc communications are present in Wireless Sensor Networks (WSNs), Mobile Ad hoc Networks (MANETs) and Vehicular Ad hoc Networks (VANETs). In WSNs, nodes are usually static and the communications are more reliable compared to MANETs wherein nodes are mobile. Movements of vehicles in VANETs could be predicted, because it is dependent on streets, traffic and specific rules. Communication in VANETs is less reliable compared to MANETs due to the high mobility, dynamic topology and different traffic patterns.

Moreover, in VANETs, safety information should be disseminated to other surrounding vehicles in order to inform 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 [2].

Flooding is a fundamental mechanism to disseminate information in ad hoc networks. However it causes increased redundancy of messages, contention, collision, and wastage of channel bandwidth within the network. Several techniques have been proposed to solve these problems in the context of MANETs. However, in the context of VANETs, these protocols may behave in a different way than MANETs due to the fact that nodes (i.e., vehicles) can move too fast as compared to ordinary MANETs' nodes. In VANETs, the network topology changes regularly since vehicles can frequently leave and join the network. Therefore, dynamic and adaptive protocols are essential to establish reliable communication in ad hoc networks, especially in VANETs.

In this work, information dissemination approaches in ad hoc networks are developed by taking inspiration from self-organized natural swarms, particularly ant- and bee-colony. They have collective behaviors that result from the local interactions with each other and with their environment. Despite ants are simple insects, they 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 shortest routes from the nest to food locations [3]. 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 [4]. Similarly, a honey bee colony also achieves coordination among its thousands of members. Bees called "scouts" navigate the surrounding side to search food sources. They share information about these discoveries with the other hive mates when they return to the bee hive through round or waggle dances according to the discovery distance, quality etc.

1.3 Motivations

VANET applications can generally be categorised into two types, safety applications and user applications. The former deals with the safety of drivers and the latter deals with driver

comfort services. For safety, vehicles in close proximity can exchange information to increase awareness of driving problems and road conditions. The aim is to enhance safety by triggering alerts of emergency situations. Applications such as traffic and congestion monitoring require collecting information from vehicles that span multiple kilometers. In contrast, safety oriented applications has strict latency constraints of the order of few milliseconds, and very high reliability and relevance requirements.

1.4 Problem Statement

It should be noted that, 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. Several techniques have been proposed to solve this problem by preventing certain nodes from rebroadcasting received messages and/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 receiver and sender, the location (i.e., position) in an appropriate cluster of nodes. However, it should be noted that these methods used various static threshold parameters which is not very appropriate for dynamic networks, such as VANETs. Therefore, adaptive approaches are required, where in each node can dynamically adjust the values of its local parameters using information from its environment and the neighboring nodes.

In this work, the main emphasis is put on critical emergency information dissemination in VANETs by mimicking swarm communication principles. More precisely, swarm based context aware information dissemination approaches that take inspiration from bee and ant colony communication principles for information dissemination in VANETs are proposed.

1.5 The contributions

The work deals with information dissemination in Ad hoc Networks, particularly, targeted to improve safety in VANETs. Safety applications in VANETs extend driver knowledge about the surrounding environment and warn drivers of undesirable road conditions. For example, if the in-vehicle ABS is activated, it might indicate bad road conditions, and if this information is shared between vehicles, other drivers are warned to take preventive actions before getting to a dangerous situation. Information dissemination in VANETs relies on broadcasting protocols. The main advantage of a broadcasting scheme is that a vehicle does not need to know a destination address and a route to a specific destination. This eliminates the complexity of route discovery, address resolution, and topology management, which are difficulties in dynamic networks such as VANETs [7]. It should be noted that broadcasting protocols refers to network layer whereas information dissemination regards to application layer. Information dissemination in application layer does not rely on an end-to-end semantic implemented in networks layer, i.e. the safety information issued as single-hop broadcast by a source node is processed at every receiving node, and afterwards (modified or not) re-distributed if required. Thus, the responsibility of information dissemination resides on the application itself [8].

Particularly, within the scope of the thesis the following contributions have been made:

- An adaptive information dissemination algorithm is evaluated for Mobile and Vehicular Ad hoc Networks;
- Novel information dissemination approaches are developed for safety applications in VANETs by taking inspiration from swarm communication system, i.e., ants and bees foraging principles;
- A new message relevance concept is introduced into safety message content as an analogous to ants' "pheromone", and bees' "profitability" parameters.

1.5.1 Adaptive information dissemination algorithm in MANETs/VANETs

We have evaluated an adaptive, scalable and effective information dissemination approach, “Adaptive Information Dissemination (AID)”, in the context of Mobile and Vehicular Ad hoc Networks. In this approach, each node can dynamically adjust the values of its local parameters using information from neighboring nodes without requiring any additional effort, such as distance measurements or exact location-determination of nodes. The details will be provided in the Chapter 3.

1.5.2 Ant-based Information dissemination approach in VANETs

We have developed a decentralized context aware information dissemination approach by taking inspiration from Ant communication principles, targeted to provide each vehicle with the required information about its surrounding and assist drivers to be aware of undesirable road conditions. The details will be provided in the Chapter 4.

1.5.3 Bee based information dissemination approach in VANETs

We have developed roadside unit (RSU) based information dissemination approach by taking inspiration from the Bee communication system. Bees communicate with each other in their hives by round and waggle dances to share information about food sources and for which, intensity and shape depends on distance and quantity. Vehicles communicate with each other via RSUs, similar with bees, to increase reliability and minimize redundancy in our proposed approach. The details will be provided in the Chapter 5.

1.6 Organisation of the Dissertation

1.6.1 General presentation

The Dissertation is structured in six chapters, including a general introduction, conclusions and perspectives. The first chapter provides General introduction and information about the

problem statement, the objectives and the contributions. The second chapter overviews the main concepts of information dissemination in Ad hoc Networks: MANETs and VANETs. The third chapter proposes an Adaptive broadcasting algorithm in MANETs and VANETs. The fourth and fifth chapters propose Ant- and Bee-inspired information dissemination approaches in VANETs respectively. Simulation results of bee-based approach are studied comparatively with ant-based approach in the fifth chapter. Finally, we present conclusions and perspectives in the sixth chapter.

1.6.2 Global view

- Chapter 1: General Introduction
- Chapter 2: State of the art
- Chapter 3: An adaptive broadcasting algorithm in Ad hoc Networks
- Chapter 4: Ant-inspired Information dissemination approach in VANETs
- Chapter 5: Bee-inspired Information dissemination approach in VANETs
- Chapter 6: Conclusions & Perspectives

1.6.3 Chapter Contents

A. Chapter 1: General Introduction

The General introduction chapter provides information about background and motivation, problem statement, the objectives and contributions of the dissertation.

B. Chapter 2: State of the art

This chapter presents the main concepts of Ad hoc Networks, basic mechanisms and classification of information dissemination algorithms in Mobile and Vehicular Ad hoc Networks, together with some swarm-inspired approaches implemented for different area of research.

C. Chapter 3: An adaptive broadcasting algorithm in Ad hoc Networks

In this chapter, we present in details our adaptive broadcasting approach in Mobile and Vehicular Ad hoc Networks. In the concept of mobility in Ad hoc Networks, adaptive approaches are important to perform information exchange effectively. In this approach, each individual node can dynamically, based on the number of received messages from its neighbors, decide on rebroadcasting them or not.

D. Chapter 4: Ant-based Information dissemination approach in VANETs

In this chapter, we present our Information dissemination approach in VANETs inspired by swarm communication principles, particularly using ant colony communication system. 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 other vehicles and roadside units, to allow drivers to be aware of undesirable events and road conditions.

E. Chapter 5: Bee-based Information dissemination approach in VANETs

In this chapter, we propose an RSU-based Information dissemination approach in VANETs inspired by bee communication principles. Foragers in bee-colony communicate with hivemates in their hive by round and waggle dances to share their food findings. Similarly, in our approach, the communication is organized via RSUs. RSUs collect information from surrounding vehicles and disseminate them by their priority. Safety related messages with higher relevance value are disseminated immediately. Ant- and bee-inspired approaches are comparatively studied using network simulator NS2, to show their advantages and disadvantages.

F. Chapter 6: Conclusions and perspectives

In this part of the dissertation, we present the summary of the work and future work, i.e., perspectives will be listed in the end of the chapter.

Chapter 2 - State of the Art

The major contribution of this chapter is a comprehensive introduction of main concepts and communication protocols of Mobile and Vehicular Ad hoc Networks. First we will talk about communication mechanisms, applications, followed by classification of information dissemination approaches in Mobile and Vehicular Ad hoc Networks.

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2.1 Introduction

The major contribution of this chapter is a comprehensive introduction of main concepts and communication protocols of Ad hoc Networks, particularly inspired by natural swarms. First we will talk about communication mechanisms, applications, followed by classification of information dissemination approaches.

A wireless ad hoc network is a decentralized type of wireless network, where communication does not rely on a pre existing infrastructure, such as routers in wired networks or access points in managed (infrastructure) wireless networks. Instead, each node participates in routing by forwarding data for other nodes, so the determination of which nodes forward data is made dynamically, “on the fly”, on the basis of network connectivity. Such wireless ad hoc networks can be categorized via their application, such as Wireless Sensor Networks (WSN), Mobile Ad Hoc Networks (MANET) and Vehicular Ad hoc Networks (VANETs).

2.1.1 *Wireless Sensor networks*

Wireless sensor network (WSN) is a particular type of ad hoc network, in which the nodes are ‘smart sensors’, that is, small devices (approximately the size of a coin) equipped with advanced sensing functionalities (thermal, pressure, acoustic, and so on, are examples of such sensing abilities), a small processor, and a short-range wireless transceiver. In this type of network, the sensors exchange information on the environment in order to build a global view of the monitored region, which is made accessible to the external user through one or more gateway node(s). Sensor networks are expected to bring a breakthrough in the way natural phenomena are observed: the accuracy of the observation will be considerably improved, leading to a better understanding and forecasting of such phenomena. The expected benefits to the community will be considerable [9].

A sample application scenario could be a situation in which a WSN is used to monitor a vast and remote geographical region, in such a way abnormal events (e.g. a forest fire) can be quickly detected. In this scenario, smart sensors, each equipped with a battery, and significant processing and wireless communication capabilities, are placed in strategic positions, for example, on the top of a hill or in locations with wide view. Each sensor covers a few hectares area and can communicate with sensors in the surrounding. The sensor node gathers atmospheric data (e.g. temperature, pressure, humidity, wind velocity and direction) and analyzes atmosphere makeup to detect particular particles (e.g. ash). Furthermore, each sensor node is equipped with an infrared camera, which is able to detect thermal variations. Every sensor knows its geographic position, expressed in terms of degree of latitude and longitude. This can be accomplished either by equipping every node with a GPS receiver, or, since in this scenario sensor position is fixed, by setting the position in a sensor register at the time of deployment. Periodically, sensors exchange data with neighboring nodes in order to detect unusual situations that could be caused, for instance, by a starting fire (e.g. temperature at a sensor much higher than those of the neighbors). These routine data are aggregated and propagated throughout the network and can be gathered by the external operator to collect atmospheric data (e.g. to check the air quality). When a potentially dangerous situation is detected (e.g. the infrared camera detects a rapid thermal increase in a certain zone), an emergency procedure is started: the sensor node that has detected the abnormal condition communicates with its neighbors in order to verify whether the same condition has been detected by other sensors; then, it tries to accurately determine the geographic position of the hazard (if the same abnormal situation has been detected by other sensors, this can be accomplished using triangulation techniques; furthermore, the information on the wind velocity and direction can be useful both in the localization of the fire and in forecasting the direction of its propagation); once the position of the fire has been determined, an alarm message containing the fire's geographic coordinates and (possibly) its propagation direction

is disseminated with the maximum priority. This way, the external operator (e.g. a park ranger equipped with a portable device) is promptly alerted of the presence of fire, of its position, and of the forecasted propagation direction of the fire, and can intervene quickly [9].

A WSN is typically composed of nodes with the same features. A partial exception to this rule is when different types of smart sensor nodes are used in the same network: for instance, a few super nodes with more memory and/or with a longer transmitting range could be used in combination with standard sensor nodes to increase the network monitoring ability. Typically, the number of nodes composing a WSN is quite large, ranging from few tens to thousands of nodes that are dispersed in a relatively large geographical region, so that 1-hop communication between nodes is, in general, not possible.

Nodes composing a WSN are typically stationary, or at most slowly moving. Given the very wide range of WSN applications, exceptions to this rule are possible. This is the case, for instance, of a sensor network used to track animal movements.

2.1.2 Mobile Ad hoc Networks

Mobile Ad hoc Networks is the another form of ad hoc networks different than WSN with its node mobility features. Mobile and static nodes in battlefields or within the vicinity of disaster areas may not depend on fixed infrastructure for communication. To rapidly provide the required communication between the nodes in such environments, a Mobile Ad hoc Network is the only available platform. With no fixed infrastructure, the efficient use of MANET resources is highly crucial for the successful communication between mobile nodes. In situations where both the transmitting and the receiving nodes are placed within the transmission range of each other, communication is possible through a single-hop connection. In all other scenarios where the nodes are distanced, the exchange of packets is possible as long as a multi-hop path is available between them. Despite the unique characteristics of MANETs, they share many attributes and operations with other traditional networks [10].

In the past few years, several broadcasting protocols have been proposed for MANETs to solve so named broadcasting storm problem which is directly related with flooding. Flooding is the most simple broadcasting technique in which the source node disseminates a message to all its neighbours, each of these neighbour will check if they have seen this message before, if yes the message will be dropped, if not the message will be re-disseminated at once to all their neighbors. Broadcasting through flooding causes increased redundancy of messages, contention, collision, and wastage of channel bandwidth within the network. Other protocols can be categorized as Probabilistic, Counter, Distance, neighbor knowledge and cluster based categories. Besides those the approaches could be based on action-selection mechanisms that allow network nodes to decide on message rebroadcasting (re-broadcast or discard) with the objectives are like to minimize the redundant messages, increase the reachability, and minimize latency.

2.1.3 Vehicular Ad hoc Networks

Vehicular Ad hoc Networks are special subclass of MANETs for inter-vehicle communication and have relatively more dynamic nature compared to MANETs due to the rapid network topology changes. 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, dynamic topology and different traffic patterns compared to MANETs, as mentioned above.

The development and implementation of efficient and scalable algorithms for information dissemination in VANETs is a major issue which has taken enormous attention in last years. Substantial research efforts on Ad hoc networks have been devoted to VANETs to target Vehicle to Vehicle (V2V) and Vehicle to Roadside unit (V2R) communication in order to increase driver/vehicle safety, transport efficiency and comfort. Generally, vehicular networks

are considered to contain two types of nodes: vehicles and roadside stations. Both are dedicated short-range communications (DSRC) devices. DSRC works in 5.9 GHz band with bandwidth of 75 MHz and approximate range of 1000 m [11].

The IEEE 802.11 working group proposed a family of standards for vehicular networks called WAVE (*Wireless Access in the Vehicular Environment*). WAVE is composed by two categories of standards: (i) 802.11p for the physical and medium access control layers and (ii) IEEE 1609 for security, network management as well as other aspects of VANETs [12]. 802.11p supports Intelligent Transportation Systems (ITS) applications such as cooperative safety, traffic and accident control, intersection collision avoidance, and emergency warning. In Europe, 802.11p was used as a basis for the ITS-G5 standard, supporting the GeoNetworking protocol for V2V and vehicle to infrastructure (V2I) communication. ITS G5 and GeoNetworking is being standardised by the European Telecommunications Standards Institute (ETSI) group for ITS [13].

2.2 VANETs applications

Applications in VANETs can be classified into two main categories, i.e., comfort and safety applications [14] [15]. In general comfort related applications is aimed to improve passenger comfort and traffic efficiency, e.g., traffic-information, weather information, gas station or restaurant location, advertisements and other Internet services [16]. 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 [17]. 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 [2].

2.2.1 Safety applications

Safety applications play a significant role in reducing the number of accidents. The goal is to improve the safety level of passengers by exchanging safety relevant information between vehicles. The information is either presented to the driver or used by automatic active safety system. Typically, safety applications can be classified as shown in Figure 2.1.

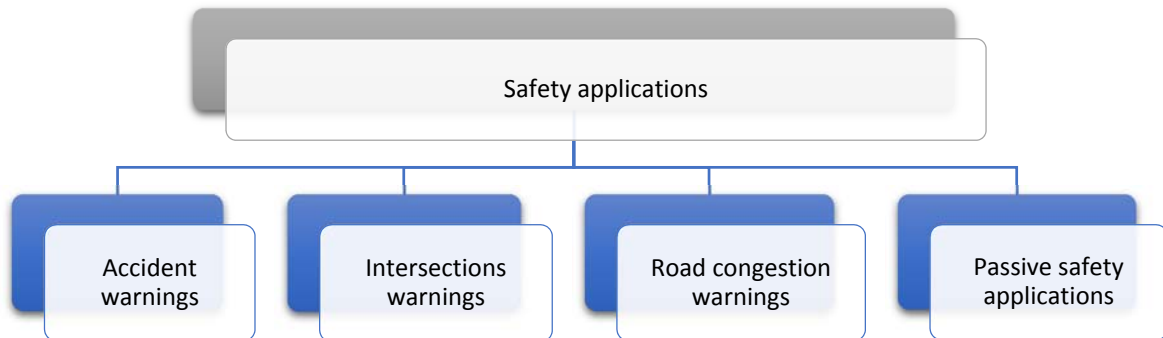


Figure 2.1: General view of Safety applications

Vehicles on road generally travel at very high speed which gives the driver only a short span of time to react to vehicles in front of them. In many emergency cases this reaction time is very less to avoid an accident, especially when the driver cannot see the vehicles upfront due to some bad weather condition, sharp hair pin bends and when they violate traffic rules etc. The safety applications warns the drivers early by giving a alert message of an accident occurred further ahead of the road, thus preventing the accident by giving some extra time for the driver to react.

The possibility of accidents is very high as two or more traffic flows intersect in junctions which makes it a complex challenge for the driver. Large number of accidents could be prevented if the driver is warned early by the safety application in this situation. It is worth noting that safety applications could provide the best route to drivers to their destinations and also decreases road congestion, ensures smooth traffic flow and in turn prevents traffic jams.

It eases the driver's job by providing a clear mind-set and makes them less frustrated and in turn indirectly it reduces the number of accidents.

In addition, modern vehicles are equipped with special devices to provide passive safety applications to protect the passenger from injuries during the accident occurrence. Air bags and safety belts are some examples of passive safety applications. It doesn't help to avoid accidents but it is quite useful in critical situations, accidents and it finds the exact locations of the people affected and provides assistance to them effectively. Post crash emergency applications are an effective subset of passive applications.

2.2.2 User applications

User applications can provide road users some valuable information, entertainment services, advertisements etc. Some applications are related only to user entertainment and cannot be linked to safety applications. The main role of the user applications is to comfort the passengers, improving traffic system, adding entertainment but make sure that, it doesn't affect the safety applications. Parking availability services and Internet connectivity are examples of the user applications.

By providing a clear picture on a empty parking slot in a specific region, provides safety and saves time by finding an exact place to park your vehicle in crowded places like shopping mall, restaurants, theatres etc. Nowadays constant internet connectivity is unavoidable for many users and vehicle occupants as it is the backbone for many other VANET applications to function properly [6]. This also means that without a requirement of a specific re-development, usual business framework should be seamlessly present in the vehicle.

In order to alleviate boredom, especially for the vehicle occupants, some of the entertainment applications like sharing the movies, music, chatting with each other could be done during their long journeys.

2.3 Information Dissemination in Vehicular Ad hoc Networks

Information dissemination is the basic operation in VANETs safety applications. Vehicles participate in collecting and reporting useful traffic information such as section travel time, flow rate, and density in a self-organized, distributed network of vehicles. Disseminating traffic information relies on broadcasting protocols. It is worth noting that dissemination/broadcasting is an essential building block for most Mobile and Vehicular Ad hoc Network protocols. For example, most unicast [18], multicast [19] and geocast [20] routing protocols use broadcasting to establish routes or to transmit an error packet for an invalid route [21]. Traditional unicast and multicast protocols using ID-based addressing might still be needed for infotainment applications or the extension of hotspot access. However, the challenge for VANET network protocols targeted to safety applications address mainly geographical areas in which data needs to be distributed [22].

Taking into account the considerable differences existing between VANETs and conventional networks, protocol layering is regarded as a reasonable approach to manage the complexity of VANET technology. Therefore, the different OSI layers, precisely network and application layers are referred when assigning the different functionalities for different types of information dissemination. Two opposite approaches for information dissemination in VANETs: packet-centric forwarding (PCF) and information-centric forwarding (ICF) are identified in [8]. PCF refers to the conventional approach for packet-switched communication where the source breaks the information into data packets and addresses them to one or more network nodes. With PCF the responsibility of information dissemination resides on the network layer, i.e., specific forwarding algorithms, located at the network layer in stacked protocol architecture as in the OSI model, try to provide efficient and reliable delivery of these packets over potentially multiple wireless hops. In contrast, with ICF, the responsibility of information dissemination resides on the application itself. Thus, communication system is

basically comprised of two main interconnected entities, a communication domain (radio modem, medium access, routing and transport protocols) and an application domain [8].

It should be noted that broadcasting protocols refers to network layer whereas information dissemination regards to mainly application layer. Information dissemination in application layer does not rely on an end-to-end semantic implemented in networks layer, i.e. the safety information issued as single-hop broadcast by a source node is processed at every receiving node, and afterwards (modified or not) re-distributed if required [8]. Recently, there have been a significant number of broadcasting protocols for VANETs reported in the literature [23]. The main advantage of a broadcasting scheme is that a vehicle does not need to know a destination address and a route to a specific destination. This eliminates the complexity of route discovery, address resolution, and topology management, which are difficulties in dynamic networks such as VANETs [7].

We have classified broadcasting protocols used for information dissemination in VANETs in the next sub-section 2.3.1.

2.3.1 Classification of broadcasting protocols

Several broadcasting protocols for information dissemination have been recently proposed [23] [24] [25]. These protocols can be classified into two main categories: *Statistical- or geometric-based* and *Network topology-based* protocols. The first protocols' category depends upon certain threshold values (e.g. distance, redundant message counts, or broadcast probability) to estimate the network density while protocols in the other category use sophisticated structures or neighborhood information to construct the broadcast schedule. Figure 2.2 depicts the whole classification.

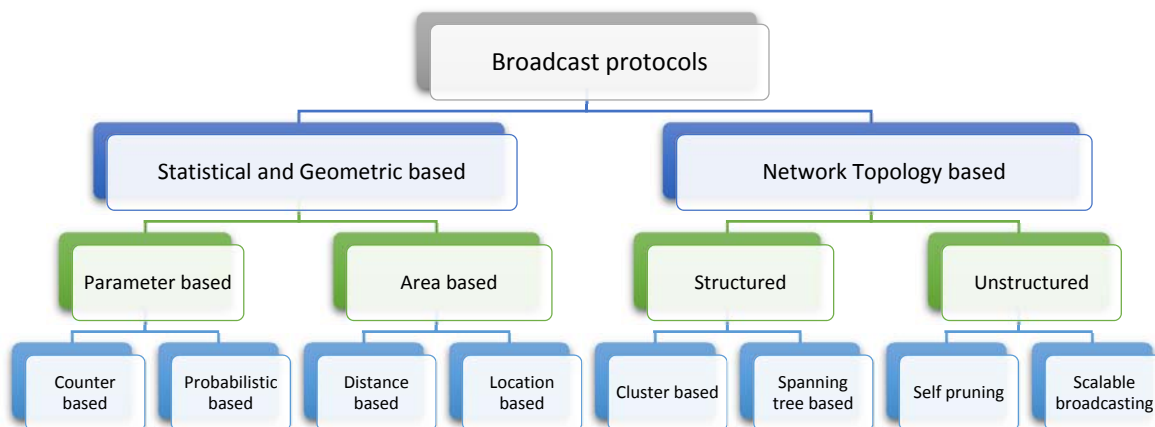


Figure 2.2: The classification of broadcasting protocols

2.3.1.1 Statistical or Geometric Based Protocols

The statistical- or geometric-based protocols are also subdivided into sub-categories: parameter-based and area-based.

A. Parameter-based protocols

The parameter-based protocols basically extend the flooding technique [26] [27], in which the source node disseminates a message to all its neighbors only if this message is seen first time. The classical flooding algorithm has several drawbacks; first it is rather costly in terms of air interface usage, secondly, it is not reliable since most of the nodes are expected to broadcast the message at the same time, thus collisions are likely to occur, thirdly, it causes broadcast storm problem [24] that severely affect the resources consumption due to redundant message re-broadcast. Therefore, flooding has been modified by using certain parameters like broadcast probability and hop counters to reduce the number of redundantly received packets.

For example, in counter based broadcasting, a message will be rebroadcasted only if the number of received copies at a host is less than a threshold after random delay time (RDT) [27] [24] [28]. In [29], authors have modified the counter based protocol and named the new protocol as Hop Count Ad hoc Broadcasting (HCAB) protocol. In HCAB, upon receiving a

broadcast message for the first time, the node initiates a flag $R = true$ and records initial hop count value HC_0 of this message. Meanwhile, this node sets a RDT value between 0 and T_{max} . During the RDT, the node compares the hop count of redundantly received message HC_x with HC_0 and flag R is set to false if $HC_x > HC_0$. When the random delay expires, the node will relay this message if R is true. Otherwise, it just drops this message. The counter based techniques rely only on fixed counter HC_0 and also the message delay at each hop is increased due to RDT and counter comparison.

Another statistical-based scheme is based on a probabilistic technique in which mobile hosts rebroadcast messages according to certain probability that is defined at the initial stage. The fixed probabilistic approach reasonably reduces the number of redundant re-broadcasts; however, its performance suffers in less dense networks and need high probability to achieve good reachability. In other words, in dense networks, multiple nodes share similar transmission coverage, and therefore some nodes doesn't need to retransmit (the threshold need to be low), and in sparse networks, there is much less shared coverage, some nodes have to retransmit (the threshold needs to be high).

B. Area-based broadcasting techniques

Unlike the parameter-based protocols, the area-based broadcasting techniques exploit the geographical location of the node to calculate the additional coverage area of the sender. In other words, area based information broadcasting schemes take advantage of the geographical location of the nodes [30]. Two main approaches belong to this category, distance-based and location-based schemes. In the distance-based scheme [24], only the neighbor far away from the current node rebroadcasts the message i.e. a distance threshold value is defined. Upon reception of a previously unseen message, a RDT, a random value chosen between 0 and T_{max} seconds, is initiated and redundant messages are cached. When the RDT is expired, all source

node locations are examined to see if the node is closer than a threshold distance value. If true, the node doesn't rebroadcast.

The location-based scheme uses a more precise estimation of expected additional coverage area in the decision to rebroadcast. In this method, the source node also appends its geographical position information with the message. The receiving node then calculates the additional broadcast coverage area with the help of positioning data sent by the source node. If the additional area is less than a threshold value, the node will not rebroadcast, and all future receptions of the same message will be ignored. Otherwise, a node assigns a RDT before delivery. If the node receives a redundant message during a RDT, it recalculates the additional coverage area and compares it with the threshold. This process is continued until the message is rebroadcasted or finally dropped. The major drawback of this scheme is that it assumes the node in a network should be equipped with a GPS receiver. Moreover, area-based methods also presume that visibility can be estimated merely from the position of the nodes i.e. it mainly depends upon the distance of the nodes. This is realistic only if there is no shading objects, e.g., users are in a plain field. Finally, the distance calculation also increases computational overhead that ultimately cause increases broadcast latency.

2.3.1.2 Network topology-based protocols

The network topology-based protocols are further categorized into structured and unstructured protocols. Unstructured protocols use neighborhood information to calculate an additional number of nodes as broadcast recipients. Structured protocols use geometrical shapes or data structure to make an information dissemination plan.

C. Structured protocols

For example, the cluster based approach, in which mobile hosts form clusters, can be used for broadcasting. Within one cluster, each host is treated as a member, and there is one cluster

head and one gateway node responsible to relay messages [24] [31] [32]. However, maintaining such structure is too costly especially when the nodes mobility is very high. Furthermore, each node periodically sends ‘Hello’ messages to advertise its presence, which can create contention and therefore messages will be dropped. In [24], a cluster-based scheme was compared to other schemes and results show that it saves rebroadcasts and has short average broadcast latencies but it leads to a weak reachability in sparse areas.

In [33], the authors have described a spanning tree based algorithm for broadcasting in ad hoc networks. The whole broadcasting mechanism is divided into two parts: (i) the maintenance of the broadcast tree, and (ii) the broadcast process itself using the tree. The spanning tree based broadcasting scheme, which is more appropriate for wired networks, is inadequate for ad hoc networks, being too difficult to maintain and due to resource consuming and being too sensitive to link failures.

D. Unstructured protocols

Unlike structured protocols, unstructured protocols use neighbor nodes knowledge to make broadcast decision. For example, in self-pruning protocol [34], each node maintains the knowledge of its neighbors by periodically exchanging the “Hello” messages. The receiving node first compares its neighbors list to that of sender’s list, and rebroadcast the message only if the receiving set can cover additional nodes. The neighbor knowledge attached with the identity of the node from which the message is received allows a receiving node to decide if it would reach additional nodes by or not re-broadcasting it. Another approach, called scalable broadcasting [35], further enhances the self-pruning scheme by gathering neighbors’ information up to two hop distance. Thus, each node has two hops topology information. It is worth noting that neighbor knowledge based algorithms also consume extra resources since they require substantial communication between the nodes to exchange the topological structure of the network.

2.4 Swarm based information dissemination approaches

This section overviews swarm based approaches implemented in different area of research. More precisely, we outline bees' and ants' communication system with a brief summary of ongoing research in swarm-inspired algorithms and their implementations, focusing on enhancing communication system in vehicular networks. Swarms form a self-organizing, intelligent system where members interact locally with each other and/or with their environment to provide collective problem decision. It is vital for the survival of social insect societies being able to search large regions for food sources and act quickly to exploit any rich discoveries. In adapting to perform these tasks, social insects have developed many ways of communicating/exchanging information between individuals [36] [37].

2.4.1 *The implementations of Ant and Bee communication principles*

Ants communication system is a great source of inspiration to develop new approaches of problem solving in different areas of research and development, e.g., route optimization, wireless network routing, scheduling problems, vehicles routing [3] [38] [39] [40]. 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 shortest routes from the nest to food locations [41]. 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 [42]. Number of applications published so far implemented ants' communication principles in optimization of vehicular network performance [4] [43]. For example, a self-organizing approach for routing in MANETs, called distributed ant routing, is proposed in [44]; 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. Authors in [45] studied how 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 offered to the ants to reach a food source. After the experimental study authors developed an individual-based model whose parameters were based on the different decisions made by real ants when moving in the network when the access to all branches was allowed.

The ant colony optimization (ACO) algorithm is one of the most studied and successful optimization techniques [46]. 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 in [47]. 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 in [48], 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 in [49]. 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.

Another group of swarm algorithms is inspired by honey bees (hereinafter, bees) communication system. In the early-twentieth-century Karl von Frisch made a revolutionary discovery about the communication paradigm that bees use to share information about flower sites around the hive [50]. He experimentally verified that bees can inform hive-mates the

direction and the distance to a food source by means of a dance. The bees' communication is shared when they search food sources, starting with some bees called "scouts" which navigate and explore the region aiming to find a food source [5]. In the positive case, according to von Frisch, they return to the bee hive at a level named "dance floor" to transmit and share this discovery with the others through round or waggle dances according to the discovery distance, quality etc. Thus, some bees are recruited and become foragers which increase with the proportion of food found.

Numerous researchers have recently worked on developing bee-inspired algorithms. One of the most popular algorithms used bee colony communication system is Artificial Bee Colony (ABC) algorithm. In ABC algorithm, the position of a food source represents a possible solution to the optimization problem and the amount of a food source corresponds to the quality of the associated solution. The number of the employed bees or the onlooker bees is equal to the number of solutions in the population. A detailed description of ABC and comparative study of its modifications are given in [51]. Another approach inspired from the honey bees' behavior, BeeJamA, is proposed in [52], based on a multi-agent system and relies on a decentralized vehicle-to-infrastructure architecture. The BeeJamA is a self-adaptive and distributed vehicle route guidance approach, provides drivers with safety routing directions before each intersections to avoid traffic congestions. This algorithm is based on the BeeHive packet switching algorithm [5]. In the BeeHive routing algorithm, each node in the network is considered as a hive that consists of bee agents. Each node periodically launches the bee agents to explore the network and collect the routing information. These bee agents is considered as scouts, propagation delay as a distance information, queuing delay as a direction information, and routing table as a dance floor where bee agents exchange information. Data packets are considered as foragers that access the information in the routing tables, stored by bee agents, about the quality of different neighbors of the node for reaching their destinations. There are many other research works devoted on modeling interactions of

social insects in quickly selecting the best food source in the dynamically changing environments [53] [54] [55].

2.5 VANET simulations

In this section we discuss network and traffic simulators. In general there are three different techniques for performance evaluation of systems and networks: mathematical analysis, measurements, and computer simulation [56]. As measurements require an implementation of the system to be available, often either analysis or computer simulation must be applied due to cost and effort reasons. Both evaluation techniques are based on a model which represents the system with respect to the goal of the study as accurate as possible. As mathematical analysis can often only provide a limited insight for system design, in fact computer simulation is very often applied either for comparing different design alternatives or for optimizing a certain design.

In a computer simulation a real-world process or system is "imitated" over time. In the field of computer networks the dominant simulation technique is discrete-event simulation. The key property of discrete-event simulations is that the state of the simulation model can only change at discrete points in time which are referred to as events [57]. To date, discrete-event simulation is used to do research on all layers of computer networks, including signal processing issues in the physical layer, medium access in the link layer, routing in the network layer, protocol issues in the transport layer, and finally design questions of the application layer. The reason behind the success of discrete-event based simulation in computer networking is on the one hand that the simulation paradigm fits very well to the considered systems while on the other hand discrete-event based simulation is easily applied. Hence, discrete-event simulation provides a simple and flexible way to evaluate their approaches and study their behavior under different conditions. A further important aspect of

computer simulations is repeatability, i.e. different designs can be evaluated under exactly the same environment parameters.

VANET relies on and is related to traffic/mobility simulation and network simulation. Network simulators are used to evaluate network protocols and applications in a variety of conditions. The traffic simulators are used for transportation and traffic engineering. These simulations work independently but to satisfy the need of VANET, a solution is required to use these simulators together. There are a large number of traffic and network simulators and they need to be used together into VANET simulators. There are few tools for VANET simulation but most of them have the problem of proper interaction. Therefore, studying of present tools is important to choose proper interaction of various VANET traffic and network simulators [58].

Currently, different kinds of simulators are necessary for the simulation of vehicular communication. A realistic simulation of vehicular communication scenarios needs to consider various aspects of simulation, i.e. the vehicular traffic, the communication network, and the application. Vehicular traffic includes the physical movements of vehicles on an arbitrary road network. The simulation of the vehicular communication network handles the wireless message transmission among vehicles, and between a vehicle and the fixed infrastructure. Application simulation means the integration of applications that are to be implemented in real world vehicles. For this purpose, inner vehicle interfaces have to be emulated to allow the application to interact with other components of the vehicle [59].

One key requirement is the interaction at runtime of the simulation between communication, traffic, and application simulator, because modifications of traffic parameters, like movements of vehicles and characteristics of roads, need to be made at runtime. So, for example, when an obstacle warning application of a vehicle detects a dangerous situation, this vehicle sends a warning message to the vehicles in its neighbourhood

using the communication simulator. As a result, the receivers of this warning could, then, change their routes, which is triggered by the application simulator and has to be fed into the traffic simulator.

For example, in TRaNS, realistic joint and network simulator for VANETs [60], the mobility traces are not generated prior to network simulation, but, rather, both simulators operate simultaneously. In a safety application, as it would be communicated to the driver, the command *avoid crash* can be translated into the following three consecutive mobility commands: *change speed (reduce)*, *change lane* and *change speed (increase)*. The decision when and which mobility commands should be sent to the traffic simulator are taken by the driver behavior model. Ideally the decision-making process should depend on both the information about the driving infrastructure, such as number of lanes on a road segment or number of cars in front, and the VANET-related information. A simple driver behavior model is implemented, which takes decisions upon reception of messages exchanged between vehicles.

Chapter 3 - An adaptive information dissemination algorithm

In this chapter we present an Adaptive information dissemination (AID) algorithm in Mobile and Vehicular Ad-hoc Networks. The AID protocol efficiently disseminates received messages in distributed manner. Each individual node can dynamically, based on the number of received messages from its neighbors, decide on rebroadcasting. The proposed AID algorithm is evaluated in the concept of MANETs and VANETs. Simulation results showed that AID is the most efficient with respect to Saved ReBroadcast (SRB) both in terms of network density and nodes mobility. It provides a near-optimal solution in terms of maximum SRB and average latency while maintaining good reachability.

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3.1 Introduction

The dynamic nature and directional mobility of the vehicles, delivering messages to one or all vehicles, represents a major challenge. Moreover, due to the absence of the infrastructure and the higher mobility of the vehicles, relying messages between vehicles require broadcasting schemes. The core problem in multi-hop broadcasting is how to minimize the number of redundantly received messages while maintaining good latency and reachability, since rebroadcasting causes tradeoff between reachability and efficiency under different host densities [24]. Therefore, the selection of relay nodes is a major design consideration in broadcasting algorithms.

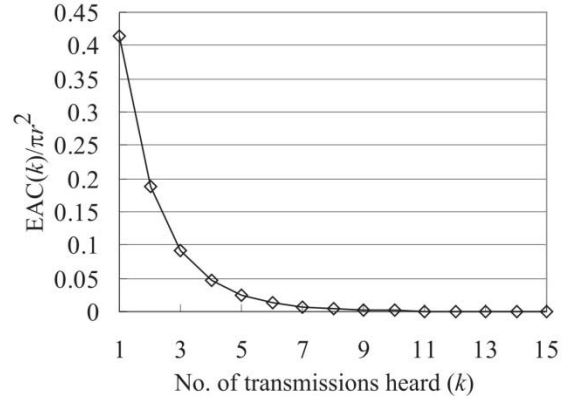
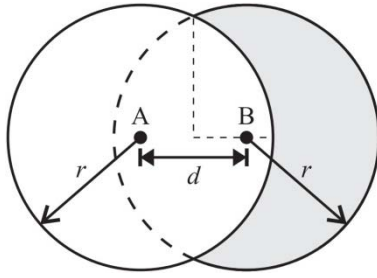
Several broadcasting schemes for information dissemination have been proposed in the context of MANETs that can be classified as topology-based and statistical- or geometric-based schemes as mentioned in the section 2.3.1. In topology-based schemes, nodes require neighbor topology information to decide on message rebroadcast. These schemes can minimize the number of rebroadcast messages and ensure reachability, but maintaining neighbor information requires extra overhead especially for network with high speed nodes. In the second category schemes, no information about neighbors is required to be maintained by the nodes and rebroadcast decision is based only on local information. These schemes are based on various threshold parameters to help nodes to decide whether to rebroadcast or discard received messages. However, in dynamic networks, it is difficult even impossible to determine a priori these parameters. Recently, some schemes to adjust these thresholds on-the-fly have been proposed in [28] [61] [62]. For nodes to decide to rebroadcast, they need local information obtained through periodical hello messages and from other protocols such as routing protocols. However, some additional fixed parameters are used to adjust these thresholds.

This chapter focuses on statistical-based broadcasting schemes and introduces an Adaptive approach to disseminate information in Ad hoc Networks. In this approach, each node can dynamically adjust the values of its local parameters using information from neighboring nodes. It is worth noting that in the context of VANETs, broadcasting protocols may behave in a different way than MANETs due to the following reasons. Since vehicles are treated as VANETs' nodes, these entities can move too fast as compared to ordinary MANETs' nodes. In VANETs, the network topology changes regularly since vehicles can frequently leave and join the network. We can also anticipate the direction of vehicles' movement since their routes are predefined. Furthermore, the number of vehicles participating in VANETs may vary depending on the traffic situation at a particular point in time. This can be classified as light (for small number of vehicles e.g., rural area traffic), medium (for average number of vehicles e.g., urban area traffic), and congested (for large number of vehicles, e.g. in case of traffic jam situation).

Due to these differentiable characteristics of VANETs, we have evaluated the performance of the proposed scheme and compared its performance with common statistical-based broadcasting protocols in the context of MANETs and VANETs with respect to the following two parameters: (1) the speed in order to evaluate the performance of each protocol under different vehicles speeds, and (2) the number of vehicles to check the performance of each protocol under different traffic situations.

3.2 Algorithm of AID approach

In a counter-based scheme, a fixed threshold value C is used to inhibit nodes from rebroadcasting messages [24]. For example, if a node already heard the same message more than C times, it is unlikely to rebroadcast the message because of negligible coverage area.



(a) Analysis on the extra area that can benefit from a rebroadcast: A sends a broadcast packet and B decides to rebroadcast the packet.

(b) Analysis on redundancy: the expected additional coverage $EAC(k)$ (divided by πr^2) after a host heard a broadcast message k times.

Figure 3.1: Analysis on Redundant Rebroadcasts [24]

It is worth noting that recent studies showed that there is no benefit to rebroadcast a message after heard it k times when $k \geq 4$, because the expected additional coverage area is below 0.05% (Figure 3.1) [24]. So, it is imperative to have a control mechanism whereby the threshold C can be adjusted to balance between reachability and saving rebroadcast depending on dynamic changes of the topology (i.e., network density). For example, when nodes are located in a highly dense area, they may receive a lot messages causing the storm problem [24]. Therefore, fixing parameters at each node and dynamically adjusting their values based on geographical distribution of nodes are required. In other words, in dense networks, multiple nodes share similar transmission coverage, and therefore some nodes doesn't need to retransmit (the threshold need to be low), and in sparse networks, there is much less shared coverage, some nodes have to retransmit (the threshold needs to be high).

In order to tackle these issues we propose a distributed Adaptive Information Dissemination (AID) approach that allows nodes to efficiently rebroadcast received messages. This scheme allows nodes to select an appropriate action (i.e., re-broadcast, or discard) in distributed manner, i.e., without the aid of a central controller. The principle of the algorithm

is as follows. Each individual node can dynamically, based on the number of messages received from its neighbors, decide on rebroadcasting. On hearing a broadcast message for the first time, the node initializes a local counter c to 1 to keep track of the number of times the message is received and waits for a random number of slots τ . Another counter s , initialized to 0, is used to help nodes for deciding on the rebroadcast. A list ℓ is also used to track the time between successive messages Δt . Each time the same message is heard again, the counter c is increased by one and the node calculates the intensity of arrived messages Δt to be recorded in ℓ . In other words, a node receiving a message at time t_b extracts the value of the time of the last message received denoted by t_a , calculates a value $\Delta t = (t_b - t_a)$, and add it to the list ℓ . When the duration τ has expired, the Δt values of inter-arrival times between successive messages are compared with the value τ/c , considered as the mean inter-arrival time baseline. If Δt is greater than τ/c , the value s is increased by 1; otherwise it will be decreased by 1. When all values in the list ℓ are compared with τ/c , the node can decide to rebroadcast or discard the message based on the value of s . If s is below 0, the node discard the message, i.e., don't forward it to neighboring nodes. On the other hand, if the value of s is greater or equal 0, the node broadcasts the message.

The value s is smaller than 0 means that several inter-arrival times are smaller than τ/c , which is interpreted by an excessive number of received broadcast messages. Each node adjusts its own value s depending on its local information based on the number of times the message is received and the inter-arrival times between two successive messages. When the slot time τ expires, the node decides to re-broadcast or discard the received message. The rebroadcasting decision algorithm is given in Figure 3. 2 and Figure 3. 3 [63]:

- S1. On hearing a broadcast message M for the first time at time t_a , the node initializes a counter c and a counter s .
- S2. Generate a random value τ (RDT) for M transmission.
- S2.1. Wait until the transmission actually starts, i.e., until τ has expired. If M is received again at time t_b during τ , go to S2.2.
- When τ has expired, if M was heard again (i.e., $c > 0$), go to S4, otherwise go to S3.
- S2.2. Increase the counter c by 1, and update the list ℓ by recording $\Delta t = (t_b - t_a)$, then go to S2.1.
- S3. Rebroadcast M and procedure exit.
- S4.
- S4.1. For all the values Δt_i recorded in ℓ , compare each one of them with τ/c : when $\frac{\tau}{c} - \Delta t_i > 0$, decrease s by 1, otherwise increase it by 1.
- S4.2. If $s > 0$, then go to S3, else go to S5.
- S5. Discard the transmission of M and the procedure exit.

Figure 3. 2: Algorithm of AID

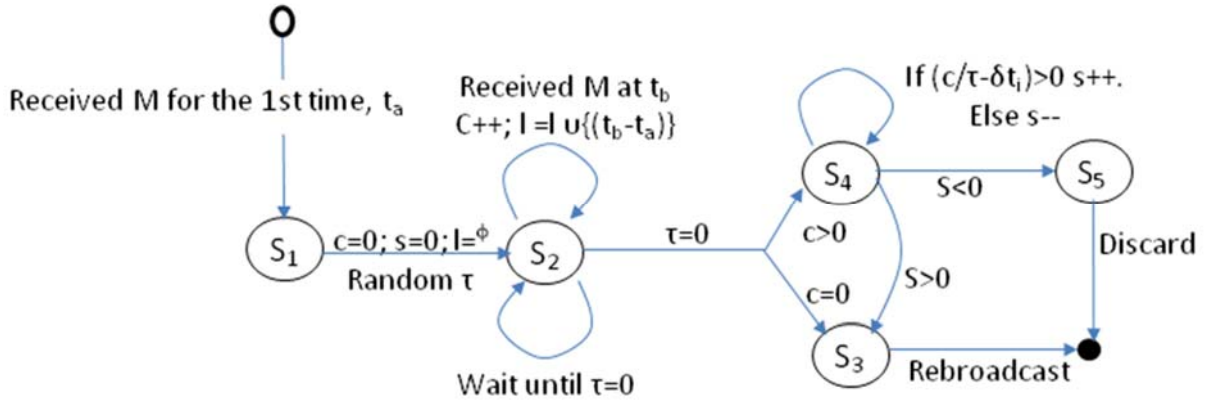


Figure 3. 3: Schematic view of AID algorithm

3.3 Performance analysis

In this section, the performance evaluation of the proposed scheme against (some parameter-based) counter-, probabilistic- and distance-based schemes using the network simulator, ns2 [64], is presented. We have evaluated the approach separately in the context of

MANETs (section 3.3.1) and VANETs (section 3.3.2). Parameters related to mobility, traffic scenarios and performance metrics are presented in respective subsections.

3.3.1 *Evaluation in the context of MANETs*

MANET nodes have limited battery charging capacity that requires energy efficient protocols especially for broadcast purpose since broadcast operation requires subsequent routing and re-transmissions in order to disseminate the information among all network nodes. In this work, we first surveyed the most common broadcast protocols that are used in MANETs. Since our main objective was to find the most efficient protocol with respect to energy consumption, we selected two distinguished broadcasting protocols (probabilistic-, and distance-based) to measure and compare their performance with the AID algorithm under different network topologies, and host densities.

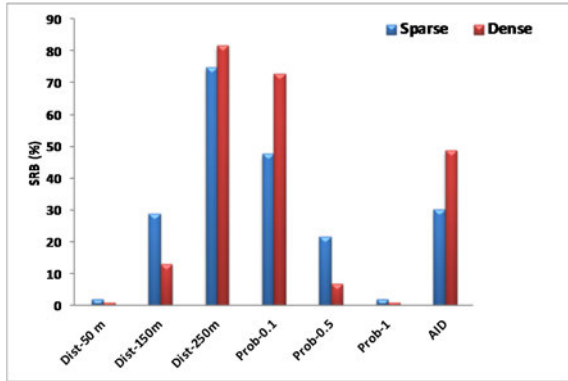
Different threshold values for the protocols under investigation were defined as follows: for probabilistic-based, the relay probability was set to 0.1, 0.5, 1; for distance-based, the distance threshold was set to 50m, 150m, and 250m (equal to transmission range). We mainly investigated the effect of node density within the range from 50 (as a sparse network) to 100 nodes (as a dense network) where the maximum speed of nodes is fixed to 5 m/s.

A simulation time of 100s was used; it was long enough to evaluate the broadcasting protocols by varying network densities. We used network range of 800mx800m, bandwidth equal to 2Mbps, transmission range equal to 250m, Initial Energy equal to 100J, and message size equal to 1000 bytes.

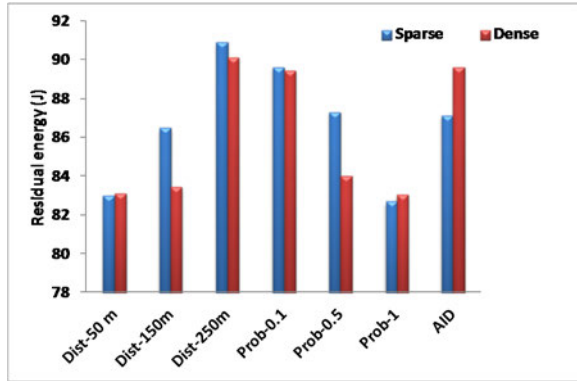
The key performance metric that we are interested to measure is the SRB which is the ratio between the number of hosts receiving the message and the number of hosts actually rebroadcasting the message. Since our goal is to measure the transmission energy consumption against each protocol, the number of SRB is inversely proportional to the transmission energy. So the greater number of SRB will represent the lesser transmission

energy consumed during the broadcasting. Another metric we have observed is Reachability (RE): the number of mobile nodes receiving the broadcast message divided by the total number of mobile nodes that are reachable, directly or indirectly, from the source node.

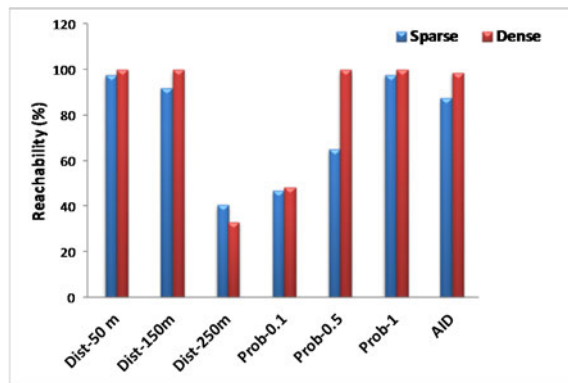
We performed several simulation trials for each scenario and calculated the average number of SRB, remaining energy and reachability against each protocol.



(a) SRB-save broadcast



(b) Remaining energy



(c) Reachability

Figure 3.4: Evaluation of AID with distance- and probabilistic-based algorithms

Figure 3.4 shows the SRB, energy consumption, and percentage of nodes that actually received the message (i.e., reachability).

For a distance-based protocol, as distance threshold value increases the SRB increases because only neighbors far away from the current node rebroadcast the message. For example, a higher SRB is shown when the distance threshold is equal to the transmission range 250m.

As expected, rebroadcasting causes a tradeoff between energy efficiency and SRB. As more rebroadcast sent, more energy is consumed. For example, when the distance threshold is fixed to 50m, more messages are submitted, and then more energy is consumed, but higher reachability is achieved. When the distance threshold is higher (250m), fewer messages are sent and reachability dropped to lower levels, but less energy is consumed.

In a probabilistic-based protocol, as the threshold value increases, more messages are rebroadcast (a threshold value of 1, prob-1, corresponds to flooding protocol), which means higher reachability is achieved but more energy is consumed. Flooding (prob-1) shows the worst performance in both sparse and dense networks, as almost all nodes rebroadcast the message (lower SRB) to achieve higher reachability causing but more energy to be consumed and thus lowering the network lifetime.

Under different node densities, AID has significant SRB, less energy consumption, and higher reachability, as compared to the other broadcasting schemes. Distance- and probability-based protocols have higher SRB than an AID scheme with critical threshold values such as dist-250m and prob-1 causing lower reachability than AID scheme (almost 100% reachability) while consuming almost the same transmission energy. When the distance threshold is fixed to 50m, almost all nodes participate in the message dissemination process, resulting in good reachability but consuming more energy. A similar situation can be observed when selecting 150m as a threshold for distance. Over-using transmission energy could result in a shorter lifetime for the whole network. The obtained results justify the effectiveness of the AID scheme.

3.3.2 Evaluation in the context of VANETs

The AID scheme was also evaluated in the context of VANETs. In MANETs, saving energy is one of the important issues since nodes are fitted with limited capacity batteries and energy consumption reduces the wireless network connection lifetime. However, energy

consumption is not a major problem in the context of VANETs due to equipments could be recharged during driving time. Therefore we have evaluated the performance of AID algorithm in terms of SRB, awareness and latency within the scope of VANETs.

A. Mobility scenarios and traffic parameters

The performance evaluation of the proposed scheme against counter-based and distance-based-schemes was conducted using the network simulator, ns2. The mobility scenario was generated by MObility model generator for Vehicular networks (MOVE) [65] and Traffic and Network Simulation Environment (TRaNS) [60], which are built on top of SUMO, an open source micro-traffic simulator [66]. The scenario generated by using these tools is a grid topology of 800m×800m with a block size of 200 m×200 m as depicted in Figure 3.5.

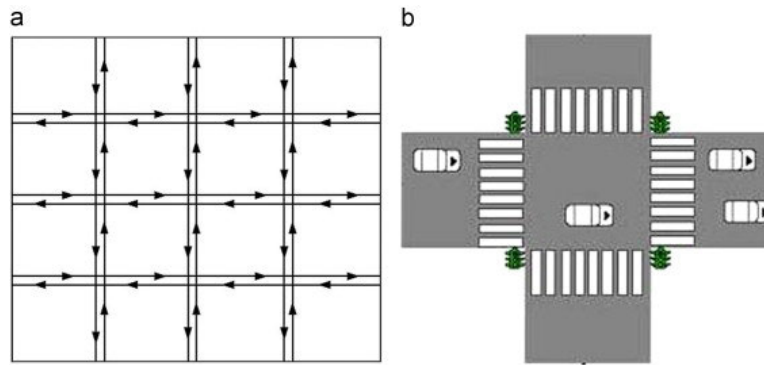


Figure 3.5: (a) Mobility scenario and (b) structure of each intersection.

The speed of vehicles was fixed to 1, 15, 25 m/s and the number of vehicles was fixed to 50, 100, and 150. The scenarios were randomly generated and each contained six roads, nine intersections, and twelve crossover points at the border. Vehicles moved along the grid of horizontal and vertical streets on the map. Each line represented a single-lane road and vehicular movement occurred along on the directions shown by arrows. At a crossover, vehicles chose to turn left or right with equal probability, 0.5. At an intersection of a horizontal and a vertical street, each vehicle chose to keep moving in the same direction with a probability of 0.5 and to turn left or right with a probability of 0.25.

It is worth noting that several mobility models have been proposed for MANETs and VANETs as well. The most known one is Random Waypoint mobility [67] proposed mainly for the evaluation of MANETs. Other models are artificial mobility and real-world mobility models, which can be considered as a major step towards generating realistic vehicle traces. More depth analysis and details of these models can be found in [67] for MANETs and in [68] and [69] for VANETs.

A simulation time of 100 s is used, which is long enough to evaluate the broadcasting protocols by varying nodes speed and densities. We used two-ray ground model for radio propagation [64] and the transmission range is 250 m. The simulation parameters are described in Table 3.1.

Simulation parameters	Values
Network range (m x m)	800 x 800
Transmission range (m)	200
Number of nodes	50, 100, 150
Nodes speed (m/s)	1, 15, 25
Bandwidth (Mbps)	2
Message size (byte)	1000
Simulation time (s)	100

Table 3.1: Simulation parameters.

B. Simulation results

As mentioned above, the performance of the proposed scheme are measured and compared with statistical-based schemes mainly, Counter-based, and Distance-based, under different node speeds and densities. Different threshold values for these schemes are used as follows:

for Counter-based scheme, the counter threshold is set to 3 and 5, and for Distance-based scheme, the distance threshold is set to 50 and 100 m.

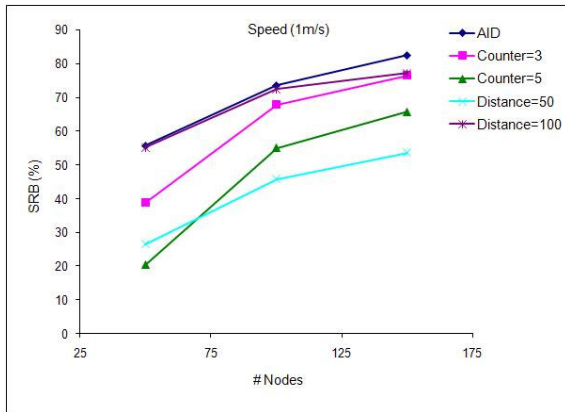
The following performance metrics have been used to evaluate each scheme [24] [61] [70]:

- *Saved ReBroadcast (SRB)*: is the ratio between the number of hosts receiving a message and the number of hosts actually rebroadcasting the message. In the context of VANETs SRB depends on relevant geographical area. For example, usually, for driver-comfort applications information is disseminated as large area as possible while for safety-related applications information is disseminated to limited related area. In this section we compute SRB for nodes located in 800m×800m area by considering that reaching information is important for all nodes in this area.
- *Latency*: the interval from the time the broadcast was initiated to the time the last host finished its rebroadcasting. It includes buffering, queuing, retransmission, and propagation delays. Suitable latency is an important metric to figure out the efficiency of a protocol to delay sensitive applications like safety applications.
- *Awareness*: commonly called *Reachability* is the state or ability to perceive or to be aware of an event. Within the scope of VANETs, awareness is defined as a driver's perception and cognitive reaction to a condition or event. Awareness is directly related to the reachability of the data to be disseminated.

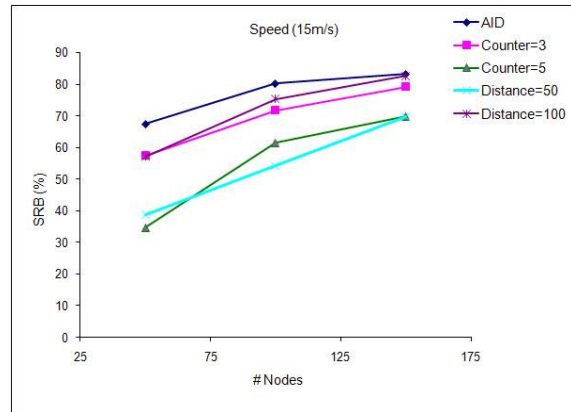
We performed ten simulation trials for each scenario and calculated the average number of SRB obtained with each protocol. It is worth noting that reducing the number of rebroadcasts and lowering latency is our primary concern in the context of VANETs. Furthermore, the importance of safety related information to a vehicle increases when the distance decreases between the vehicle and the place where safety data was generated, and vice versa. Receiving such message when approaching this place can help drivers to decide next actions such as decreasing/increasing speed, finding an efficient route, and avoiding traffic jam, etc. Drivers

far away from this place may not be interested since no actions are need from them to avoid such a dangerous situation.

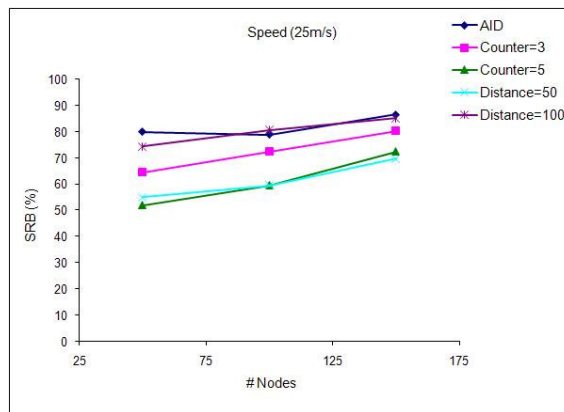
Figure 3.6 plots the SRB comparison of the AID scheme with the two common statistical-based broadcasting schemes (Distance- and Counter-based) as a function of network road density within the range from 50 to 150 nodes where node speed is fixed to 1, 15, and 25 m/s, respectively. We can observe that SRB increases proportionally with the increase in the number of nodes for the all schemes. The results show that in a dense network the counter and distance-based schemes exhibit lower SRB. Under different nodes density and speed, the AID scheme has significant SRB as compared to the other broadcasting schemes.



(a) low speed (1 m/s)



(b) medium speed (15 m/s)



(c) high speed (25 m/s)

Figure 3.6: SRB comparison according to number of vehicles.

Table 3.2 illustrates the ratio of the AID scheme over the other schemes for number of vehicles equal to 50, 100, and 150 by varying the speed: low speed (1m/s), medium speed (15m/s), and high speed (25m/s). We can see that AID scheme has good SRB over considered schemes. For example, in a network of 50 vehicles with a speed fixed to 1 m/s, AID is 1.44 better than counter-based scheme ($C=3$) and 2.1 better than distance-based scheme ($D=50$ m). These results justify the effectiveness of the proposed scheme, i.e., without using any fixed threshold, over counter- and distance-based schemes.

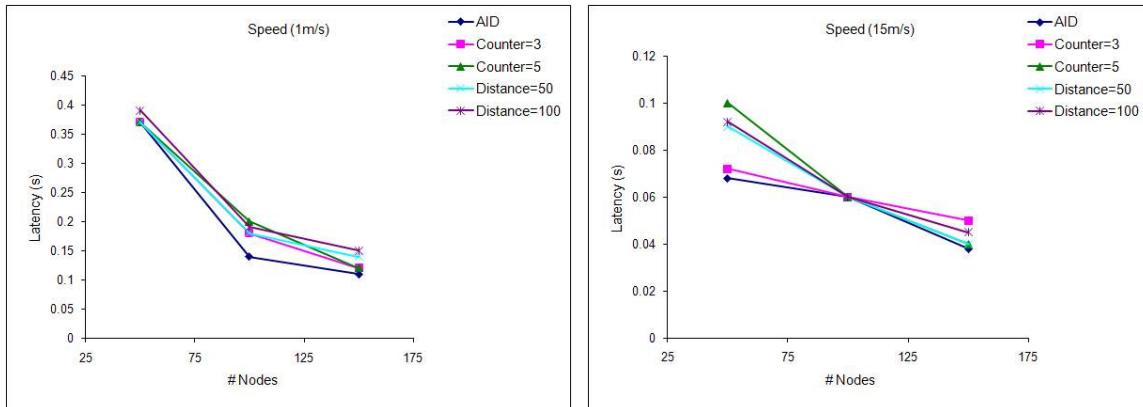
Nodes	50				100				150			
Speed/ Scheme	Counter		Distance		Counter		Distance		Counter		Distance	
	3	5	50m	100m	3	5	50m	100m	3	5	50	100m
1m/s	1.44	2.73	2.10	1.01	1.08	1.34	1.60	1.02	1.08	1.26	1.54	1.07
15m/s	1.17	1.94	1.74	1.18	1.12	1.30	1.48	1.07	1.05	1.19	1.19	1.01
25m/s	1.24	1.54	1.45	1.13	1.09	1.32	1.32	1.04	1.08	1.19	1.24	1.05

Table 3.2: SRB ratio between AID scheme over counter- and distance-based schemes.

Figure 3.7 shows the broadcast latency at various network densities with low, medium, and high vehicles speed. When the number of vehicles increases, the retransmission of messages increases, and hence, resulting in decreasing latency. AID scheme is a more efficient alternative protocol since it increases the number of SRB and the network becomes less congested. This, therefore, results in lower end to end message delays. We can see that counter- and distance-based schemes have higher latency values due to higher redundant rebroadcasts. The results presented in Table 3.3 show that the AID scheme outperforms the other schemes in terms of latency with the number of vehicles equal to 50, 100, and 150 by varying the speed: low speed (1 m/s), medium speed (15 m/s), and high speed (25 m/s). For example, in a network of 50 vehicles with a speed fixed to 1 m/s, there is no or little improvement compared to counter scheme and distance scheme. With speed fixed to 15 m/s,

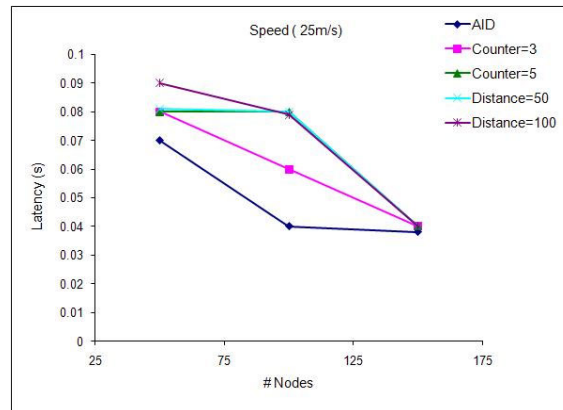
Chapter 3: An adaptive information dissemination algorithm

AID shows a ratio of 0.70 than counter scheme (C=3) and a ratio of 0.78 than distance scheme (D=50 and D=100).



(a) low speed (1 m/s)

(b) medium speed (15 m/s)



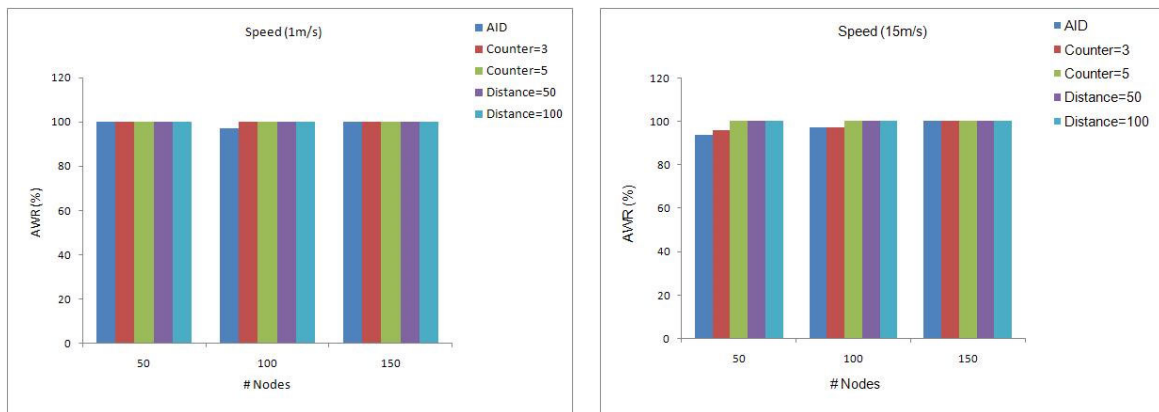
(c) high speed (25 m/s)

Figure 3.7: Average latency comparison according to number of vehicles.

Nodes	50				100				150			
	Counter		Distance		Counter		Distance		Counter		Distance	
	3	5	50m	100m	3	5	50m	100m	3	5	50	100m
1m/s	1	1	1	0.95	0,78	0,78	0,78	0.74	0.92	0.92	0.79	0.73
15m/s	1	0.70	0.78	0.78	1	1	1	1	0.76	0.95	0.95	0.95
25m/s	0.88	0.88	0.88	0.78	0.67	0.5	0.5	0.5	0.95	0.95	0.95	0.95

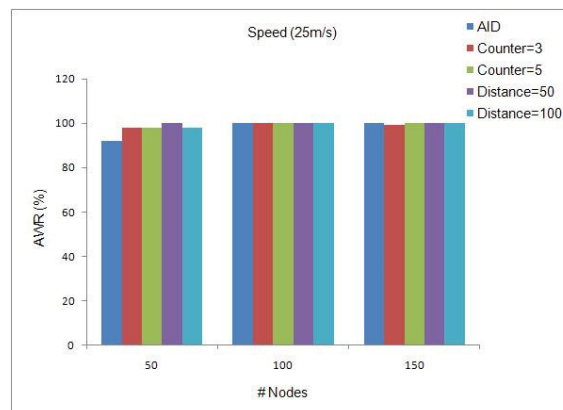
Table 3.3: Latency ratio between AID scheme over counter- and distance-based schemes.

Figure 3.8 shows the awareness (i.e., reachability) comparison of AID scheme against the counter- and distance-based schemes. We can see that in dense networks, all broadcasting schemes show equal strength in term of awareness with different vehicles speed. Table 3.4 presents awareness ratio between AID scheme over other schemes for number of vehicles equal to 50, 100, and 150 by varying the speed: low speed (1 m/s), medium speed (15 m/s), and high speed (25 m/s). Results show that, in some scenarios, AID protocol improves somewhat the awareness, with a maximum shift of 8%, compared to counter- and distance-based schemes.



(a) low speed (1 m/s)

(b) medium speed (15 m/s)



(c) high speed (25 m/s)

Figure 3.8: Awareness comparison according to number of vehicles.

Nodes	50				100				150			
Speed/ Scheme	Counter		Distance		Counter		Distance		Counter		Distance	
	3	5	50m	100m	3	5	50m	100m	3	5	50	100m
1m/s	1	1	1	1	0.97	0.97	0.97	0.97	1	1	1	1
15m/s	0.98	0.94	0.94	0.94	1	0.97	0.97	0.97	1	1	1	1
25m/s	0.94	0.94	0.92	0.94	1	1	1	1	1.01	1	1	1

Table 3.4: Awareness ratio between AID scheme over counter- and distance-based schemes.

3.4 Conclusion of the chapter

In this Chapter, we have presented Adaptive Information Dissemination approach in Ad hoc Networks. The effectiveness of the proposed approach has been proved by simulation experiments using network simulator NS2. The results show that AID is the most efficient with respect to SRB both in terms of network density and nodes mobility. It provides a near-optimal solution in terms of maximum SRB and average latency while maintaining good reachability.

Swarm intelligence, its applications are the great source of inspiration for developing adaptive protocols in Ad hoc Networks, which will be discussed in the next chapters, chapter 4 and chapter 5.

Chapter 4 - Ant-based Information Dissemination approach in VANETs

In this chapter, a distributed, self-organized approach to disseminate information about safety critical incidents on roads is presented, which is inspired by Ants' direct and indirect communication. We overview an Ant-colony organization and communication principles, its implementation in VANETs, followed by details of proposed approach and its performance evaluations.

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4.1 Swarm intelligence

Swarm intelligence is the discipline that deals with natural and artificial systems composed of many individuals that coordinate their activities using decentralized control and self-organization principles. In particular, this discipline focuses on the collective behaviors that result from the local interactions of the individuals with each other and with their environment [71]. Ants and bees colonies are well studied examples of systems by swarm intelligence [72]. During the past few years, research in swarm intelligence has focused on the development of adaptive approaches and systems that modify their own behavior at run-time to address constantly changing environments [73] [74]. The capabilities of these systems have been exploited in a variety of computation systems and been perceived as an efficient system model for developing adaptive systems and reconfigurable/evolvable hardware systems [75] [76] [77] [78]. The objective of such research is to develop autonomic systems with self-aware (e.g., self-configuration, -organization, -optimization) properties at component level and strengthen the self-design and fault-tolerance aspect (emergence of self-* [79] [80]).

It is worth noting that in the control engineering field, research has focused on the design and development of complex adaptive systems by emphasizing positive and negative feedback loops also seen in natural and biological systems. Complex systems are *complex* because of the multiple *feedbacks/interactions* among the various components of the system. In other words, actions taken on an element in a system might result in changes in the state of the element and these, in turn, might bring about changes in other linked elements. The effects may trail back to the first element, which is called *feedback* that can be positive or negative. Positive or self-reinforcing feedback amplifies the current change in the system. Negative or self-correcting feedback seeks balance and provides equilibrium by opposing the changes taking place in the system. The two types of feedback should be combined to insure the stability of the system [81] [82]; positive feedback alone pushes the system beyond its limits

and, eventually, out of control, while negative feedback alone prevents the system from reaching its optimal behavior. Examples of combinations of such positive and negative feedbacks include the pheromone deposit and evaporation by Ants [36] and recruiting waggle dance and stop signal by Bees [83] [84] (Figure 4.1).

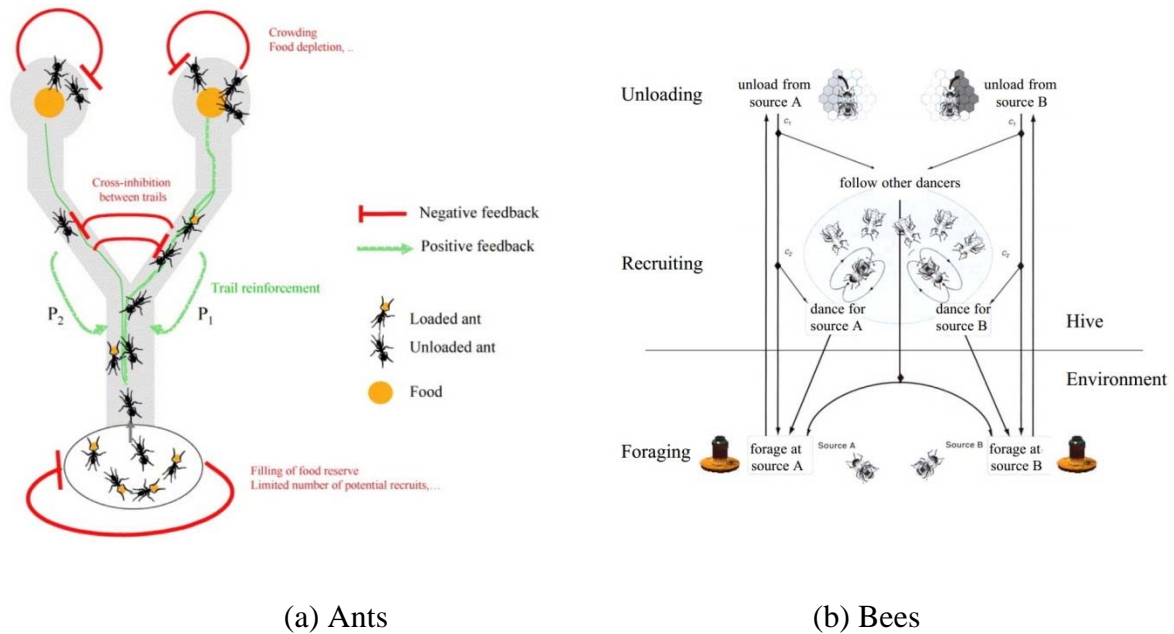


Figure 4.1: Examples of feedback loops between Ants and between Bees [85] [86].

In this chapter we propose adaptive information dissemination approach in VANETs, which we have taken inspiration from ant-swarms' communication system. The rest of this chapter presents ant-colony organizational principles, mapping rules into VANETs communication system and details of our approach with simulation results.

4.2 Ant-colony communication system and its implementation in VANETs

4.2.1 Ant-colony self-organization concept

Ant colony receives similar attention like other biological-inspired approaches [87]. Ants communication system is a great source of inspiration to develop new approaches of problem solving in different areas of research and development, e.g., route optimization, wireless

network routing, scheduling problems, vehicles routing [3] [88], and many other applications [36] [89].

In Ants' colony, two types of communication can be distinguished: ants' direct and indirect communication [36]. By the direct communication, an ant can exchange information with other ants when they come closer to each other (e.g., about found food source or in danger). Direct communication is important when a fast reaction is urgent, for example, when a danger is observed and it can impact to neighbors [90] [91].

Ants use stigmergy¹ to communicate indirectly. Two distinct types of stigmergy are observed within ants [3]. 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 a 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 encountering a previously laid trail in its road, it decides to follow it with a high probability. Thereby, the follower ant also reinforces it with a further quantity of pheromone. In some ant species the amount of deposited pheromone is proportional to the quality/quantity of food source found: paths that lead to better food sources receive a higher amount of pheromone [3]. For example, during their food search, all ants deposit a small quantity of specific pheromone type on the ground. As soon as an ant discovers a food source, it evaluates the quantity and the quality of the food and carries some back to its nest. During the return trip, every ant with food leaves on the ground a different type of pheromone of specific quantity, according to the quality and quantity of the food found [92].

Despite ants are simple insects, they can collectively perform complex tasks with remarkable consistency. Examples of such complex problem solving behavior include:

¹ Stigmergy is stimulation of workers by the performance they have achieved [3] [39].

building nests, co-operating in carrying preys, and finding shortest routes from the nest to food locations [3]. How a real ant colony manages to find the shortest route from their nest to the food, based on different quantities of pheromone deposited, analogous to different routes is demonstrated in the experimental setting of Figure 4.2 [92]. The ants move along the path from food source F to the nest N. At point B, all ants walking to the nest must decide whether to continue their path from point C or from point H. A higher quantity of pheromone on the path through point C provides an ant a stronger motivation and thus a higher probability to follow this path. As no pheromone was deposited previously at point B, the first ant reaching point B has the same probability to go through either point C or point H. The first ant following the path BCD will reach point D earlier than the first ant which followed path BHD, due to its shorter length. The result is that an ant returning from N to D will trace a stronger trail on path DCB, caused by the half of all the ants that by chance followed path DCBF and by the already arrived ones coming via BCD. Therefore, they will prefer path DCB to path DHB. Consequently, the number of ants following path DCB will increase with time unlike those following path BHD. This causes the quantity of pheromone on the shorter path to grow faster than that of the longer one. Consequently, the probability a single ant will choose the shorter path is greater.

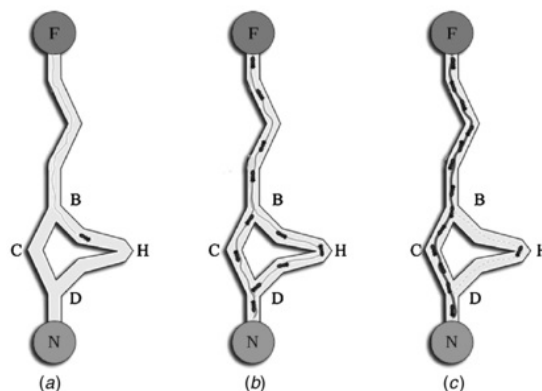


Figure 4.2: An example of shorter path selection in a real ant colony [92].

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 [45]. If the shorter path is blocked or unavailable, then the longer route may still be used. The pheromone concentration gets stronger for repeated use of other path which leads to that path being used as the preferred route. A classical example of the construction of a pheromone trail in the search for a shorter path is shown in Figure 4.3 and was first presented by Colormi et al. [93]. In Figure 4.3(a) there is a path between food and nest established by the ants. In Figure 4.3(b) an obstacle is inserted in the path. Soon, ants spread to both sides of the obstacle, since there is no clear trail to follow (Figure 4.3(c)). As the ants go around the obstacle and find the previous pheromone trail again, a new pheromone trail will be formed around the obstacle. This trail will be stronger in the shortest path than in the longest path, as shown in Figure 4.3(d).

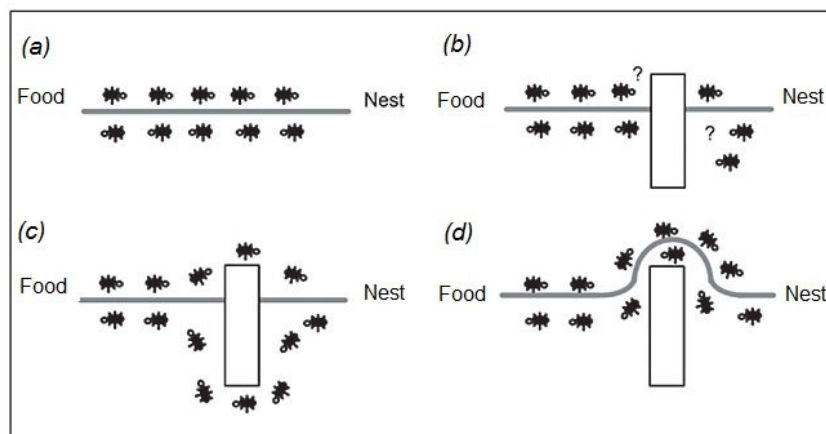


Figure 4.3: Construction of a pheromone trail in the shorter path search by ants in sudden disruption of the path [94].

Thus, Ants develop a solution when a path is blocked. This illustrates how swarm intelligent systems adapt with changes in the environment. The process is thus characterized by a positive feedback loop, where the probability with which an ant chooses a path increases with the number of ants that chose the same path in the preceding steps. As regards negative feedbacks, the limited size of ant population participating in a given activity, e.g. decreasing number of ants that continue using longer paths causes to less pheromone throw, and respectively very low probability for potential recruits. As a result, routes not recently used

are purged by means of pheromone evaporation. This leads to gradually vanish the lesser used paths.

4.2.2 The mapping of Ant communication principles to 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 behaviour i.e., when an Ant observes a food source it left pheromone traces to convey indirectly to other Ants about route information of that food source. Research published by E.O. Wilson in 1962 demonstrated that ant pheromone trails provide positive and negative feedback to organise foraging at the colony level [95]. 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 [96]. Moreover, according to [3], 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 [97]. 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 [3] [4]. In fact, when the food runs out, foragers refrain from reinforcing it on their return, so providing negative feedback [96] [98]. 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,

section 4.3.1) module (see Figure 4.4). Table 4.1 presents the mapping between Ants' foraging behaviour and the proposed decentralized system for information dissemination in VANETs.

Ants' communication behaviour	Vehicles communication system
Ants use pheromones to communicate indirectly	Vehicles communicate through RSU, updating each other's knowledge base (vehicle 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 stored messages is automatically decreases based on the time and distance to the location of the event. 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

Table 4.1: Mapping rules of ant communication system and its implementation in VANETs

4.3 The dissemination strategy

In this section we will present the CAID module structure that is designed under our proposed approaches which are presented in the next subsections [43].

4.3.1 Context aware information dissemination module

Figure 4.4 depicts the different components of the CAID module as follows:

- *GPS receiver*: available in modern cars and will be used to get position information [99].
- *Sensors*: different sensors will be used to monitor road conditions, vehicles' states, and drivers' behaviours. These sensors will be part of each vehicle and RSU taking part in dissemination process, e.g., ABS, ESP [100] [101].

- *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 analyse 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 [14].

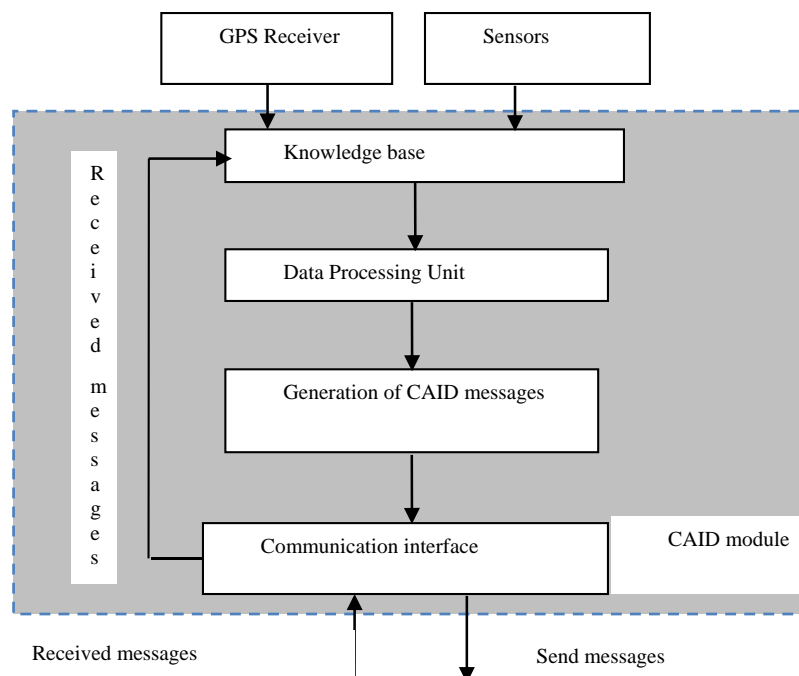


Figure 4.4: The CAID module Architecture

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

As stated above, we use Ants communication principles for information dissemination in VANETs 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 [102]. 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 ($R_{v_i,p_j}^{(0)}(t_0)$) 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 ($R_{v_i,p_j}^{(0)}(t)$) associated to a generated message at time t , by a source node, is expressed by the following equation:

$$R_{v_i,p_j}^{(0)}(t) = \begin{cases} R_{v_i,p_j}^{(0)}(t_0) \cdot \frac{T-(t-t_0)}{T}, & t_0 \leq t < T \\ 0, & t \geq T \end{cases} \quad (4.1)$$

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.

4.3.2 Strategy G1

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:

$$R_{v_k, p_j}(t + \tau) = \frac{2 \cdot R_{v_i, p_j}^{(0)}(t)}{1 + e^{\frac{d + \lambda \cdot \tau \cdot s}{D}}} \quad (4.2)$$

where $R_{v_i, p_j}^{(0)}(t)$ 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 is appeared (source), which can be calculated as $d = \sqrt{(X_{v_k} - X_{p_j})^2 + (Y_{v_k} - Y_{p_j})^2}$; τ 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 ; λ - is a sign, representing vehicles direction: if it is moving toward the accident location its value will be (-1), otherwise it's 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 τ .

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. (4.2); 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 travelling in communication area among neighbour 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.

4.3.3 Strategy G2

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., $R_{v_i, p_j}^{(0)}(t)$) in the computation of the new relevance value. Thus, the eq. (4.2) is reformulated for strategy G2 as follows:

$$R_{v_k, p_j}(t + \tau) = \frac{2 \cdot R_{v_i, p_j}^{(0)}(t)}{1 + e^{-\frac{d + \lambda \cdot \tau \cdot s}{D}}} \xrightarrow{R_{v_i, p_j}^{(0)}(t) \rightarrow R_{v_x, p_j}(t)} R_{v_k, p_j}(t + \tau) = \frac{2 \cdot R_{v_x, p_j}(t)}{1 + e^{-\frac{d + \lambda \cdot \tau \cdot s}{D}}} \quad (4.3)$$

In other words, by strategy G2, the relevance of received messages is calculated using both information submitted by intermediate nodes and the source node. If a message is relevant, it will be re-disseminated with the new computed relevance value that needs to be included in the message header (relevance value stored in the header of the message will be changed).

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 Figure 4.5, 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.

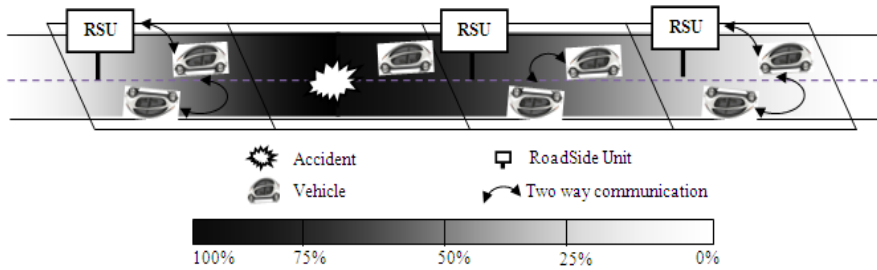


Figure 4.5: Relevance concentration during information dissemination process

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 Figure 4.6.

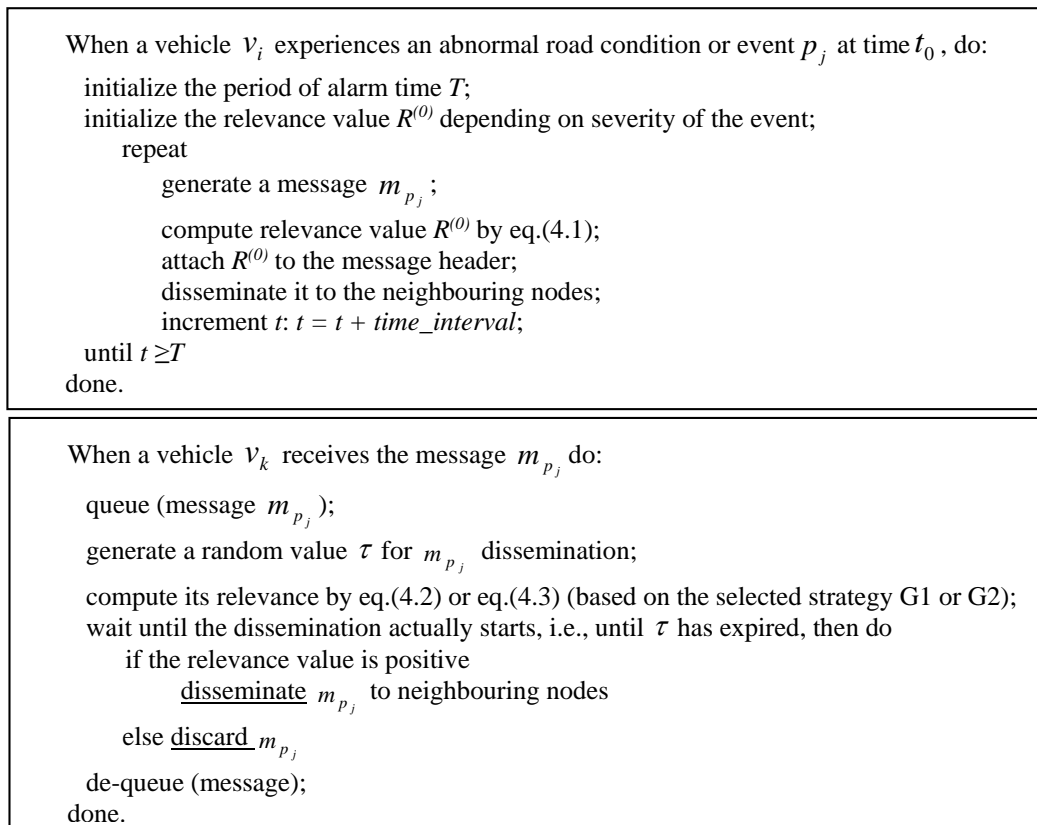


Figure 4.6: Message dissemination process by ant-inspired approach

4.4 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 analysed. The performance evaluation of the proposed scheme is studied using the network simulator ns2 [103]. 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 [3]) 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.

4.4.1 Simulation parameters

In this study, simulations are conducted using a realistic mobility scenario similar with one generated in section 3.3.2, a grid topology of $800 \times 800 \text{m}^2$ with a block size of $200 \text{m} \times 200 \text{m}$ as depicted in Figure 3.5. The maximum speeds of vehicles are fixed to 1, 5, 15, 25 m/s and the number of vehicles are fixed to 25, 50, 75, 100 for each simulation, respectively. Other simulation parameters are described in Table 4.2.

Simulation parameters	Values
Network range (m ²)	800x800
Transmission range (m)	300
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

Simulation parameters	Values
Initial relevance value	0.1, 0.5, 1.0
Bandwidth (Mbps)	2
Message size (bytes)	1000
Simulation time (s)	100

Table 4.2: Simulation parameters.

4.4.2 Simulation results

For both strategies G1 and G2, we have evaluated the average relevance value for different geographical area- D (Figure 4.7), alarm time- T (Figure 4.8 and Figure 4.10), initial relevance value- $R^{(0)}$ (Figure 4.9 and Figure 4.11), network density (Figure 4.12), and vehicles' speed (Figure 4.13) variations.

Figure 4.7 presents average relevance value comparison according to different geographical area (D , 100m, 200m, 400m, and 600m) for both strategies G1 and G2 (with $R^{(0)}=1$, $T=300s$), for vehicles moving with maximum 15m/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 that the average relevance value increases for coming vehicles and decreases for going away vehicles. As depicted in these graphs, average relevance value of the received messages depends on their targeted geographical area (D). For example, the average relevance value of the received messages targeted to larger geographical areas is higher compared to small geographical areas for both strategies G1 and G2. For the strategy G1, as illustrated in Figure 4.7a and Figure 4.7b, the average relevance value for vehicles that are located at 400-500m far away from the event location is greater than 0.6 for $D=600m$ and about 0.2 for $D=200m$. 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 400-500m far from the event location (Figure 4.7c and Figure 4.7d) is almost two times less than G1 (e.g., average relevance value is about 0.3 for $D=600\text{m}$, about 0.2 for $D=400\text{m}$, less than 0.1 for $D=200\text{m}$, 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., $D=100\text{m}$) may not be interesting for vehicles located far away from the event location (i.e., far than 400m), 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.

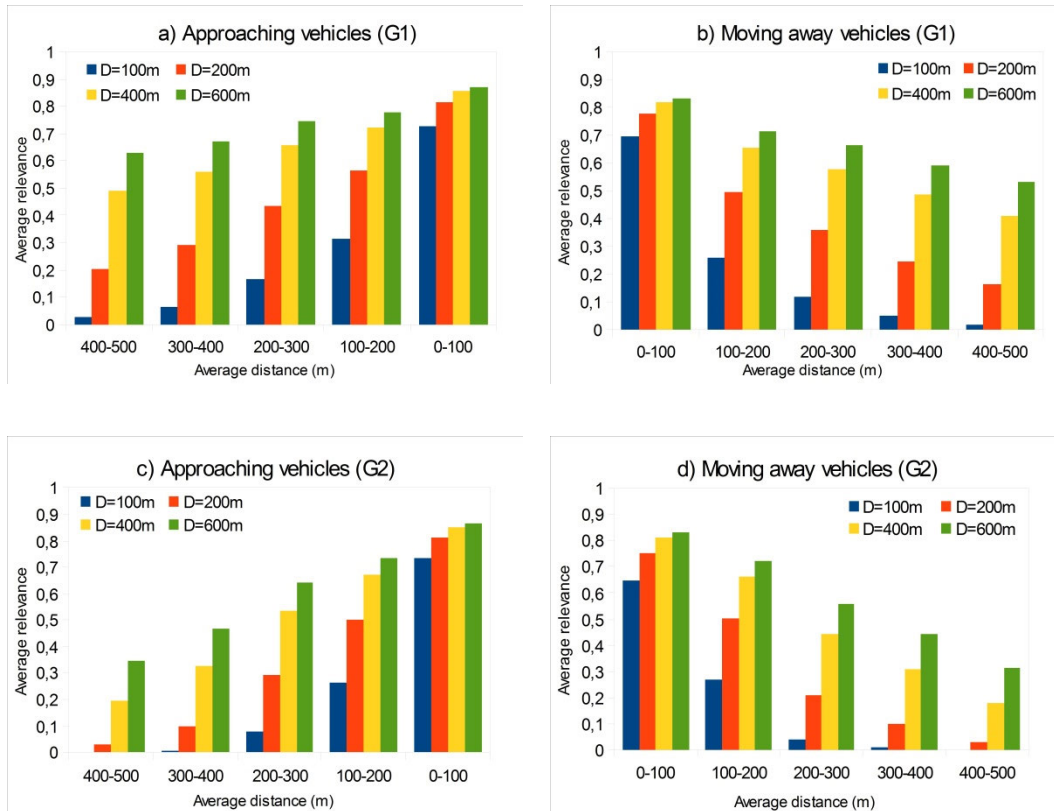


Figure 4.7: Comparison of average relevance value according to determined geographical area (D) for both strategies G1 and G2 (with $R^{(0)}=1$, $T=300\text{s}$).

Figure 4.8 shows the average relevance values according to time T required to solve the problem caused by the event on the road (i.e., time needed to return regular traffic conditions

after the emergency situation). In these graphs, the relevance value is initialized to 1 and the geographical area is fixed to 200m (equal to transmission range). As shown in these figures, the average relevance value is lower when T is small. As long time needs to warn 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 in 100-200m distance, the average relevance value is more than 0.5 with 300s alarm time while this value is about 0.3 for vehicles located within the same distance with $T=60s$ 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 Figure 4.8c and Figure 4.8d, the average relevance value, when using the strategy G2, is less than those values obtained when using G1 mainly for vehicles farther than 200-300m from the event location. Moreover, vehicles located at 400-500m 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 in 400-500m distance from the event location, and there is minor difference among average relevance values for different T in 300-400m distance, which has significant difference for 0-100 m distance.

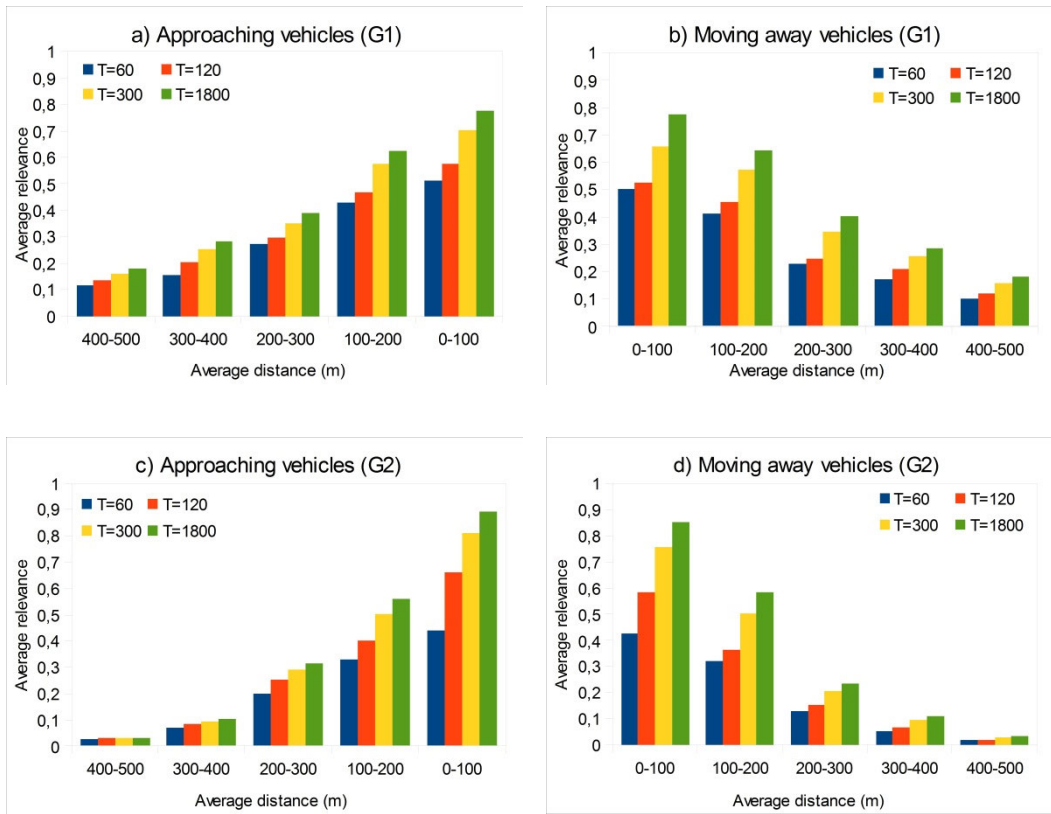


Figure 4.8: Comparison of average relevance value according to alarm time (T) variation in 200m geographical area with $R^{(0)}=1$.

Figure 4.9 compares the average relevance value when using different initial relevance values (i.e., generated by the source node). Warning time T is fixed to 300s and the relative geographical area D is fixed to 200m. 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 (200m) of the source node is almost same for both strategies G1 and G2. For example, the average relevance value for vehicles located within 0-100m 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 100-200m distance from the event. This value decreases slowly to reach 0.18 for strategy G1 (Figure 4.9b), while it decreases faster to become almost 0 for strategy G2 (Figure 4.9d) when vehicles are situated within 400-500m.

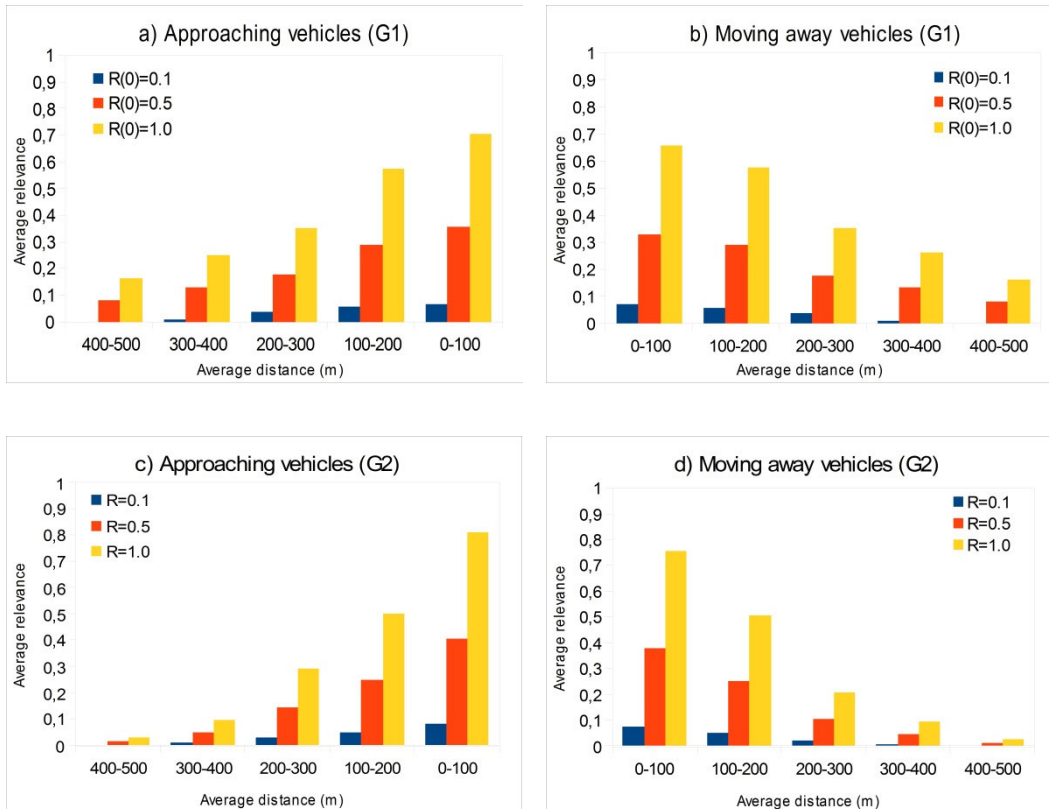


Figure 4.9: Comparison of average relevance value according to initial relevance value ($R^{(0)}$) variation in 200m geographical area with 300s alarm time.

It's worth noting that the values of T , $R^{(0)}$ are directly dependent on each other. More precisely, let's 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. 4.1) 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. Figure 4.10 and Figure 4.11 show the variation of relevance values over time based on different initial relevance values and warning time for *individual nodes*.

Figure 4.10 shows the relevance value for different warning time T (T is fixed to 300s for long warning and 60s for short warning) for both strategies G1 and G2. Emergency messages are periodically disseminated with 10s time interval during T . Every time the original relevance value (set as $R^{(0)}=1$ in the beginning) is decreased according to eq. (4.1). 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 (Figure 4.10a, Figure 4.10c) 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 (Figure 4.10b, Figure 4.10d).

As illustrated in Figure 4.10b and Figure 4.10d, 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 sec 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 sec), 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 Figure 4.10a and Figure 4.10b. 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 Figure 4.10c, Figure 4.10d the new computed relevance values are lower when compared to those obtained when using strategy G1 (Figure 4.10a, Figure 4.10b) 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.

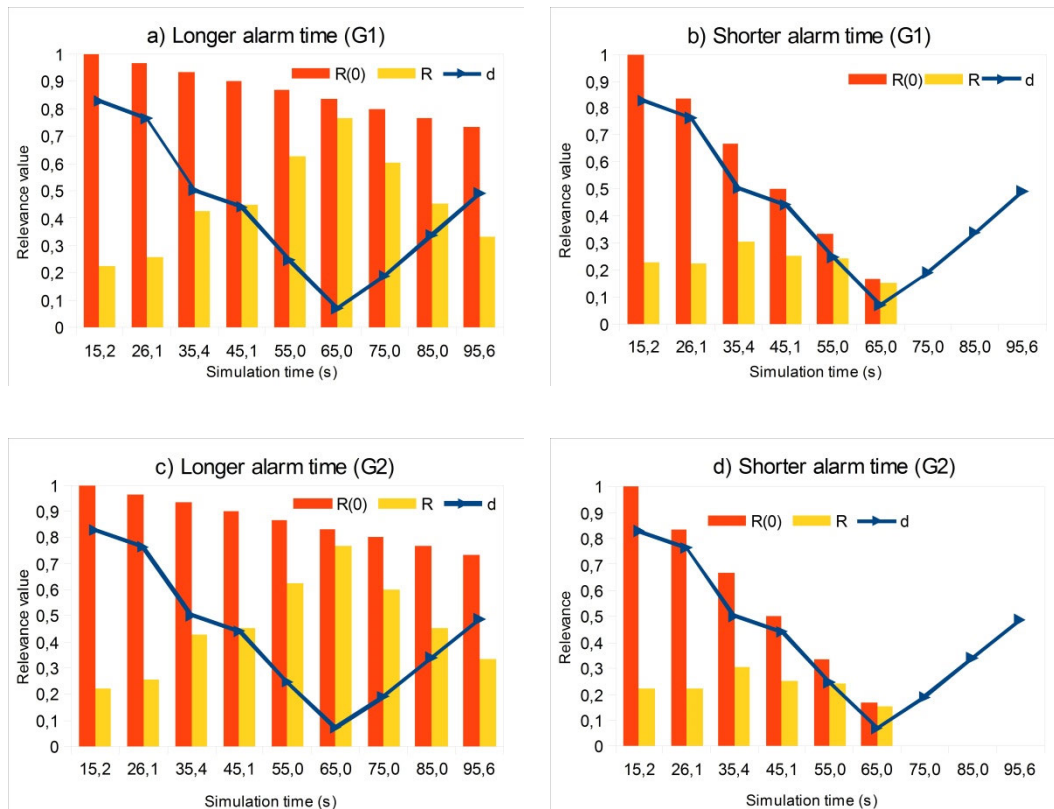


Figure 4.10: Comparison of relevance value according to alarm time (T) variation for individual given node ($D=200m$, $R^{(0)}=1$).

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 ($R^{(0)}=1$, Figure 4.11a and Figure 4.11c) for very critical events, and lower (Figure 4.11b and Figure 4.11d) for less important events. Consequently, when messages are received by neighbouring 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 Figure 4.11. 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).

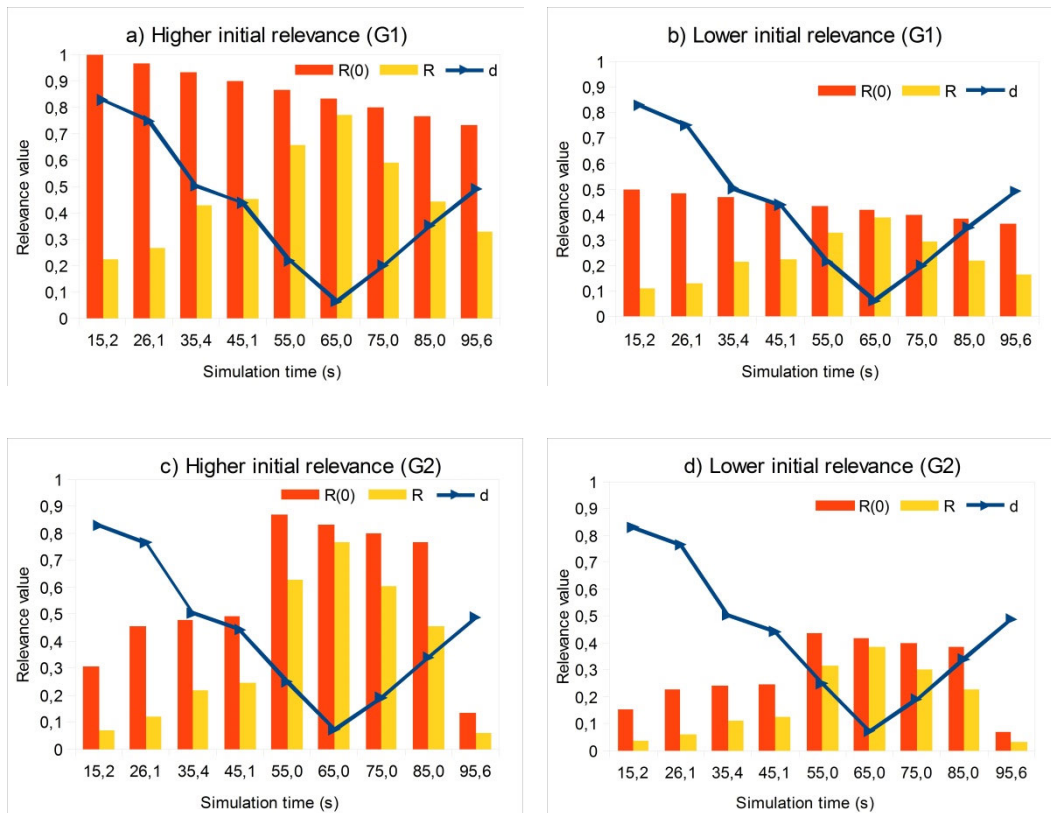


Figure 4.11: Comparison of relevance value according to initial relevance value ($R^{(0)}$) variation for individual given node ($D=200m$, $T=300s$).

The impact of network density on the average relevance computation is illustrated in Figure 4.12. We have simulated 100 nodes for dense network and 50 nodes for sparse network. Parameters used are fixed as follows: 200m for geographical area, 300s 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 (Figure 4.12a). 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 neighbour 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 behaviour as depicted in Figure 4.12.

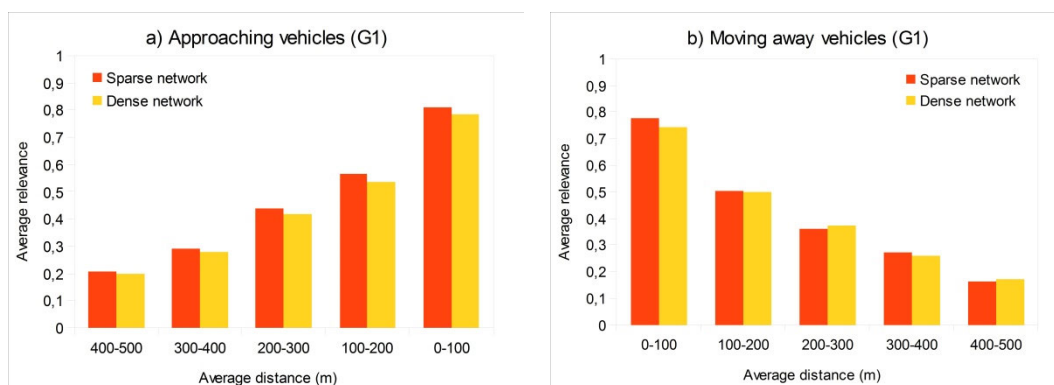


Figure 4.12: Comparison of relevance value according to network density variation ($D=200m$, $T=300s$, $R^{(0)}=1$).

Figure 4.13 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: $R(0)=1$, $D=200m$,

and $T=300s$. As it can be seen from the graphs, vehicles' speed is not influencing very much on average relevance value, 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 500~200m distance in Figure 4.13a). Because, high speed vehicles can reach 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 (Figure 4.13b).

It is worth noting that, according to eq. (4.2) and eq. (4.3) the value of λ influences when computing the relevance value of received messages. For example, for coming vehicles, the quantity of $\lambda \cdot \tau \cdot s$ influences on the relevance value increasing, e.g., higher/lower relevance value for high/low speed.

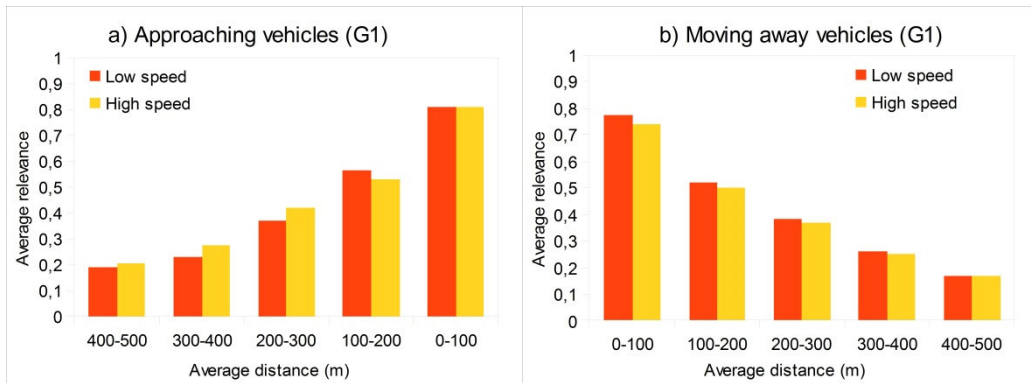


Figure 4.13: Comparison of relevance value according to speed variation in 200m geographical area.

As we observed above in figures 4.7-4.13, for both strategies G1 and G2, new computed relevance value R is 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 200m 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.

4.5 Conclusion of the chapter

In this chapter, a decentralized information dissemination method inspired from Ants' colony behaviour 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.

Chapter 5 - Bee-based Information Dissemination algorithm in VANETs

In this chapter we present bee-inspired information dissemination approach in VANETs. We use bee communication principles to develop our information dissemination strategies in vehicular networks.

First we give information about bee communication principles, its implementation into vehicular communication system, followed by a description of our proposed algorithm.

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5.1 Introduction

Decision making in superorganisms such as honey bee colonies often uses self-organizing behaviors, feedback loops that allow the colony to gather information from multiple individuals and achieve reliable and agile solutions [83]. Despite the fact that each individual follows only a few simple rules, interactions between individuals can lead to the emergence of a collective behavior, which enables the colony to make intelligent decisions in a complicated and changing environment [104]. The entire system can adapt to internal and external changes efficiently. Cycles of positive and negative feedbacks are key elements of information processing in such dynamic biological systems. Such feedback cycles improve information flow and decision making at multiple levels.

The role of self-organizing feedback loops has been particularly well explored in foraging, which is frequent and plays a crucial role in colony fitness. Positive feedback means that an individual recruits other individuals by some directive, such as dancing of bees in order to lead some other bees onto a specific food source site. Negative feedback avoids all individuals accumulating on the same task by counterbalancing the attraction negatively, such as abandoning the exhausted food source [84].

Bee swarms exhibit many intelligent behaviours in their tasks such as nest site building, marriage, foraging, navigation and task selection. There is an efficient task selection mechanism in a bee swarm that can be adaptively changed by the state of the hive and the environment. Foraging is also crucial task for bees. Forage selection depends on recruitment for and abandonment of food sources [84]. A bee is able to indicate to the unemployed workers the direction and distance from the hive of a patch of flowers, using a “dance” that gives also information on the quality and the richness of the food source [37].

In the previous chapter we have presented totally distributed Ant-based Information Dissemination approach in VANETs that is taken inspiration from communication principles

of ants. This chapter presents RSU-based information dissemination approach in VANETs that is taken inspiration from Bee-swarms communication system. Forager and scout bees seek for abnormal road conditions and immediately inform RSUs about each sudden accident in forms of emergency messages. RSUs process received messages and disseminate them according to their relevance value considered as forage site profitability level in bee-colony. The dissemination process will be terminated when the road become in normal condition similar with bee's negative feedback that fully exploited site are abandoned by forager bees.

RSUs could be exploited for efficient data dissemination to avoid excessive retransmissions in both comfort and safety related applications. Particularly, the role of RSU is important in urban areas where density of vehicles is commonly very high. Thus, vehicles cannot always verify all components of messages sent by neighbors in a timely manner, which causes in 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 [105], to achieve maximum performance, namely Binary integer programming and Balloon expansion heuristic methods. These methods were used to solve the optimization problem of minimizing the average reporting time. Inter vehicle communication is integrated with vehicle to infrastructure communication as an extension of IEEE 802.11p MAC standard to increase driver's awareness in safety-critical cases in [106]. 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 in [107].

In the following sections we will provide a Bee communication system overview, its mapping into VANETs, and details of proposed approach with simulation results. Proposed Bee-based approach is compared with Ant-based approach, i.e. RSU-based approach against

totally distributed approach in terms of average latency, message redundancy in different network density (sparse and dense).

5.2 The Bee communication system

A honey bee colony achieves coordination among its thousands of members without any central authority. The colony does not have a hierarchy where some individuals require information and then allocate tasks to different members and monitor them. Each individual decides to do a job depending upon the need of the colony that it estimates using the communication facilities and measures [108].

In the early-twentieth-century Karl von Frisch made a revolutionary discovery about the communication paradigm that bees use to share information about flower sites around the hive [50]. He experimentally verified that bees can inform hive-mates the direction and the distance to a food source by means of a dance. The bees' communication is shared when they search food sources, starting with some bees called "scouts" which navigate and explore the region aiming to find a food source [5]. In the positive case, according to von Frisch, they return to the bee hive at a level named "dance floor" to transmit and share this discovery with the others through round or waggle dances according to the discovery distance, quality etc.

The first type of the dance is the round dance which indicates that a food source is present near the hive (about 100 m), it shows only the direction. The second type of the dance is the waggle dance in which the bee effects a repeated movement that forms a drawing like the number eight (Figure 5.1). This scheme indicates the distance and the direction of the food source (up to few kilometers). The distance between the food source and the hive is transmitted depending on the speed of the dance. If the dance is faster, then the food distance is smaller. The food nature is indicated by the odor of the bee when it is rubbed.

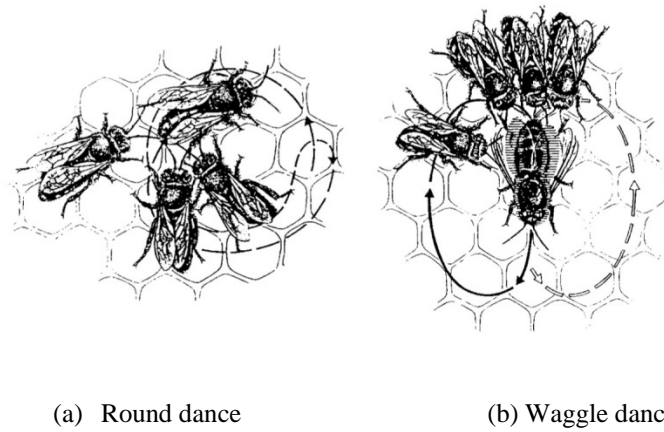


Figure 5.1: Running curve of bees. Bees that follow the dancer take in information [109].

It should be apparent that a memory of the sun (or of a dance angle based on the sun) would be useful only if it could be updated as the sun moves. Von Frisch's studies of how bees use the sun for navigation were one of the first demonstrations of a time-compensated sun compass in any animal. These experiments involved training bees to find food in a particular compass direction and then assessing the accuracy of orientation relative to the sun after various time intervals during which the sun moved. More recently, the dances of returning foragers have been used to study the details of sun compensation. To indicate a fixed feeding place, dances oriented to gravity (which is also fixed) must shift to compensate for the changing angle between the sun's azimuth and the direction of the food. As the sun's azimuth shifts relative to the direction of the resource, the dance angle relative to gravity changes. By knowing the location of a resource (e.g., an artificial flower), an observer can assess the dancer's knowledge of the sun's changing position over time (Figure 5.2). If one knows the location of the food, the waggle dance provides readout of where the bee has determined the sun to be. This technique has led to several insights into the sun compass of bees. Observations of dances over several hours of over-cast weather, when bees can see no celestial cues, have documented the accuracy with which experienced bees can compensate for the sun's movement by memory [110].

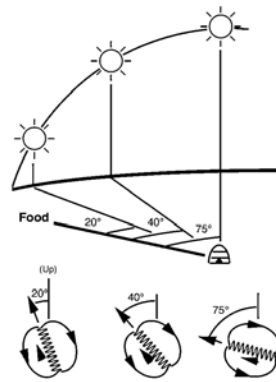


Figure 5.2: Dance communication as a window on the bee's ability to compensate for changes in the sun's azimuth (the sun's projection to the horizon) [110].

The essential details are the following: in context, the dance is performed in alignment with a particular aspect of the hive structure, which provides an absolute reference against which the bee audience can perceive specific angles. The main dance is the 'waggle' dance, which consists of a straight line movement, during which the bee waggles from side to side along the way. This straight line movement is done upwards at a particular angle from the vertical. At the end of the straight line part, the bee loops round to the starting point and repeats (actually, it alternates the direction of this loop, drawing a figure "8"). The angle of this dance from vertical indicates to the bee audience the direction they need to take with respect to the current position of the Sun. Among various extraordinary aspects of this, it is known that the bee automatically corrects for movement of the Sun during the day, and communicates the correct direction. Also, at times, the bee will pause its dance, and allow watching bees to sample the nectar it is carrying, giving an indication of the quality of the food source. How a dancing bee encodes information about the distance and direction to a rich patch of flowers is depicted in Figure 5.3. The duration of each waggle run is proportional to the length of the outbound light. The bee notes the angle of her outbound light relative to the sun's direction outside the hive, and then inside the hive she orients her waggle runs at the same angle relative to straight up on the comb [111] [112].

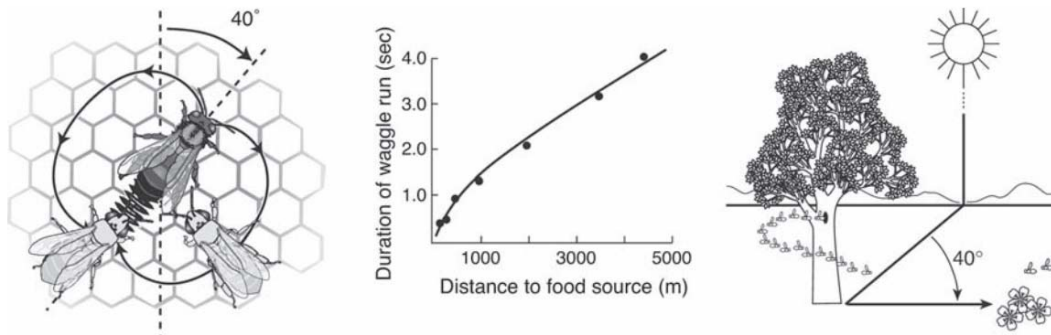


Figure 5.3: How a dancing bee encodes information about the distance and direction to a rich patch of flowers. Two followers are acquiring the dancing bee's information [111] [112].

The food amount depends on the wriggling of the bee. The more the wriggling, the higher is the quantity [5]. Thus, some bees are recruited and become foragers which increase with the proportion of food found. This step is known as the exploration phase, which is followed by the exploitation, in which the forager collects food and calculates the quantity to make a new decision. The forager can continue to collect food by remembering the best location, or it leaves the source and returns to the bee hive as a simple bee. The food sources located in the direction of the sun are represented as an upward direction on the vertical comb, and any angle to the right or left of the sun is encoded as any angle to the right or left of the upward direction. The recruited foragers maintain this angle from the sun to reach in a small region around the flower and then use the flower fragrance, which clings to the body of a forager and which they smell while observing the dances, to identify the food source unambiguously.

Whenever a food source is fully exploited with the passage of time, all the employed bees associated with it abandon the food source [113]. The ability of information to be reproduced by itself, or its fitness, is proportional to the quality of the food source. The mechanism is defined thus by a positive feedback. The dissipation of information occurs when foragers abandon unrewarding food sources. This ensures the mechanism of changing in the system and prevents its sticking in local optima. The carriers of information, i.e., employed foragers exploit an available “resource” to the pool of unemployed bees. The natural physical

limitation of the hive, i.e. the condition for mass conservation, restricts the number of information carriers. The replication of information is thus naturally limited. All these factors lead to the competition of information and, as a result, only the most useful information, trail to the most profitable food source, survives in the system [104].

5.3 The mapping of Bee communication system to VANETs

In our work, each RSU is considered as Bee Hive [114]. RSU broadcasts echo packets to vehicles within its communication range in order to inform them that they are in its coverage area. It is similar with scouts/foragers fly from the Bee Hives to find food sources in bee colony. Every vehicle entering RSU's coverage area updates its knowledge base with RSU's ID when it receives broadcasted (periodically hello) echo packets. When an abnormal environmental event is noticed on the road surface, a safety message is created to inform other vehicles and will be sent back to respective RSU. This is similar to a Bee behavior i.e., when a Bee observes a floral findings it returns to Bee Hive and performs a dance in order to attract the other bees' attention to forage in the same area [50]. Bees carry with them information about the profitability of the source with its location [37]. According to [53], the recruitment of other bees is proportional to profitability of a food source, i.e., the greater the profitability of a food source, the higher is the probability of its followers. Similarly, in the proposed Bee inspired information dissemination method, the *relevance* of safety messages will depend upon the severity and type of events took place on the road. Furthermore, since information about all current rich sources being exploited is available to an onlooker bee on the dance floor, in bee colony, presumably she could choose to employ herself at the most profitable source [53]. Similar in VANETs, RSU can receive several messages at the same time from different sources and it disseminates a message with high relevance (or higher than given threshold value). According to [37], a number of employed bees independent from each other perform a dance for the same richer source side in the given period of time till this source will

be depleted. Similar in VANETs, safety messages for critical/danger events are periodically transmitted from source to RSU during related time period till road will be processed. Whenever a food source is fully exploited with the passage of time, all the employed bees associated with it abandon the food source [113]. It should be noted that the most profitable exploiting sites are the ones that is the richest or closest (distance) to the nest [54].

Hence, taking the concept of bee communication principles, we defined the *relevance* of safety messages as an analogue to profitability value in Bee colony, to take an appropriate action. As profitability value depends on source richness, distance and exploited fully over time, and finally be vanished from the system, the relevance value depends upon the severity and event types. Furthermore, the relevance value decreases over time, with distance, till the corresponding safety message is vanished and dropped from the system. Table 5.1 presents the mapping between Bees' behavior and the proposed information dissemination approach.

Bee communication system	Vehicular Ad hoc Networks
Bee hives	Road Side units (RSUs)
Scout bees fly from the bee hives to forage (richer) sources	RSU broadcasts Hello messages to vehicles located in its coverage area (vehicles will update their knowledge base with RSUs ID)
Floral finding (food source)	Event (Accident/abnormal condition)
After finding richer sources employed bees return to the bee hive	Safety messages for abnormal road conditions are generated and sent back to RSU
Bees carry with them information about the profitability of the source with its spatial information	Each message include a relevance value depending on the event severity and type
Bees choose to employ herself at the most profitable source	RSU disseminates messages with high relevance
Fully exploited sources will be abandoned by the passage of time	Dissemination process of an event message will be terminated as relevance value decreases over time

Table 5.1: Mapping rules of Bee communication system to VANETs

5.4 RSU-based information dissemination approach inspired by Bee communication behavior

For our application, we use Bees communication principles for information dissemination in VANETs more focused on Safety-critical reason. In practice, providing such a service i.e., safety-critical services only take a short period of time and consumes a small fraction of bandwidth [102]. RSU plays an important role in the today's developed driving experience, especially in urban areas. RSUs provide drivers with up-to-date information to comfort and safe driving.

There are three types of messages in our application: (i) periodically hello message (echo), which is broadcasted from RSU to vehicles located in its coverage area; (ii) event message, which is generated for abnormal road conditions and destined to nearest RSU; (iii) alert message, which is processed by RSU and disseminated to surrounding vehicles.

Vehicles entering to a RSU's coverage area update their knowledge base by receiving Hello message from RSU, which includes its ID, location, and approximate time how long will move in its zone depending on speed and direction. When a vehicle v_i observes an event p_j that needs to be disseminated to other vehicles, it will generate a safety message m_{p_j} and will report to RSU. This message include the timestamp (t_0), location information, and the initial relevance value ($R_{v_i, p_j}^{(0)}(t_0)$) generated at time t_0 . Alarm triggered by the event p_j is generated and disseminated periodically up to a time T, similar with one described in section 4.3.2, where the relevance initial value ($R_{v_i, p_j}^{(0)}(t)$) associated to a generated message at time t (by source node) is expressed by eq. (4.1).

When an event message is received by RSU, its relevance value will be computed by eq. (5.1) and it will be put in message queue if it is relevant (i.e., $R_{RSU,p_j} > 0$, or greater than given threshold value):

$$R_{RSU,p_j}(t + \tau) = \frac{2 \cdot R_{v_i,p_j}^{(0)}(t)}{1 + e^{d/D}} \quad (5.1)$$

where $R_{v_i,p_j}^{(0)}(t)$ is the relevance of the message m_{p_j} generated by the vehicle v_i (source) at time t ; d is the distance between RSU and the location where the event is appeared (source); D is the radius of the relative geographical area (the emergency zone or alert region, defined as all the roads leading to the emergency location); τ is the assessment delay needed to compute message relevance before re-disseminating it to other surrounding vehicles .

Afterwards, messages in queue will be processed and the highest relevant messages are disseminated as early as possible. By the strategy G1, messages are disseminated with original relevance value initialized by the source while new relevance value (computed by RSU, eq. (5.1)) replaces it in strategy G2. When vehicles around the RSU receive disseminated message, i.e. vehicle v_k , compute its relevance value depending on selected strategy. For example, by strategy G1 relevance value is computed using original relevance value, eq. (4.2), and by strategy G2 with RSU computed relevance value, eq. (5.2):

$$R_{v_k,p_j}(t + \tau) = \frac{2 \cdot R_{RSU,p_j}(t)}{1 + e^{\frac{d + \lambda \cdot \tau \cdot s}{D}}} \quad (5.2)$$

where d is the distance between the current location of receiver vehicle v_k and the location where the event is appeared (source); s - is the current speed of v_k ; λ - is a sign, representing direction of the vehicle: if it is moving toward the event location its value will be (-1), otherwise its value will be (+1); and the quantity of $\lambda \cdot \tau \cdot s$ represents the influence of distance variation during the assessment delay τ .

In both cases, when using strategy G1 and G2 in bee-inspired approach, neighbour vehicles use received messages only for own safety reason, e.g., take preventive actions before getting into same dangerous situation, such as speed slow down, change the road or stop moving. They will not re-disseminate them. The overall process in the bee-inspired algorithm is given in Figure 5.4.

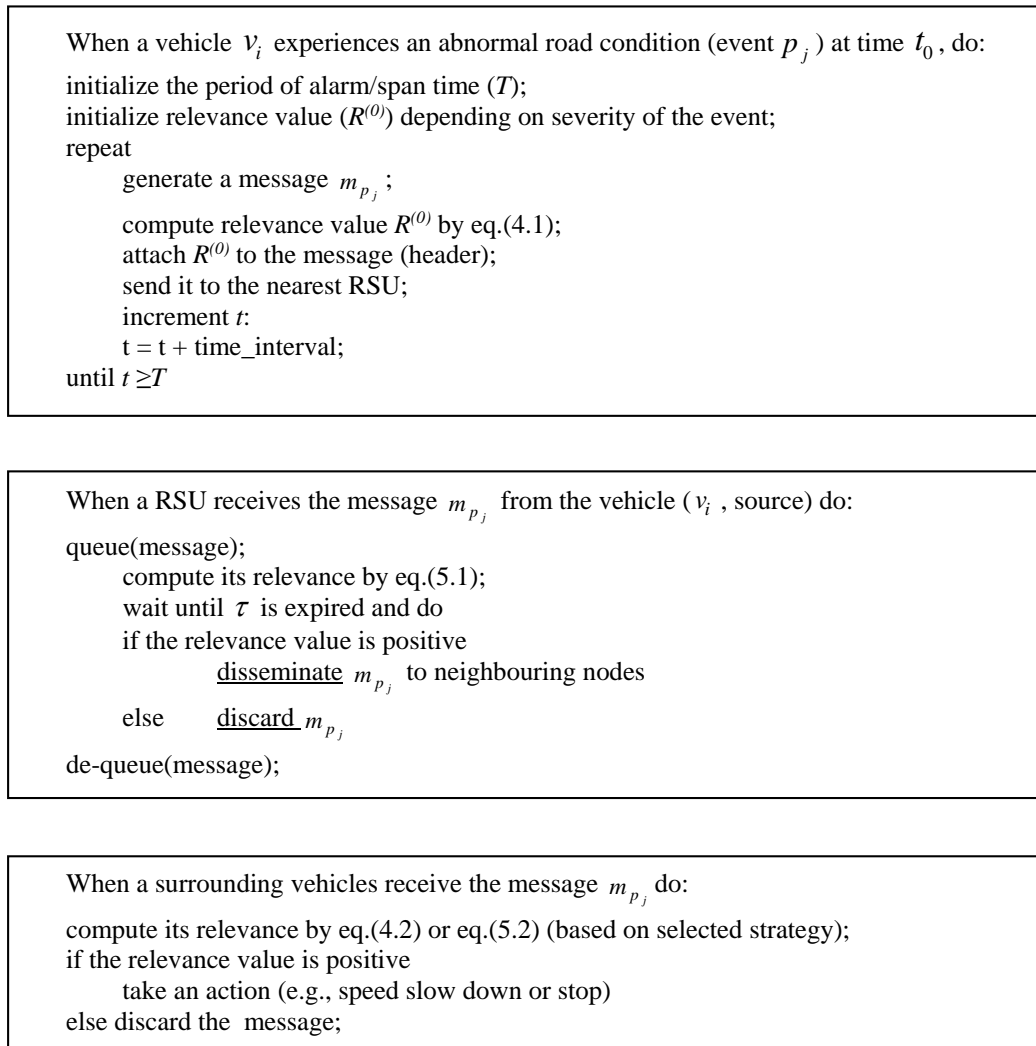


Figure 5.4: Message dissemination process by bee-inspired dissemination algorithm

5.5 Performance evaluation

In this section, we provide a comparative study of our proposed information dissemination approaches inspired by ant and bee communication principles based on simulation results. The objective is to evaluate the relevance of messages and its influence on broadcasting to the

entire network. Because, drivers far away from this place may not be interested since no actions are needed from them to avoid such a dangerous situation. The relevance value increases when the distance decreases between the vehicle and the place where safety data was generated, and vice versa.

Simulation parameters related to mobility and traffic scenarios are first described. Performance metrics together with simulation results are then reported and analysed.

5.5.1 *Simulation parameters*

In order to simulate bee inspired approach and compare results with ant inspired approach we have used same simulation parameters described in section 4.4.1. We also installed one RSU in the center of every generated network.

5.5.2 *Simulation results*

We have done simulations several times by varying initial network parameters, i.e., with different relative geographical area (D), different alarming span time (T), different initialized relevance value ($R^{(0)}$), using bee and ant inspired approaches. Overall outputs showed that relevance value increased when vehicles moved towards to the event location and decreased for opposite directed vehicles.

Figure 5.5 and Figure 5.6 show average relevance value comparison according to related geographical area and distance between receiver vehicles and event location, using strategies G1 and G2 respectively. Average relevance value has almost same tendency of increase/decrease according to vehicles' movements (moving towards/away in certain geographical area) for similar strategies, i.e., Ant-G1 with Bee-G1 (Figure 5.5), and Ant-G2 with Bee-G2 (Figure 5.6). However, when we used G2-type strategies, average relevance value was low compared with G1. For example, average relevance value was around 0.7 for vehicles located in 0-100 m distance from the event with 200m geographical area when we used strategy Ant-G1 (Figure 5.5a). This value was about 0.4 when we used strategy Ant-G2

(Figure 5.6a). These facts due to messages are re-disseminated with new computed relevance value in strategy G2, i.e., computed by eq. (5.4) or eq. (4.3), while messages are re-disseminated with (source generated) original relevance value in strategy G1, i.e., every intermediate vehicle/RSU forwards/re-disseminates received message without any modification.

Thus, the main influencing factor to new relevance value is previous/sender node's (i.e., intermediate node's) relevance value. The second influencing factor is the distance between receiver and event location. If the distance is less than radius of related geographical area, i.e., receiver locates within geographical area relevance value will be high, otherwise it will be low. Hence, if third node receives message from low relevant node (located, for example, in the border of geographical area, with low relevance) its new computed relevance value will be lower than sender's.

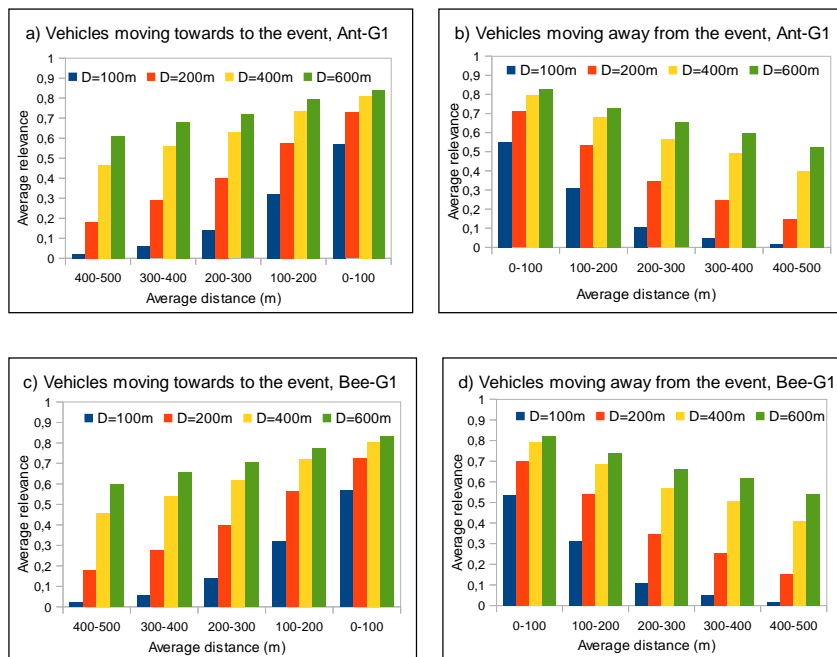


Figure 5.5: Average relevance value behavior according to different selected geographical area – D, using strategy G1.

Since, all messages are re-disseminated through RSU (which is located in the center of network) with RSU-computed relevance value in bee-inspired approach, nodes computed

received messages' relevance value according to this value when we used strategy G2. In ant-inspired approach nodes compute new relevance value according to third (intermediate) node's relevance value which could locate in different place of network. Therefore, average relevance value was higher with bee-inspired approach than ant-inspired approach when we used strategy G2 (Figure 5.6).

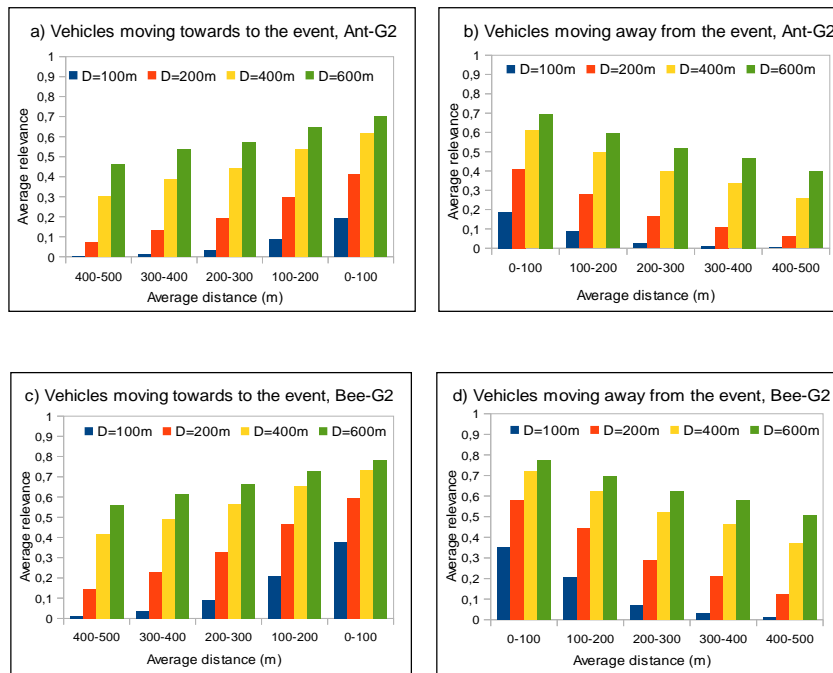


Figure 5.6: Average relevance value behavior according to different selected geographical area – D, using strategy G2.

Overall, the simulation results showed that the average relevance value is high with high values for the initial geographical area, the alarm/alert span time, and the original relevance value. Therefore, we did not provide simulation results according to alarming span time and original relevance value for bee-based approach in this chapter. It is worth noting that, high value of the relevance influences to prolongation of the message dissemination time while messages with low relevance value are rapidly dropped by receivers as expected.

Simulation results related to latency and SRB comparisons of proposed approaches are given in Figure 5.8 and Figure 5.9. Since messages are distributed through RSU, and vehicles do not participate in dissemination process (i.e., vehicles are disabled from re-dissemination),

bee-inspired approach achieved not only high/perfect SRB, but also good/effective results in terms of latency. Besides, the results according to latency and SRB were poor for ant-inspired approach. For example, SRB was near to 0, because almost all vehicles participated in the message dissemination process (to provide high reachability), i.e., the main principle of the proposed approaches is to inform all nearby vehicles. When vehicles receive a message with high relevance value, they immediately re-disseminate it without any additional checking processes. But, it performs similar with simple flooding that cause the well-known broadcast storm problem.

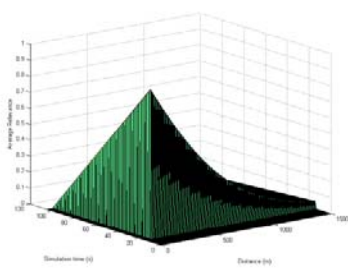
In order to solve/eliminate this problem, we need a relevance threshold value to prevent vehicles from re-dissemination of the low relevant messages outside of a given geographical area. This value could be selected adaptively according to initial values of the related geographical area, the distance between receiver and the event location, and receiver vehicle's speed/velocity and the time delay.

To select the Relevance threshold value adaptively, we show analytical computations and visual shapes of average relevance value according to time and distance (using MATLAB). According to eq. (5.1), initial relevance value $R^{(0)}$ decreases by time going (i.e., every time in periodically message generation process), and consequently, the relevance value of this message decreases as distance increases (i.e., according to eq. (5.3) and/or eq. (4.3)) and vice-versa. In the eq. (5.3), taking into account an emergence of the message, we omit the expression $\lambda \cdot \tau \cdot s \cong 0$ by considering that τ is very small, near to 0 (i.e., received message should be immediately processed).

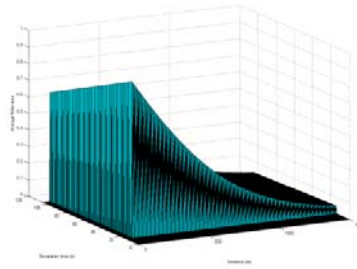
We put eq. (5.1) to the place of $R_{v_i}^{(0)}(t)$ into eq. (5.3), and we will have

$$\begin{aligned}
 R_{v_k, p_j}(t, d) &= \frac{2 \cdot R_{v_i, p_j}^{(0)}(t)}{1 + e^{-\frac{d + \lambda \cdot \tau \cdot s}{D}}} \Rightarrow R_{v_k, p_j}(t, d) = \frac{2 \cdot R_{v_i}^{(0)}(t_0) \cdot \frac{T - (t - t_0)}{T}}{1 + e^{-\frac{d}{D}}} \Rightarrow \\
 &\Rightarrow R_{v_k, p_j}(t, d) = \frac{2 \cdot R_{v_i}^{(0)}(t_0)}{T} \cdot \frac{(T + t_0) - t}{1 + e^{-\frac{d}{D}}}
 \end{aligned} \tag{5.5}$$

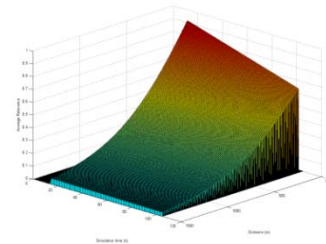
By varying constants in this function, i.e., initial values of $T, R^{(0)}, D$ and t_0 we obtained shapes as given in Figure 5.7. According to simulations results, e.g., given in Figure 5.5 and the shapes given in Figure 5.7, average relevance value of received messages (with highest original relevance value, i.e., $R^{(0)} = 1$) was about half of the initial relevance value, i.e., $\frac{1}{2} \cdot R_{v_i}^{(0)}(t_0) = 0.5$ for vehicles located around border of related geographical area, i.e., $d = D$. This value is decreased by increasing the distance and time going. We can see the impact of the different initialized related geographical area D (400m, 1000m and 1500m) and the time delay (90s, 300s) to the average relevance value in these shapes. For example, when related geographical area D is initialized to 400m, the average relevance value was dropped sharply with 90s alarm time while it was decreased gradually (slowly) with 300s alarm time.



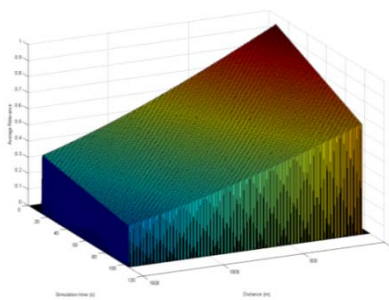
a) $D=400m, T=90s, t_0=15, t_0 < t < T, d < 1500m$



b) $D=400m, T=300s, t_0=15, t_0 < t < T, d < 1500m$



c) $D=1000m, T=300s, t_0=15, t_0 < t < T, d < 1500m$



d) $D=1500m, T=300s, t_0=15, t_0 < t < T, d < 1500m$

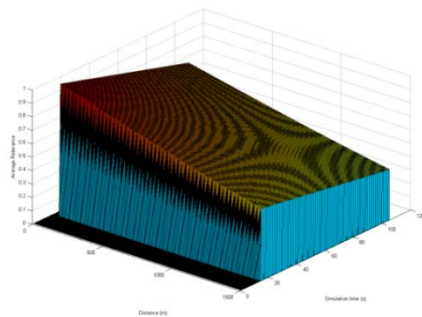


Figure 5.7: Average relevance value behavior according to different selected geographical area D and alarm time T , using Ant-G1 approach.

For instance, let us consider relevance value is initialized as 0.5 for a message generated after certain seconds for the same event; its relevance value will be about 0.265 for vehicles located around border of related geographical area. Thus, by considering that according to applied application the emergency level set/fixed corresponding relevance threshold value to 0.5, we have evaluated its influence to Latency and SRB. Generally, for vehicles located around the border of D , received a message directly from the source, the relevance value will be higher than 0.5 ($R \geq 0.5$), therefore the message will be re-disseminated; but, if message is received after certain time it could not be re-disseminated due to low relevance value ($R \leq 0.5$). We leave open the question of how to select the threshold value dynamically, but we provide experimental comparison results with default threshold 0, and selected threshold value 0.5 in Figure 5.8 and Figure 5.9.

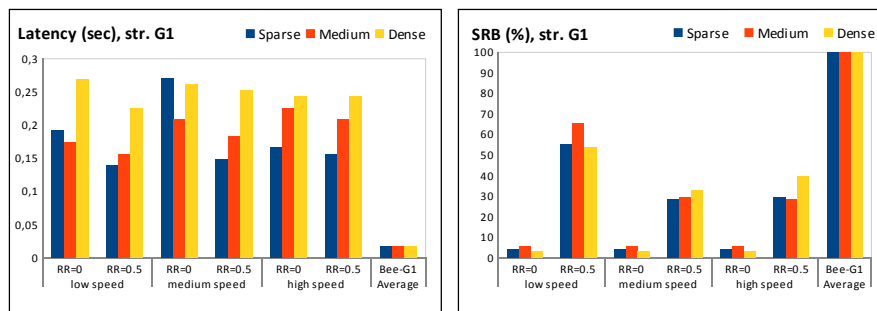


Figure 5.8: Latency and SRB comparison of Ant-G1 approach using default (RR=0) and certain (RR=0.5) relevance threshold values vs Bee-G1.

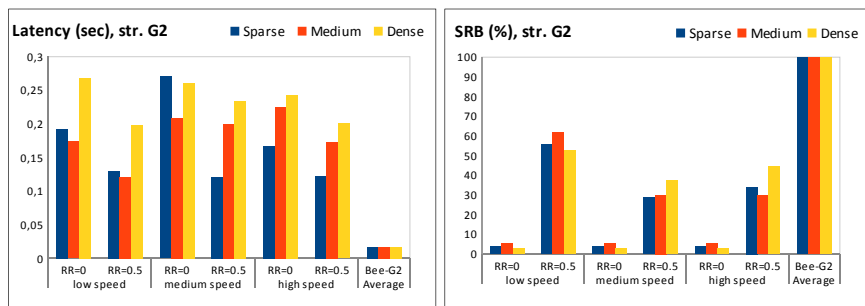


Figure 5.9: Latency and SRB comparison of Ant-G2 approach using default (RR=0) and certain (RR=0.5) relevance threshold values vs Bee-G2.

As it is presented in Figure 5.8 and Figure 5.9, we have compared latency and SRB according to relevance threshold values. We have achieved better SRB using the relevance threshold value 0.5 compared with default value, 0 in ant-inspired approach. Latency and SRB was almost same when we used default value of relevance threshold (RR=0) in both strategies. When we used relevance threshold value 0.5, latency was low/better in strategy G2 compared with strategy G1. When we used strategy G1, threshold value 0.5 influenced to latency increase according to density of network and vehicles' speed. For example, in sparse network latency was about 0.13s with low speed and it increased to 0.14s and 0.15s with medium and high speed, respectively. The latency 0.15s for vehicles moving with high speed in sparse network increased by growing a density of network, e.g., it became about 0.21 and 0.25 in medium and dense networks respectively.

Message dissemination by number of sources	Density	Bee-inspired approach RR=0, RR=0.5		Ant-inspired approach RR=0		Ant-inspired approach RR=0.5	
		Max number of received messages (C)	Max latency (ms)	Max number of received messages (C) SRB/MaxC	Max latency (ms)	Max number of received messages (C) SRB/MaxC	Max latency (ms)
1 source node, 1 time	Low (50 nodes)	1	17.504	4/20	26.97	61.9048/14	28.016
	High (100 nodes)	1	17.504	6/27	37.7065	52.7473/15	51.9643
1 source node, Periodically 10 times	Low (50 nodes)	10	16.494	4/158	39.189	31.9149/101	46.6639
	High (100 nodes)	10	16.494	6/ 196	70.9778	36/ 147	81.056

Table 5.2: Latency and Maximum number of received messages according to number of sources and network density (with Relevance threshold 0 and 0.5)

Simulation results according to latency, SRB and maximum number of same received message is given in Table 5.2. Relevance threshold value (0 and 0.5) did not impact to Bee-based approach performance (because original relevance value was initialized to 1, and this value was enough high during simulation time). However, the relevance threshold value 0.5 significantly increased SRB in Ant-based approach, because vehicles did not re-disseminated

received messages with low relevance value. But, this process led to slight increase in latency, i.e., messages are delivered to some related nodes via farther nodes with high relevance since nearest vehicles did not send it to him because of low relevance.

5.6 Comparison of Ant- and Bee- inspired approaches

In this and previous chapters, swarms-inspired information dissemination approaches in VANETs are presented. We mainly implemented ant and bee communication systems to information dissemination process in vehicular networks. The main idea of proposed approaches is to provide each vehicle with the required information about its surrounding and assist drivers to be aware of related undesirable road conditions. In these approaches, we introduced information relevance parameter into emergency messages. In bees colony it is analog of source profitability, bees dance longer and attentive for more profitable findings [50]; in ants colony it is analog of pheromone, the amount of pheromone deposited is proportional to the quality/quantity of the food source found [3].

In both cases, the relevance of safety related information received by a vehicle mainly depends on the distance between the current location of the vehicle and the place where safety data was generated. The relevance value increases when the distance decreases (i.e., vehicle moves toward Accident/event direction), and decreases when the distance increases (i.e., vehicle goes away from the event/dissemination area). Receiving such a message can help drivers, before approaching this place, to decide next actions, such as decreasing/increasing speed, finding an efficient route, and avoiding traffic jam, etc. This is quite similar to the pheromones of ants and the profitability value of bees' discoveries, they also decreases as the distance between nest/hive and food sources increases.

Two modes are distinguished in data dissemination process in VANETs, i.e., dissemination through V2R communication and dissemination through V2V communication. Ant inspired approach supports both two modes while bee inspired approach is based on first mode.

In bee inspired approach, all necessary communication between vehicles are organized and controlled through RSUs, in other words, the approach is RSU based, i.e., particularly centralized. As bees communicate with each other in their hives to share their findings, proposed its analog in VANETs considers that the hive corresponds to RSU, food sources to events/accidents, and bees to emergency messages that are aimed to inform others. Vehicles are disabled to re-disseminate received messages, and they could exchange information with each other via RSU. If vehicles observe an abnormal situation on the road they inform nearest RSU by unicasting emergency messages; afterwards, RSU disseminate them if their relevance value is positive.

Bee communication principles inspired approach	Ant communication principles inspired approach
Source generated message is unicasted to nearest RSU	Source generated message is disseminated to neighborhood
Vehicles communicate with each other indirectly through RSU	Vehicles communicate with each other both directly and/or indirectly through RSU
Vehicles not allowed re-disseminate information (it helps to minimize redundant messages)	Vehicles re-disseminate relevant information to neighborhood
Vehicles accept only RSU disseminated messages, messages sent by other vehicles are ignored/discarded	Vehicles can listen and process all messages
Communication is reliable, controlled by RSU	Vehicles trust to each other
Partly-centralized, RSU-based communication	Distributed communication
The approach is more appropriate to use in urban areas, because it is difficult to have RSUs everywhere.	The approach could be used everywhere, but more appropriate for suburban areas.

Table 5.3: Comparison of information dissemination approaches inspired by bees' and ants' communication principles

In ant-inspired approach, in the first mode, when a vehicle passes through RSU and one/both have some new message(s) 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 new message to RSU such that other vehicles could get this information. Similarly, vehicles can get information from RSU that has been provided by previous vehicles or RSU itself. In the second mode, when two vehicles (moving in opposite

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. Table 5.3 presents the comparison of both approaches.

Simulations are conducted for both approaches, and comparative study is stated to show the advantages and disadvantages of ant- and bee-inspired approaches in VANETs. Bee-inspired approach is more suitable and effective for urban areas in terms of latency and SRB compared with ant-inspired algorithm. However, it has some drawbacks compared with Ant-inspired approach. For example, vehicles could receive (in worst cases, even cannot receive) an emergency message for the event that occurred near to its location with high latency/delay if RSU locates far from them (i.e., message travels through RSU). Moreover, strategy G2 in bee inspired approach could be ineffective, because vehicles located near to the accident/event could receive a message with low (RSU computed) relevance value. It could cause to rejection of vital messages because of RSU computation. From this point of view, ant-inspired approach is showed its distributiveness /effectiveness during our study.

In order to provide related vehicles around the event/accident location, we have not set higher Relevance threshold value in message dissemination decision. Received messages were immediately re-disseminated if their relevance value were positive (i.e., in default $R > 0$). Therefore ant-inspired approach caused to poor latency and SRB. Afterwards, we have done simulations with different relevance threshold values and provided results with the value 0.5. It improved latency and SRB in ant-inspired approach. Thus, to increase effectiveness of proposed approaches, appropriate/adaptive relevance threshold value should be adaptively implemented according to initialized related geographical area, distance to the event and speed of the receiver vehicle.

A hybrid approach combined centralized (Bee) and decentralized (Ant) approaches are required in order to be used for both urban and highway scenarios. However, more

simulations with different scenario's (highway and urban areas) will be conducted to study this statement and this will constitute our future work.

Chapter 6 - Conclusions & Perspectives

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6.1 Summary

The work presented in this thesis deals with information dissemination in Ad hoc based networks. Particularly, adaptive information dissemination algorithm is proposed in chapter 3, where, each node can dynamically adjust the values of its local parameters using information from neighboring nodes without requiring any additional effort, such as distance measurements or exact location-determination of nodes. Bio-inspired approaches for information dissemination in VANETs, i.e., Ant- and Bee-based approaches are proposed in chapter 4 and chapter 5, respectively.

The main objective of these approaches 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 analogue to pheromone throwing in Ant colony, and as an analogue to profitability value in Bee colony, to disseminate safety information within related geographical area. Safety applications, as primary application type in VANETs, address mainly geographical areas in which data needs to be distributed. Because, drivers far away from the event location (i.e., outside of the related geographical area) may not be interested since no actions are need from them to avoid such a dangerous situation.

In Ant-based approach, each vehicle is considered as an Ant. When an Ant observes a food source it left pheromone traces to convey indirectly to other Ants about route information of that food source. Moreover, according to [41], 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 [97]. Similarly, in the proposed Ant inspired information dissemination method, we defined the *relevance of safety messages* depending upon the severity and type of events that took place on the road. When an

abnormal environmental event is noticed on the road, a safety message is created and disseminated to other vehicles and roadside units, to allow drivers to be aware of undesirable events and road conditions. Furthermore, as pheromones evaporate with the passage of time, the lesser used ant paths are gradually vanished [3] [4]. 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.

In Bee-based approach, each RSU is considered as Bee Hive. RSU broadcasts echo packets to vehicles within its communication range, vehicles entering to RSU's coverage area updates its knowledge base with RSU's ID. When an abnormal environmental event is noticed on the road surface, a safety message is created to inform other vehicles and will be sent back to respective RSU. It is similar with scouts/foragers fly from the Bee Hives to find food sources in bee colony. When a Bee observes floral findings it returns to Bee Hive and performs a dance in order to attract the other bees' attention to forage in the same area [50]. Bees carry with them information about the profitability of the source based on its quality, quantity and the distance to the location [37]. Similarly, in our proposed approach, safety messages have *relevance* value based on the severity and type of events took place on the road. Furthermore, since information about all current rich sources being exploited is available to an onlooker bee on the dance floor, in bee colony, presumably she could choose to employ herself at the most profitable source [53]. Similar in VANETs, RSU can receive several messages at the same time from different sources and it disseminates a message with the highest relevance (or higher than given threshold value). Whenever a food source is fully exploited with the passage of time, all the employed bees associated with it abandon the food source [113]. Furthermore, the relevance value decreases over time and distance, till the corresponding safety message is vanished and dropped from the system.

In both cases, the relevance of safety related information received by a vehicle mainly depends on the distance between the current location of the vehicle and the place where safety data was generated. The relevance value increases when the distance decreases (i.e., vehicle moves toward Accident/event direction), and decreases when the distance increases (i.e., vehicle goes away from the event/dissemination area). Receiving such a message can help drivers, before approaching this place, to decide next actions, such as decreasing/increasing speed, finding an efficient route, and avoiding traffic jam, etc.

Two modes are distinguished in data dissemination process in VANETs, i.e., dissemination through V2R communication and dissemination through V2V communication. Ant inspired approach supports both two modes while bee inspired approach is based on first mode. In bee inspired approach, all necessary communication between vehicles are organized and controlled through RSUs, in other words, the approach is RSU based, i.e., particularly centralized. In ant-inspired approach, when a vehicle passes through RSU and one/both have some new message(s) to exchange, they will update each other's knowledge base by using the communication medium. Ant inspired approach is fully distributed, i.e., vehicles and RSUs participate in information dissemination process. In the first mode, when a vehicle passes through RSU and one/both have some new message(s) to exchange, they will update each other's knowledge base by using the communication medium. A vehicle throws new message to RSU such that other vehicles could get this information. Similarly, vehicles can get information from RSU that has been provided by previous vehicles or RSU itself. In the second mode, when two vehicles (moving in opposite 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.

6.2 Future work

The application area of wireless ad hoc networking is enlarging due to its easy connection features. MANETs and VANETs are examples of widely used areas that require adaptive communication techniques to connect objects in such dynamic environments. Our proposed approaches are targeted to disseminate safety information, but it could be easily applicable in other applications with some modifications. In the near future, we plan to continue our research in construction of hybrid networks where ad hoc based networks could connect to Internet and other services through combination with infrastructure techniques. For example, this research area, i.e, Internet of Things (IoT) or Internet of Everything is currently being investigated by researchers from academia and industry.

The effectiveness of distributed ant-inspired approach is shown by simulation results where every node could communicate with its neighbors to share some important information. The second approach inspired by another swarm member such as honey bees are presented as RSU-based approach where communication is controlled/organized through RSUs that achieved better SRB, lower energy consumption and lower latency compared to ant-based approach. According to their features, Bee-inspired approach is more appropriate for urban area where RSUs could be easily installed to control information dissemination by providing high reliability and low redundancy while Ant-based approach is more suitable for suburban/highway areas where installing RSUs is not simple issue.

Thus, a hybrid approach combined centralized (Bee) and fully distributed (Ant) approaches are required in order to be used for both urban and highway scenarios. For example, semi-distributed approach will be proposed where mobile nodes in ad hoc networks adaptively select relay nodes to disseminate information to wide geographical areas. By this way, a traffic information center could collect emergency information together with general information such as the vehicle locations, state of the traffic etc.

Moreover, more simulations with different scenario's (highway and urban areas) will be conducted to study these statements and those will constitute our future work.

List of personal publications

International journals

- [1] **S. Medetov**, M. Bakhouya, J. Gaber, K. Zinedine, M. Wack, P. Lorenz. A Decentralized Approach for Information Dissemination in Vehicular Ad hoc Networks. Journal of Network and Computer Applications, Elsevier, Volume 46, November 2014, Pages 154-165.

Ready to be submitted:

- [2] **S. Medetov**, M. Bakhouya, J. Gaber, K. Zinedine, M. Wack, P. Lorenz. "Swarm-based Context-aware Information Dissemination Approach in Ad-hoc Networks".

International conferences

- [3] **S. Medetov**, M. Bakhouya, J. Gaber, K. Zinedine, M. Wack, "A Bee-Inspired Approach for Information Dissemination in VANETs," in ICMCS-2014, 4th International Conference on Multimedia Computing and Systems, Marrakesh-Morocco, 2014.
- [4] **S. Medetov**, M. Bakhouya, J. Gaber, M. Wack. "Evaluation of an Energy-Efficient Broadcast Protocol in Mobile Ad Hoc Networks", in ICT-2013, 20th International Conference on Telecommunications, Casablanca Morocco, May 6-8, 2013.
- [5] **S. Medetov**, M. Bakhouya, J. Gaber, M. Wack. "An Ant-based Approach for Information Dissemination in VANETs", Les Journées des Ingénieurs/Doctorants (IngéDoc'12), Belfort, 2012.

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Acronymes and Abbreviations

Abbreviation	Designation
ABC	Artificial Bee Colony
ABS	Automatic Braking System
ACO	Ant Colony Optimization
AID	Adaptive Information Dissemination
C2C	Car to Car
CAID	Context Aware Information Dissemination
DSRC	Dedicated Short-Range Communications
ETSI	European Telecommunications Standards Institute
GPS	Global Positioning System
ICF	Information-Centric Forwarding
ITS	Intelligent Transportation Systems
MANETs	Mobile Ad hoc NETWORKs
MOVE	MObility model generator for Vehicular networks
NS	Network Simulator
OSI	Open Systems Interconnection
PCF	Packet-Centric Forwarding
R&D	Researche & Developpement
RDT	Random Delay Time
RSU	Road Side Unit
SRB	Saved Re-Broadcast
SUMO	Simulation of Urban MObility
TRaNS	TRaffic and Network Simulation environment

V2R	Vehicle to Roadside
V2V	Vehicle to Vehicle
VANETs	Vehicular Ad hoc NETWORKs
VRC	Vehicle-Roadside Communication
WAVE	Wireless Access in the Vehicular Environment

Abstract:

Information dissemination in Vehicular Ad hoc Networks (VANETs) is a fundamental operation to increase the safety awareness among vehicles on roads. Thus, the design and implementation of efficient and scalable algorithms for relevant information dissemination constitutes a major issue that should be tackled.

In this work, bio-inspired information dissemination approaches are proposed, that use self-organization principles of swarms such as Ant and Honey Bee colonies. These approaches are targeted to provide each vehicle with the required information about its surrounding and assist drivers to be aware of undesirable road conditions. In the first approach, Ant's direct and indirect communication systems are used. Ants share information about food findings with colony members by throwing pheromone on the returning to the nest. The second, an RSU-based approach is inspired by the Bee communication system. Bees share profitable food sources with hive-mates in their hive by specific messages.

A "relevance" value associated to the emergency messages is defined as an analogue to pheromone throwing in Ant colony, and as an analogue to profitability level in Bee colony, to disseminate safety information within a geographical area. Simulations are conducted using NS2 network simulator and relevant metrics are evaluated under different node speeds and network densities to show the effectiveness of the proposed approaches.

Keywords: Ad-hoc Network; MANETs/VANETs; information dissemination; swarm computing; ant colony, bee colony; performance evaluation, NS2.

Résumé :

La dissémination d'information dans les réseaux VANET est une opération fondamentale pour la sécurité routière. Il est dès lors nécessaire de concevoir et mettre en œuvre des algorithmes efficaces et adaptatifs pour la dissémination d'informations sélectives et pertinentes.

Dans ce travail, des approches Bio-inspirées sont proposées, à partir des comportements auto-organisés des essaims comme les colonies de fourmis et d'abeilles. Ces approches visent à fournir à chaque véhicule des informations en provenance de son environnement et alerter les conducteurs. Dans la première approche, le système de communication direct et indirect des fourmis est utilisé. Les fourmis partagent les informations sur les sources de nourriture avec des membres de la colonie en sécrétant la phéromone sur leurs chemins. La deuxième approche est inspirée par le système de communication des abeilles. Les abeilles partagent les informations à propos des sources de nourriture avec les autres membres de la ruche par des messages spécifiques, selon l'importance de ces sources.

Une nouvelle mesure de "pertinence" associée aux messages est définie, par analogie à la sécrétion des phéromones des fourmis et au niveau de l'intensité des messages pour les abeilles, pour disséminer des informations de sécurité dans une zone géographique. Les simulations sont effectuées en utilisant le simulateur NS2 pour mesurer l'efficacité des approches proposées sous différentes conditions, en particulier en termes de densités et vitesses des véhicules.

Mots clés : Réseau ad-hoc, MANET, VANET, diffusion d'information, essaims, intelligence collective, colonies de fourmis, colonies d'abeilles, l'évaluation des performances, NS2.

The logo for SPIM (École doctorale SPIM) features the letters 'S', 'P', 'I', and 'M' in a stylized, white, sans-serif font. The 'S' is the largest and most prominent, with the other letters stacked to its right. A blue horizontal bar is positioned to the left of the 'S'.