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Internal Research Report - LE2I

January, 6th, 2014

Bourgogne
Conseil régional
UNIVERSITÉ DE BOURGOGNE

Abstract : The broadcasting communication mode is widely used in Vehicular Ad hoc Networks (VANETs). It is used for sending emergency messages, road-traffic information or to help routing protocols to determine routes. This communication mode is known to be hard to achieve efficiently since it depends on the network density. Indeed, broadcasting methods may cause network congestion if they are not well designed. This paper introduces a novel Autonomic Dissemination Method (ADM) which delivers messages in accordance with given message classes and network density levels. The proposed approach is based on two steps: an offline optimization process and an online adaptation to the network characteristics. ADM allows each node to dynamically adapt its broadcasting strategy not only with respect to the network density, but also according to the class of the message to send: emergency (high-priority), road-traffic (medium-priority) or either comfort message (low-priority). The ultimate goal of ADM is to make effective use of radio resources when there are many messages to send simultaneously. This approach increases the efficiency of the broadcast process in terms of message delivery ratio, latency and interferences reduction. The autonomic computing paradigm improves the robustness of protocols.

keywords : VANET, Broadcasting protocol, Autonomic computing , Message priority level, Density evaluation , Optimization

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Résumé : L'opération de diffusion est une technique couramment utilisé dans les réseaux véhiculaires (VANETs). Elle est notamment employée pour envoyer des messages d'Arlette, des informations de circulation, ou encore dans l'établissement de routes pour des protocoles de routage. Ce mode de communication est connu pour être difficile à réaliser efficacement car il dépend de la densité de ce dernier : en effet, les méthodes de diffusion peuvent créer une forte congestion réseau si elles n'ont pas été correctement élaborées. Ce papier présente une méthode originale de diffusion (ADM) basée sur le concept d'informatique auto-régulée, qui diffuse des messages en fonction de leur classe, et de différents niveaux de densité. L'approche proposée est basée sur 2 phases : une phase d'optimisation offline, et une phase d'adaptation online aux caractéristiques du réseau. ADM permet à chaque noeud d'adapter localement sa stratégie de diffusion, non seulement par rapport à la densité locale du réseau, mais également en fonction de la classe du message à diffuser : message d'alerte (haute priorité), condition de trafic (moyenne priorité), ou encore information de confort (faible priorité). Le but recherché et d'optimiser l'utilisation des ressources radio dans les sudations où le nombre de messages à envoyer est élevé. Cette approche permet d'augmenter l'efficacité de la stratégie de diffusion en terme de pourcentage de messages correctement diffusés, de latence ou de réduction d'interférence. Le paradigme de l'informatique auto-régulée améliore ici la robustesse du protocole.

Mots-clés : VANET, protocoles de diffusion, Informatique auto-régulée, niveau de priorité de messages, évaluation de densité , Optimisation

Contents

1 Introduction

A Vehicular Ad hoc Network (VANET) is a collection of vehicles communicating through wireless connections. In such a network, each vehicle acts simultaneously as a client node and as a wireless router, allowing multi-hop packet forwarding. Each node has a limited coverage area that contains the neighbours it can directly communicate with. The range of this area can vary from one hundred meters to a few kilometres (depending on the wireless technology onboard, signal propagation constraints, external radio interferences, or environmental features) allowing VANET to provide vehicle-to-vehicle communications over long distance. The continuous movement of vehicles at different speeds and directions induces a highly dynamic network topology. New nodes constantly join the network while others quit when they fall out of the radio range of inner nodes. VANETs are often presented as specific MANETs (Mobile Ad hoc Networks) dedicated to inter-vehicle communications but with the same purposes, challenges, and complexity. Another characteristic of these networks is an heterogeneous node density due to road traffic conditions.

This paper focuses on broadcast communications, which are widely used for sending emergency messages, road traffic reports and information to improve drivers' or passengers' comfort, etc. Typically, a broadcast operation arises when a node produces or detects a significant information that has to be shared with all nodes. As the broadcasted message has to reach every node, the source of the broadcast sends the message to its whole neighbourhood, regardless of the receiver identities. If no collision or interference occurs, each adjacent node within the transmitter's communication range may receive the message. To achieve a multi-hop broadcast, intermediate nodes have to relay incoming messages to allow a wide dissemination. This hop-to-hop transmission would lead to a full network coverage and information delivery. Performing an efficient multi-hop broadcast in VANETs is however a difficult task. The protocols should take into account the specificities of the radio channel, the high mobility of nodes and the network density.

During a broadcast communication, every node receiving a message decides to relay the message to the other nodes within its coverage area or not. This decision is taken in a distributed way, but each node's decision has a real impact on the efficiency of the overall dissemination strategy: in high-density networks, too many relay nodes would quickly increase the number of collisions, leading to a saturation of the bandwidth and a significant increase of the latency. Conversely, if there are not enough relay nodes in low-density networks the message may not be widely disseminated. It is also important to adapt the broadcasting strategy to the message priority level. For instance, emergency messages such accident alerts, should be delivered as fast as possible to minimize the latency in the source node's neighbourhood. Conversely, it does not matter if comfort information are broadcasted with a more important latency, since it is less urgent.

This paper investigates the problem of designing and evaluating an autonomic and robust broadcasting protocol, which provides each node with the adequate strategy to determine if an incoming message has to be forwarded or not depending on its priority level and the network density. This protocol, named Autonomic Dissemination Method (ADM), follows the autonomic computing paradigm: each node continuously updates its perception of the environment, adding new informations in its knowledge-base and performs a closed control loop thanks to an autonomic manager. Moreover, ADM allows each node to dynamically adapt its broadcast strategy not only with respect to the network density, but also according to the priority level of the message to send. The ultimate goal is to make effective use of radio resources when there are many messages to send simultaneously.

The remaining of this paper is organized as follows: in Sections 2 and 3, we present a state of the art of existing broadcasting methods in wireless ad hoc networks and describe the autonomic computing paradigm. Section 4 formulates the broadcasting problem in VANETs as a multiobjective problem and introduces an optimization methodology. The proposed Autonomic Dissemination Method (ADM) is detailed in Section 5. Sections 6 and 7 present the performance evaluation of ADM respectively in a scenario with a single density level and in a network with heterogeneous density levels.

2 Multi-hop Broadcasting Protocols

In the literature, wireless ad hoc broadcasting methods are classified into two categories: deterministic and stochastic methods (see Figure 1) [1][2].

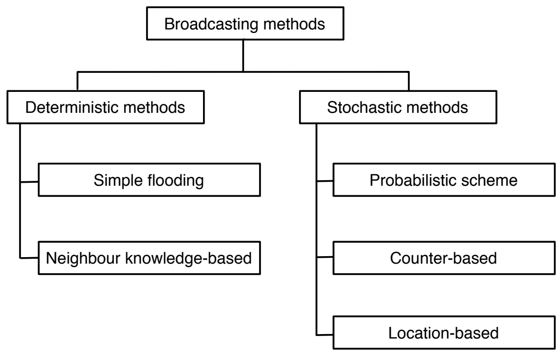

Figure 1: Categories of broadcasting methods

2.1 Deterministic Methods

A broadcasting method is deterministic if its process is predictable. This group includes simple flooding and neighbour knowledge-based methods.

2.1.1 Simple flooding

The Simple flooding is the simplest broadcasting method. Every packet is relayed exactly once by each node. Any redundant copy of the packet received later is ignored. Thus, in a network consisting of n nodes, n copies of the packet will be sent. A drawback of this method is that it does not take into account the network density. In high density networks, the Simple flooding algorithm would generate many redundant copies of broadcasted packets, leading to the overuse of the radio resources.

2.1.2 Neighbor Knowledge-based Methods

The neighbour knowledge-based methods are founded on a comparison of neighbours lists. Thanks to "Hello" packets, each node discovers its neighbours. The *Distributed Vehicular Broadcast* (DV-CAST) [3] and the *Flooding with Self Pruning* [4] allow each node to build a list of 1-hop neighbours while the *Scalable Broadcast Algorithm* (SBA) [5] draws up a 2-hop neighbours list. These lists are included in the broadcast packets so that the receiver (r) can compare the sender's list to its own list. This comparison allows to determine the additional nodes that may receive the message if r forwards it. For static or low mobility networks, it is a fair good method. But when the node's velocity is high, the information about the neighbours become quickly inaccurate.

The Multi-Point Relay (MPR) technique [6] is a neighbour knowledge-based broadcasting method. To reduce the number of redundant packets in the network, each node chooses several nodes among its neighbours that will relay its communications. The selected nodes are called MPRs. The MPRs are selected among the 1-hop neighbours so that they enable to reach all 2-hop neighbours. The goal is to have the smallest list of MPRs in the network, which optimizes communications. This method requires a bidirectional link. When a node sends a packet, all its neighbours receive it, but only the MPRs of the source node will relay the message. That means, each node will have a list of all the nodes that have chosen it as their "repeater" (MPRs selectors' list).

2.2 Stochastic Methods

The stochastic methods statistically assess the gain that could be obtained if the packets are relayed by a given node. They include probabilistic scheme, counter-based and location-based methods.

2.2.1 Probabilistic Methods

To reduce the number of collisions and to enable better use of the radio channel, probabilistic methods limit the number of relays by setting up the probability for each node to relay the packets. For a given network density, there exists p_s, a probability threshold value ($0 \leq p_s \leq 1$), that would allow all nodes receive the packets, while reducing the number of unnecessary repetitions and causing few collisions. Any other value $p > p_s$ would not lead to better coverage, but may downgrade the quality of the communication. Since p_s varies locally in the network, the main challenge of probabilistic methods is to determine its correct value. Some approaches to dynamically assign value to p_s are proposed in the literature. They combine probabilistic methods with some other techniques for assessing the network density (eg counter-based or distance-based methods).

2.2.2 Counter-based Methods

The principle of the counter-based methods is simple: the more a node receives copies of the same packet, the less likely it is useful to relay this packet. Upon reception of the first copy, the node initializes a counter C to 1 and sets a timeout RAD (Random Access Delay). During the waiting period, C is incremented upon reception of a new copy of the packet. When the RAD expires, C is compared to a threshold value C_t. If C is less than C_t, the packet is broadcasted. Otherwise, it is dropped. Like probabilistic methods, one challenge is to find an appropriate value for C_t. Ni et al. [7] demonstrate that the additional area covered by the broadcasting process decreases significantly when the number of redundant copies increases.

Yassein et al. [8] proposed the *Smart Counter Based Broadcast Algorithm* which adapts C_t according to the network density. Thanks to "Hello" packets, the nodes build neighbor lists. The size of these lists allows to dynamically adjust C_t. More recently, Karthikeyan et al. [9] proposed a protocol that defines two categories of nodes according to their number of neighbours, with respect to a given threshold τ. Each node decides to relay each packet depending on its own category and the category of the last hop of this packet

2.2.3 Location-based Methods

Before relaying a message, the node evaluates the additional coverage area that will result from this retransmission. The location-based methods do not consider whether nodes exist within that additional area or not. AckPBSM [10] and POCA [11] use this approach and set lower RAD to nodes that are far from the source (or last-hop relay) node. To evaluate the extra coverage area, the node can use the distance between itself and each node that has previously relayed the message (distance-based scheme) or the geographical coordinates (location-based scheme). In both distance-based and location-based schemes, a RAD timeout is set and the message is relayed if the additional coverage area is higher than a fixed threshold.

3 Autonomic Computing in Vehicular Ad hoc Networks

3.1 Autonomic Computing Paradigm

Traditionally, networks and systems management is a manually controlled process. Thus, it is necessary to have a human intervention of one or several operators in order to manage all the aspects in relation to the dynamic evolution of a system or a network. The creation of self-management systems with limited human interventions was the vision to bring autonomy within IT environment in order to cope with increasing complexity and excessive maintenance costs [12]. Such autonomic systems are able to be self-organized. Networks become a collection of interconnected self-governed entities where human intervention is limited to high-level directives and system management details are transparent for the administrators. The first initiative dealing with this paradigm is inspired by biological systems and in particular, the autonomic nervous system. Indeed, the term Autonomic Computing is partly owed to the autonomic nervous system [13]. This new management concept makes it possible thanks to a holistic approach where all research fields are implicated to contribute in the evolution towards a global autonomy in networks.

Although the objectives list of the self-management concept was extended since 2001 (year of this new paradigm birth), the main objectives for autonomic systems are Self-configuring, Self-optimizing, Self-healing and Self-protecting [14]. To achieve those objectives, autonomic systems have a detailed knowledge of their internal state as well as their environment [15] using a continuous monitoring of eventual changes that could affect their components. Detecting changes induce the autonomic system to adjust its resources and the monitoring continues to determine if the new measures satisfy the desired performance. That is the closed control loop of self-management systems. It enables autonomic systems to make adequate decisions while conforming to global objectives without human interventions thanks to measurements collected from its resources. This closed control loop is implemented by autonomic managers, which control managed resources using sensors and effectors manageability interfaces [16].

3.2 Autonomic vehicular communications

Adapting the Autonomic Computing paradigm to transportation systems and in particular to VANET networks in order to enhance the performance of communications within such changing environment is a challenging task. In [17] and [18], the authors describe the challenges, approaches and solutions in intelligent transportation systems. Indeed, they introduce the cooperative communication concept in vehicular networks. These networks should be self-managed thanks to a self-configuration function using decision elements and control loops. Monitoring and policing information will be used within cooperative VANET communications in conformance with the Autonomic Computing concepts in order to enhance vehicle safety. The research work presented in [19] describes the self-management capability of vehicles in order to perform autonomic cooperative communications and routing within VANETs. The author presents the architecture of an autonomic cooperative node (i.e vehicle) based on the Generic Autonomic Network Architecture (GANA). This autonomic node includes different Decision Elements (DE) controlling a Managed Entity (ME) in order to enhance Vehicle-to-Vehicle (V2V) communications performance. Research challenges concerning Inter Vehicular Communication (IVC) are presented in [20] according to four areas. The one dealing with IVC communication principles and patterns discussed emerging IVC applications such as safety traffic and described how V2V communications could be used for self-organized traffic control. The author in [21] introduces the autonomic management of Autonomous Underwater Vehicles (AUVs) in order to provide these vehicles with self-maintenance during their missions. An autonomic AUV control architecture is proposed. The objective of this architecture is to achieve the self-management capabilities described by the Autonomic Computing paradigm.

4 Definition and Optimization of Broadcasting Problem

4.1 Broadcasting in VANETs: an Optimization Problem

Designing an efficient protocol requires to meet several objectives that could be antagonistic: for instance, transmitting messages to the maximum of nodes while avoiding the overuse of the radio channel; delivering packets as quickly as possible, knowing that this speed may cause radio interferences. In a nutshell, this is clearly a multi-objective optimization problem for which each solution is a set of parameters that define a broadcasting strategy.

A broadcasting strategy may consist of the following parameters:

- the probability to relay a packet (P). It is inherited from the classical probabilistic methods. When a node receives the first copy of a broadcast packet, it decides to relay it or not, depending on the value of P. The following three parameters are applicable only if the node decides to relay the packet.
- the number of repetitions (Nr). In low density networks, when a node broadcasts a packet, it is not unusual that it has no neighbour in its coverage area that will receive the message and relays it. Sending several times the packet, particularly in a context of mobility, the node increases the chance that the packet will be received and relayed. Nr is also useful when the first transmitted packet is lost due to a collision or poor radio propagation.
- the delay between two successive repetitions (Dr). When a node transmits several times the same packet ($Nr > 1$), it is important to determine the frequency with which the copies of the same packet will be transmitted. A very short delay could result in many collisions, whereas a very long delay may slow down the broadcast.
- the packets lifetime. It allows a limited packets spread within the network and/or for a long period of time. In this paper we use the maximum number of hops allowed for each packet, TTL (*Time To Live*). This parameter can be replaced by geographical coordinates or transmission time.

Adding new parameters to classical probabilistic methods expands the search space, making it difficult to determine optimized parameters values for different network contexts. We use a genetic algorithm to perform an effective investigation of the search space.

The performance of dissemination strategies defined by P, Nr, Dr and TTL are evaluated by a network simulator. These strategies are compared on four criteria:

- the average Number of Collisions (NC);
- the Propagation Time (PT). It is the time between the transmission of a packet and the time it is received by all nodes of the studied area.
- the total number of Retransmissions during the simulation (R).
- the *Full Reception ratio* (FR). It refers to the guarantee that the broadcast packets will be received by all nodes (the reachability). A simulation in which all nodes receive the packet is considered as successful. Whereas, if the network conditions (propagation or topology) do not allow the reception of the packet by all nodes, the simulation is considered as a failure. FR is the ratio of the number of successes on the total number of repetitions of each scenario executions.

NC and R enable to measure the radio channel usage: high values indicate that the evaluated strategy is likely to interfere with other communications in the network. The calculation of NC, PT and R takes into account only successful simulations.

Determining the best broadcasting strategy can be seen as a multiobjective optimization problem that aims to find the solution $\overrightarrow{x}$ (or a solution set $\overrightarrow{X} = \{\overrightarrow{x_0}, \ldots, \overrightarrow{x_n}\}$) such that:

$$\begin{cases} NC(\overrightarrow{x}) & \textit{is to be minimized} \\ PT(\overrightarrow{x}) & \textit{is to be minimized} \\ R(\overrightarrow{x}) & \textit{is to be minimized} \\ FR(\overrightarrow{x}) & \textit{is to be maximized} \end{cases}$$

The next section describes the methodology used to solve this optimization problem.

4.2 Methodology

We optimize the parameters P, Nr Dr and TTL using an approach that combines an optimizer, a network simulator and a trace analyzer. Figure 2 illustrates the interaction of these three modules. P, Nr Dr and TTL are optimized using HOPES (Hybrid Optimization Platform using Evolutionary Algorithms and Simulations). HOPES combines an optimizer, a network simulator and a trace analyzer.

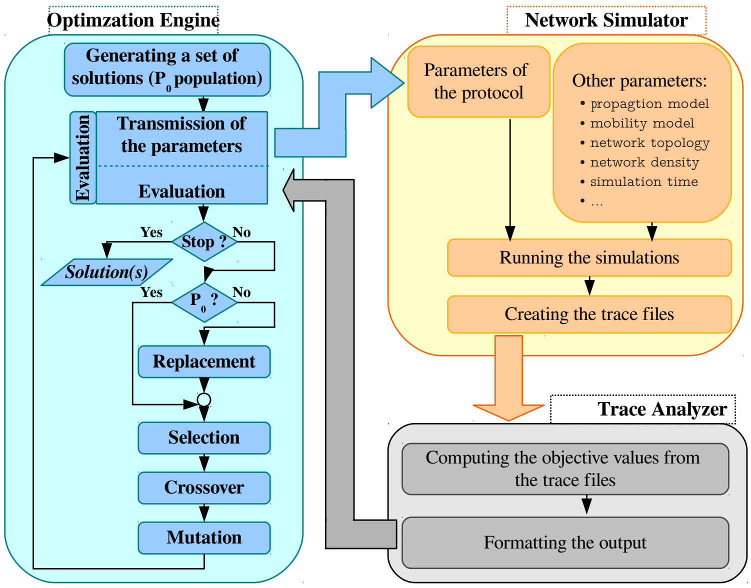

Figure 2: The flowchart of HOPES

The optimizer used is our proposed genetic algorithm aGAME [22]. The decision variables of the problem are P, Nr, Dr and TTL. They are the different genes defining a solution (a broadcast strategy). The genetic algorithm is used to traverse the search space effectively. The optimization process starts with the random generation of the initial population (P_0). The evaluation stage is split into two steps: the first one performed by the network simulator and the second one by the genetic algorithm.

Broadcast parameters (P, Nr, Dr and TTL) are transmitted to the network simulator which integrates them with other parameters in order to better reproduce the conditions of the evaluated network. The trace files generated during the simulation are then transmitted to the analyzer module. It parses the files in order to extract the evaluation criteria values (NC, PT, R, and FR) and presents the obtained results according to the genetic algorithm required format.

When the genetic algorithm receives the results of the trace analyzer module, it proceeds to the second step of the evaluation in order to classify solutions and assign values of *fitness*. To penalize solutions which do not guarantee the full reception of transmitted packets, a constraint is associated with the problem: *FR must be greater than or equal to a reachability threshold (FR_s).*

The remaining operations of the genetic algorithm are performed independently of the problem. At each iteration, the three modules are involved in the evaluation task. The second test of the optimization module denoted “P_0 ?” checks whether the current population is the initial population. The overall optimization process leads to a set of non-dominated solutions, corresponding to dissemination strategies adapted to the considered network density. This study is repeated for several densities by changing the corresponding parameter in the simulation module.

From the results of this offline optimization phase, ADM builds a knowledge-base that establishes a correspondence between density levels and broadcasting strategies. Density levels are represented by number of neighbouring intervals. Each node can therefore choose, depending on the density of the network in which it is located, the appropriate dissemination strategy. Then, depending on the probability of retransmission associated with the chosen strategy, the node decides to relay the packet or not. If the decision is to relay the communication, it applies the other corresponding parameters (Nr, Dr and TTL).

5 An Autonomic Robust Broadcasting Method

5.1 Overview

We propose in this paper an extension of our Smart-flooding protocol [23] thanks to an autonomic robust broadcasting method called ADM (Autonomic Dissemination Method). In our approach, we adapt the broadcasting strategy used by the Smart-flooding protocol according to, not only the density level of VANETs but also the priority level of the message that has to be disseminated. Indeed, ADM is based on the closed control loop implemented by an autonomic manager within a mobile node (vehicle) that we consider as a managed resource according to autonomic computing concepts presented in section 3.1. The resulting architecture, enabling broadcasting strategy optimisation according to VANET's environment characteristics and changes occurrence, is detailed in the following section.

5.2 Architecture

We adopt self-management of radio communications to ensure the robustness of broadcasting protocol. Indeed, each node (i.e. vehicle) is considered as an autonomic element thanks to an autonomic manager that enables broadcasting decisions making according to message priority level (see section 5.3) and takes into account environment changes in terms of density level (see section 5.4). To achieve those goals, the autonomic manager implements the MAPE-K closed control loop (see Figure 3) and communicates with the mobile node called Managed Element using Sensors and Effectors manageability interfaces.

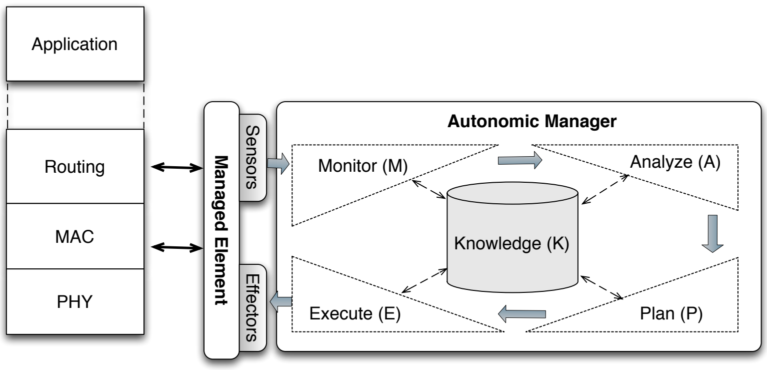

Figure 3: Autonomic manager closed control loop

Each autonomic node within a VANET continuously monitors its environment and network traffic by listening to the radio channel and provides the Monitor function (M) of the Autonomic Manager with network traffic information's thanks to the Sensors manageability interface. In the context of our ADM, the Monitor determines if the received packet is a broadcasting one thanks to its destination address. In case of a broadcasting message, the Monitor provides the Analyze function (A) with this information to follow the control loop process. The Analyze function determines, not only the priority level of the message according to the packet header information, but also the current density level of the node environment thanks to the node local view table stored within the Knowledge-base (K). After density level evaluation that we detail in section 5.4, the Plan function (P) will use the density and priority values provided by the Analyze function to retrieve the adequate broadcasting strategy from the Knowledge base thanks to the strategy table created by the optimization offline phase (see section 4.2). Then, the Plan function will provide the Execute function (E) with the broadcasting parameters (P, Nr, Dr and TTL) in order to change the behavior of the mobile node managed resource by executing the corresponding actions of broadcasting strategy thanks to the Effectors manageability interface.

The architecture of ADM enables the Autonomic Manager to determine how to adapt the dissemination strategy based on information reported by the Sensors manageability interface. Each of the four functions (MAPE) of the Autonomic Manager has a specific role, but all share the same Knowledge-base. The latter contains a set of dissemination strategies optimized for various contexts corresponding to different density and priority levels.

5.3 Priority level of broadcasted messages

Several recent works in VANETs and their applications highlight the need to classify messages into several classes [24] [25] [26]. Processing these messages depends on many criteria such as their emergency level, their impact on the road traffic management or the desired reachability.

We define three messages classes for broadcast operations in VANETs (corresponding to three priority levels) and we define for each class a broadcast policy to satisfy. These classes may be based on a single or a dual objective, and may also consider other broadcast characteristics, i.e. the covered nodes ratio evolution over time.

These policies mainly illustrate the adaptability of the protocol to the messages contents and can be easily redefined or extended with additional classes.

- High-Level priority messages (for short HL) correspond to emergency messages, e.g. safety message or accident detection. They have to be delivered as quickly as possible since they may require a prompt reaction from the driver. For these messages, ADM tries to minimize the required propagation time, so that vehicles that are close to the broadcast source may receive the message with a very short delay. Indeed, safety messaging is a near-space application where vehicles in close proximity exchange information to increase safety awareness [24]. These applications have strict latency constraints. In addition to the reduction of the propagation, ADM will try to maximize the full reception ratio.
- Medium-Level priority messages (ML) correspond to road-traffic messages e.g. traffic jam report. They suppose less-critical information, where the driving reflexes are not part of the equation and only attention is required. These messages should cover a high ratio of nodes, while the broadcast operation requires to reduce the number of radio interferences. According to [24] traffic monitoring applications require gathering information from vehicles that span multiple kilometres.
- Low-Level priority messages (LL) correspond to comfort messages, e.g. weather information, tourist attraction or point of interest. They are optional messages whose delivery must not alter the dissemination of emergency and alert messages. The use of the radio resources has to be optimized, though reducing the number of collisions as well as the number of retransmissions, for an acceptable node coverage ratio.

Table 1 sums up the classes considered in this study.

Message Classes	Examples	Strategies
High-Level (HL)	Accident reports	(1) Minimize the propagation time (2) Maximize the reachability
Medium-Level (ML)	Traffic reports	(1) Maximize the reachability (2) Minimize the interferences
Low-Level (LL)	Tourist attractions	(1) Minimize the number of collisions (2) Minimize the number of retransmissions

Table 1: Message priority levels

5.4 Density Level Evaluation

In classical approaches, the density around a node i is often calculated by counting the number of nodes (N_i) located within the coverage area of i. These methods are based on the assumption that all nodes have uniform and identical coverage areas. This is usually the case when radio propagation model is deterministic, such as free-space or Two-ray ground reflection. However, for a more realistic model where packet losses are distributed according to the distance between the transmitter and receiver, this definition is impractical. ADM evaluates the local density for each autonomic node based on the number of active neighbours from which it received the packets. During communication, each node builds a view of its neighbourhood. This view depends on the neighbour list having transmitted or relayed packets. Each autonomic node maintains a history in which it associates with each received packet a list of nodes having sent or relayed it. Upon reception of a packet first copy, its identifier and the source / relay address are recorded within the autonomic manager Knowledge base in a table called local view. When a redundant copy is received, the address of the new relay is appended to the local view table list of addresses (L) corresponding to the packet. Each address is recorded only once for each packet, so receiving multiple copies issued by one neighbour does not lengthen the list of addresses for the concerned packet. When the table is full, the oldest information is replaced by the new one according to FIFO (*First In First Out*) principle. The current number of neighbours for each autonomic node i is equal to the average number of transmitters for all the packets stored in L (see Equation 1).

$$\overline{N_i} = \frac{\sum_{i=1}^{n} |L(i)|}{n} \tag{1}$$

where n is the total number of packets in the local view table and $|L(i)|$ the number of nodes that issued / relayed the i^{th} packet in the table.

6 Calibration of ADM

ADM's broadcasting strategies consist of four parameters P, Nr, Dr and TTL. By calibration we mean the offline optimization of these parameters with respect to network density and message classes corresponding to three priority levels. The robustness of this novel protocol is especially based of this tuning process.

6.1 Scenarios

We studied the behaviour of VANETs when varying the network density. For this purpose, we simulated a convoy of vehicles lined up on 10 km. The simulations were carried out using the ns2 network simulator (ns2.34). We used the Shadowing Pattern propagation model [27] which is a realistic and probabilistic model that can produce statistical error distributions, such as slow and fast fading, while being easy enough to be carried out on medium to large simulations. We varied the density by changing the inter-vehicle distance. This leads to increase or to decrease the average number of neighbours each vehicle may have. The optimization process was repeated for different density levels. In this paper we present the tuning process for four density levels illustrated by the following scenarios:

- Urban scenario: an inter-vehicle distance of 25 m.
- Suburban scenario: 75 m between two consecutive vehicles.
- Highway scenario: an inter-vehicle distance of 200 m.
- Rural scenario: most of the time, in rural areas, a vehicle might have no neighbour within its coverage area. To simulate a sparse vehicle distribution, we configured the Shadowing pattern propagation model so that each packet has a probability of 0.2 to be received. This is like having, for each vehicle, a 20% chance to have a neighbour when it sends a packet.

6.2 Offline Optimization Process

For each scenario described in Section 6.1, we determined the parameters values of ADM not only with respect to the density level but also according to the class of messages. For this calibration process, we used the HOPES platform (see Section 4.2) with the right network topology and density values in the simulator module.

At the end of the optimization process, for each scenario HOPES produced few dozens of solutions that provide a good compromise between the four objective functions NC, PT, R and FR. This means that for a given density level, all the solutions obtained after the optimization process have very good overall performances. However, they do not result in the same behaviour in the network. For instance, some solutions will allow delivering packets as quick as possible, with a risk of overusing the radio channel. Conversely, other solutions will enable reducing the number of redundant packets to ensure wide coverage of the network. Basically, since the objective functions of a multiobjective problem are antagonistic, trying to improve one of the objective functions (even among good solutions) generally leads to the deterioration in at least one other objective. Therefore, we considered the importance of each objective function with respect to the type of messages to send. This method helps to refine the solutions sets. We used a multiple-criteria decision-making approach based on preferences.

Our preference rules are simple and take into account the type of the message to send. For emergency (high-priority level) messages, the ADM protocol should focus on solutions that enable to deliver packets as quickly as possible (lowest value of PT), especially in the close vicinity of the transmitter (tens or even hundreds of meters). For road-traffic (medium-priority level) messages, solutions that cover the largest number of vehicles (maximizing FR) while reducing the risk of interference (minimizing C) are preferred. And finally, for comfort (low-priority level) messages, the goal is to avoid impacting other higher priority communications (minimize the values of NC and R).

6.3 Optimized Broadcasting Parameters for Various Density and Priority Levels

The broadcasting parameters for the three priority levels and the objective functions values are summarized in Tables 2 to 5 (note that Dr and PT are expressed in seconds).

	Broadcasting parameters				**Performance Results**			
Message Classes	P	Nr	Dr	TTL	NC	PT	R	FR
High-Level (HL)	0.329	1		32	497	0.051	131	99.6%
Medium-Level (ML)	0.258	2	1.721	15	347	0.1063	207	100%
Low-Level (LL)	0.188	1		39	190	0.048	75	86.8%

Table 2: ADM Parameters and Performance Results for the Urban Scenario

In high-density networks, the probability to relay the packets are low (see Table 2). When Nr is equal to 1, the Dr cell (the delay between successive repetitions) has been darkened since this parameter is only applicable when $Nr > 1$. For high-priority messages (in the high density network), relaying each packet only once, with a probability of about 0.3 allows rapid dissemination of the message. However, this probability value generates a large number of collisions. This drawback is mended for medium-priority level messages. To reduce the number of collisions and increase the reachability (FR), we selected a solution with a lower probability and a number of repetitions equal to 2. Moreover, as the repetitions are not made in burst the risk of interference is reduced.

For low-priority level messages, it is worth noting that the results only concern the packets that have been received by all vehicles. In other words, 86.8% of packets that are received spread quickly (due to low competition in the access to the radio channel), but 13.2% of them are not completely delivered.

Following the same reasoning, we obtain the broadcasting parameters for suburban and highway scenarios (Tables 3 and 4 respectively).

	Broadcasting parameters				**Performance Results**			
Message Classes	P	Nr	Dr	TTL	NC	PT	R	FR
High-Level (HL)	0.776	1		26	166	0.044	104	100%
Medium-Level (ML)	0.519	2	0.951	16	93	0.121	139	100%
Low-Level (LL)	0.291	2	0.276	27	35	0.209	82	75.8%

Table 3: ADM Parameters and Performance Results for the Suburban Scenario

	Broadcasting parameters				**Performance Results**			
Message Classes	P	Nr	Dr	TTL	NC	PT	R	FR
High-Level (HL)	0.999	4	1.147	40	31	0.092	199	100%
Medium-Level (ML)	0.916	2	0.729	28	24	0.124	90	100%
Low-Level (LL)	0.649	2	1.933	34	10	1.414	66	82.8%

Table 4: ADM Parameters and Performance Results for the Highway Scenario

For the scenario of the rural area, the low density level of the network implies the need to retransmit each packet many times (see Table 5). Indeed, in this scenario, VANETs behave like delay tolerant networks (DTNs) [28]. In such a context, since the radio channel is rarely used, even if ADM is able to differentiate broadcasting strategies according to the class of a message, in practice these classes scarcely impact the communication process. The main constraints that must be met are: having a probability P close to 1 and a high number of repetition Nr.

	Broadcasting parameters				**Performance Results**			
Message Classes	P	Nr	Dr	TTL	NC	PT	R	FR
High-Level (HL)	0.833	28	0.233	28	58	13.09	1167	99.8%
Medium-Level (ML)	0.896	25	1.468	34	16	28.295	1124	100%
Low-Level (LL)	0.902	8	1.622	19	4	30.957	362	92.6%

Table 5: ADM Parameters and Performance Results for the Rural Area Scenario

The ultimate goal of this optimization step is to provide the Knowledge-base of the Autonomic Manager (see Figure 3) with broadcasting strategies. In the Knowledge-base, each set of parameters will be associated with a density level expressed in number of active neighbours. Figure 4 presents the average number of neighbours for several scenarios. If a vehicle V has n neighbours and:

- $n \in]0; 2]$, V will consider that it is in a rural area.
- $n \in]2; 6]$, V will consider that it is in a highway.
- $n \in]6; 12]$, V will consider that it is in a suburban area.
- $n > 23$, V will consider that it is in a urban area.

Obviously this list is not exhaustive. For instance, between the suburban and the urban scenarios, we may have several other scenarios. Due to a lack of space, some scenarios studied and shown in Figure 4 are not discussed in this paper.

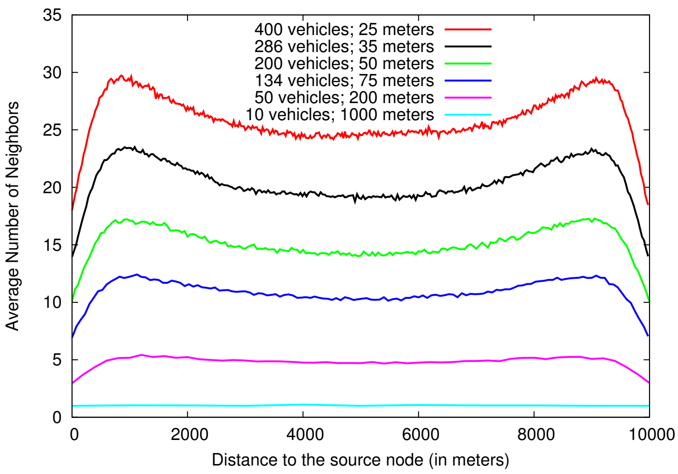

Figure 4: Average Number of Neighbours for Each Density Level

6.4 Comparative Study

To assess the performance of ADM, we compare this protocol to *Simple flooding* and *Smart-flooding*. In this section, we will just focus on the suburban scenario (134 vehicles lined up on 10 km, with an inter-vehicle distance of 75 $meters$). The case of a heterogeneous-density network (especially with mobile nodes) is described in Section 7.

Let us recall that the design of ADM had three major goals. ($g1$) swiftness: delivering safety messages as soon as possible; ($g2$) network coverage: reaching the maximum nodes for road traffic messages; ($g3$) effective use of radio channel for comfort messages. These objectives must be met even if the traffic load increases (for instance when messages are sent simultaneously).

We vary the number of source nodes from 3 to 30. With 30 source nodes in a convoy of vehicles over 10 km, a message is issued approximately every 330 $meters$. Taking into account the communication range (for WiFi broadcast messages), each node may have within its coverage area 4 or 5 neighbours which simultaneously issue a message. At the second and third hop, the number of simultaneously issued messages, within each node's coverage area, greatly increases. This may tend to quickly congest the radio channel.

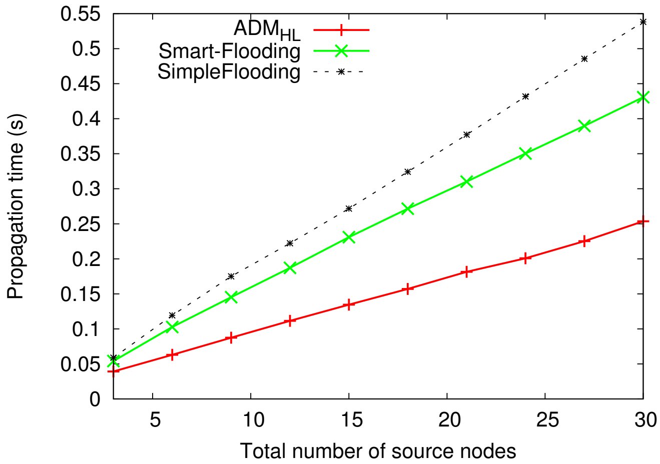

Figure 5: Propagation time

Regarding the propagation time, ADM aims to deliver emergency messages (denoted ADM_{HL}) as fast as can be done, whatever the number of source nodes. Figure 5 shows that the performances of ADM meet the first goal ($g1$). Compared to *Smart-flooding* and *Simple-flooding*, ADM is less sensitive to the number of sources than the other two protocols. Ultimately, even with 30 source nodes, the average delay of emergency (high-priority level) messages is less than 250 ms (for a 10 km line), which is acceptable. It is worth recall that a driver's reaction time to traffic warning signals can be in order of 700 ms [29].

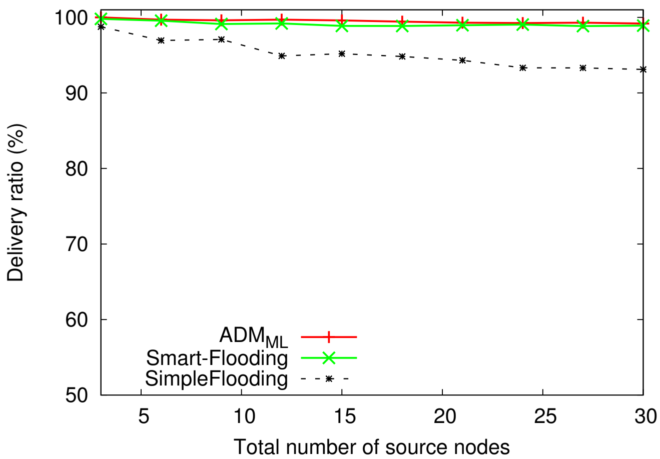

Figure 6: Delivery ratio

The goal $g2$ is assessed in Figure 6 which shows the delivery ratio. A packet is considered as "delivered" if it is received by all nodes. Road-traffic messages (ADM_{ML}) are always received by all nodes. ADM_{ML} ensures this result because it slightly decreases the probability of retransmission (see Table 3), which leads to the reduction of radio interferences. It should be noted that increasing the probability would degrade the performance of ADM and would get close *Simple flooding*'s results.

And finally, Figures 7 and 8 show that our third goal ($g3$) is met: the comfort messages use little radio channel by limiting the total number of repetitions for each packet (Figure 7). In addition, the fact that two potential successive repetitions of the same packet are spaced out (Dr value in Table 3) reduces the number of collisions (Figure 8).

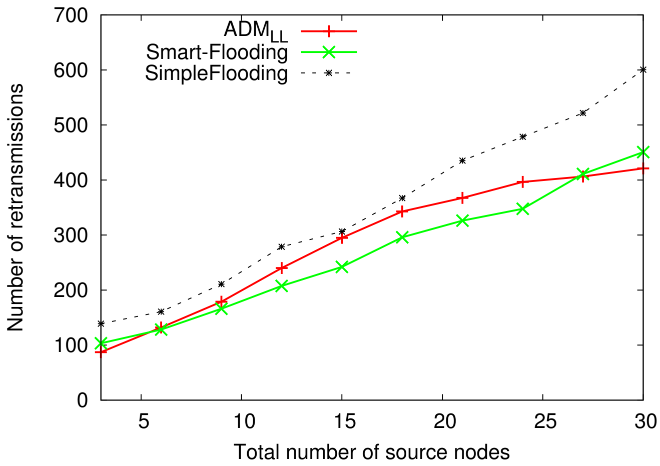

Figure 7: Number of retransmissions

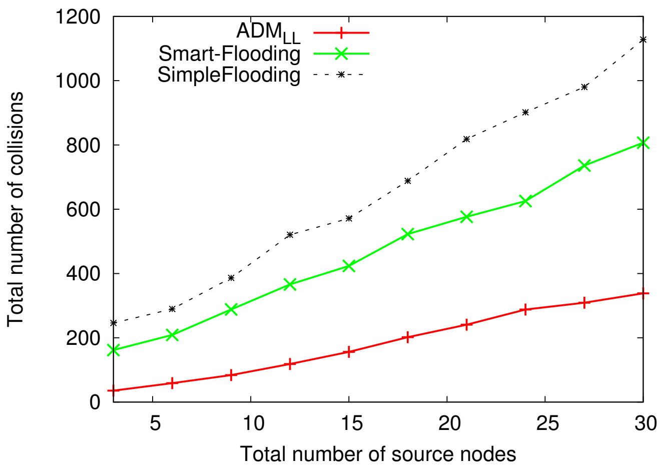

Figure 8: Number of collisions

7 Performance Evaluation in an Heterogeneous Density-levels Network

In this section, we evaluate the performance of ADM in a network where the density varies according to geographical locations. The aim is to assess the ability of ADM to adapt to density changes thanks to different broadcast strategies provided by the Knowledge-base of the corresponding Autonomic Manager.

7.1 Topology and Mobility Models

Figure 9 shows the simulated network topology which consists of three main areas. The first zone is the main road where the average speed is 130 km/h. In the second area the average speed is 90 km/h. And finally the third area tally with an urban network where the average speed is 50 km/h. These speeds correspond to the maximum speed in France respectively on highways, on back roads and in urban areas. We used a mobility model that redirects vehicles at every intersection to keep the average density (average number of neighbours) required in each area (see Figure 9). In addition, the low velocity within the third zone leads to increase the density in this part of the network.

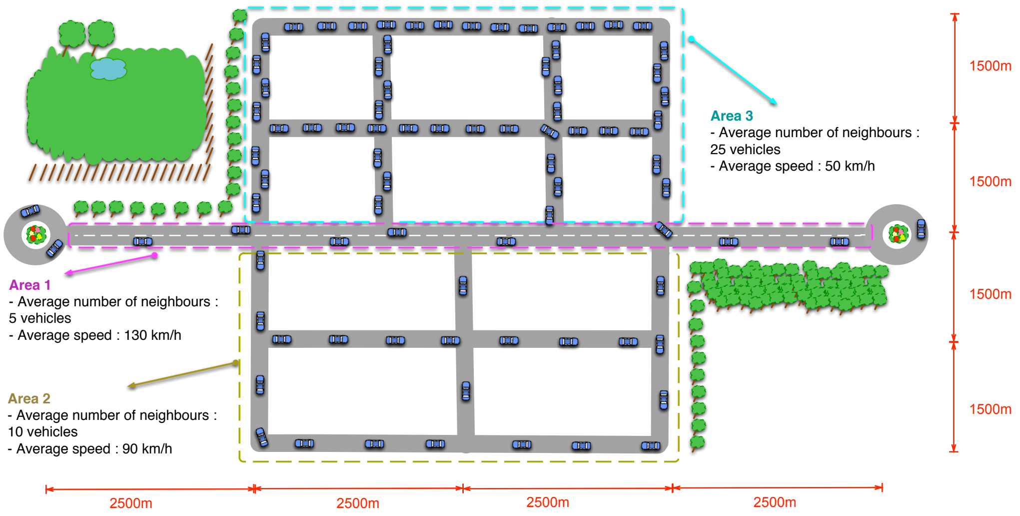

Figure 9: Network Topology

For these experiments, we simulated a network consisting of 600 vehicles. The simulation duration in set to 10 minutes. This duration allows each vehicle to move across areas and therefore to change density levels.

Packets are sent every 5 seconds. This allows to evaluate the robustness of ADM with respect to the network traffic. At each sending phase, there is a concurrent access to the radio channel because there are several source vehicles (between 3 and 30 sources depending on the scenario).

7.2 Comparative Study

The results obtained in a network with heterogeneous density corroborate the trends we observed in the suburban scenario (see Section 6.4).

The performances of communication protocols in mobile and heterogeneous-density networks depend on their ability to dynamically adapt to changes in their environment. The results in Figures 10 to 12 clearly show that the lack of adaptation mechanism to the density level leads to poor performance of the Simple Flooding. Its propagation time when there are more than 18 simultaneous source nodes is at least 1 second (see Figure 10). This delay can be detrimental for emergency messages. Moreover, one can observe that in case of concurrent access to the radio channel, Simple Flooding is struggling to deliver packets across the network (see Figure 11). This low reachability ratio is due to the collisions caused by redundant packets, especially in high-density areas (see Figure 12).

Regarding the two protocols that are able to adapt to the density, we observe that ADM has better performance results than Smart- flooding. These differences are due to the fact that Smart-flooding underestimates the network density by using a theoretical approach while ADM is based on this theory, but also uses experimental results (indeed, the results of the density evaluation in Figure 4 take into account both the number of neighbors and collisions).

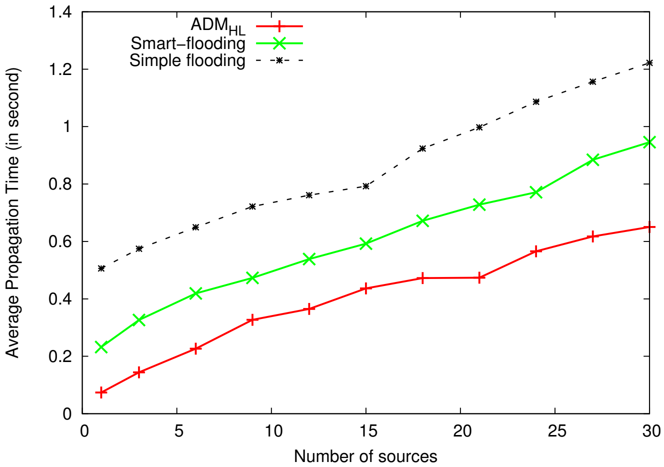

Figure 10: Propagation time

In general, ADM delivers emergency packets in less that 700 milliseconds in a relatively large area (even with 30 source nodes). This allows to be in conformance with the limits of drivers reaction upon alerts. Besides, for medium-priority messages (for instance road traffic regulation) that should be received by a maximum of nodes, in the scenario with 30 sources, ADM has a reachability ratio of almost 75%, while Smart-flooding has 66% and Simple flooding 53%.

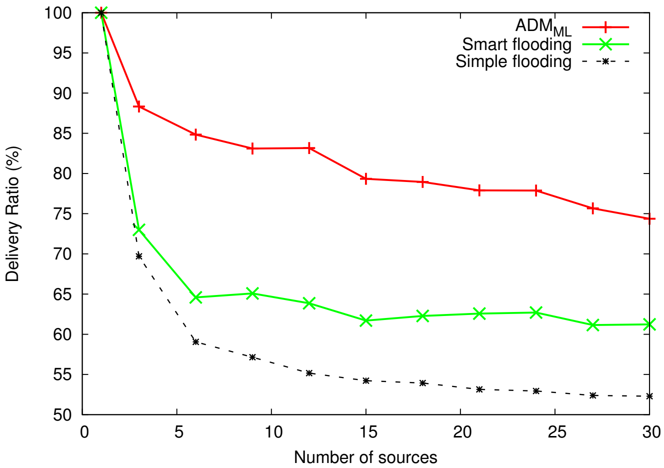

Figure 11: Delivery ratio

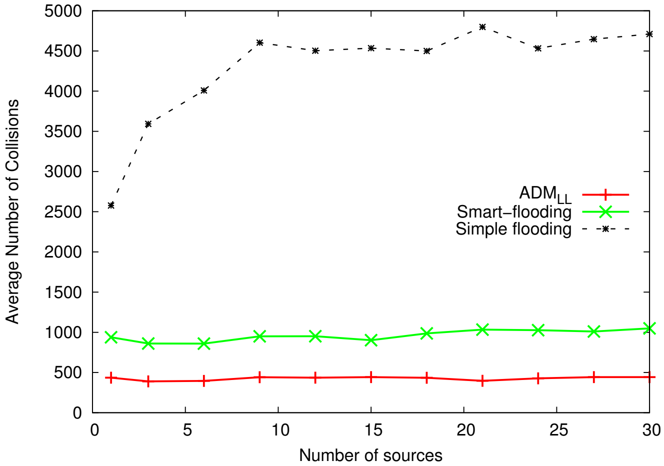

Figure 12: Collisions

8 Conclusion

We have proposed in this paper a new distributed autonomic broadcast protocol for VANETs named ADM (Autonomic Dissemination Method). Using pre-computed broadcasting strategies obtained thanks to an evolutionary algorithm, each node is able to dynamically adapt its own broadcast parameters to the network density and to the class of message corresponding to a priority level. The results of simulations carried out on both homogeneous and heterogeneous density-levels networks show that ADM outperforms two other broadcasting methods: the Smart-flooding protocol and the simple flooding method. These results also reveal the scalability of ADM when the number of simultaneous transmissions significantly increases and for different message classes. Despite we have considered three classes of message only, ADM can easily be adapted to include further other message classes, each with its own features and characteristics.

As a future work, we plan to extend ADM to dynamic multi-radio networks, stating that each vehicle is equipped with at least two radio acting on different channels. This perspective would surely increase the overall performance of broadcast operations in VANET, but also lead to several challenge, including channel assignment, solving potential load-balancing issues between radio cards, or deafness problems on mono-processor system when a node may hear incoming messages on one radio per time.

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