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Analysis of the Performance Routing Protocol in VANET using Omnet

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***Abstract*—In cities, where the number of vehicles continuously increase faster than the available infrastructure to contain them, traffic congestion is a difficult issue to deal with. This problem becomes even worse in case of accidents and affects many aspects of the modern society, including economic development, accidents, CO (Carbon monoxide) emission, trip time, and health. Several solutions for Traffic Management System (TMS) have been proposed to identify congestions and re-route the vehicles afterward. To this end, they exchange messages periodically between vehicles and central server, what can cause an overhead in the communication channel. In this scenario, it is important to identify the source of the problem and inform the drivers of new routes before the congestion takes place with, considering the limitations of vehicular communication. This work introduces ICARUS, a distributed and pro-active Traffic Management System, which receives notifications about a traffic events then it can calculates new routes, and, then, notifies drivers to follow new paths pro-actively by using inter-vehicle communications. Simulation results show the effectiveness of ICARUS in calculating new routes and disseminating them to vehicles approaching a congested area. Hence, ICARUS reduces the travel time, fuel consumption, and CO emissions of vehicles in urban environments when compared to existing approaches. In addition, ICARUS reduces the broadcast storm problem and maximizes the data dissemination capabilities with short delays and low overhead**

Keywords-VANET; routing protocol; AODV

I. INTRODUCTION

The world population is concentrated in large cities and it has mobility as one of its most basic needs. The preferred way to ac- complish mobility in modern societies is through the use of au- tomotive vehicles [1]. As a consequence, modern cities have been suffering with the steep increase in the number of vehicles. Since the road infrastructure does not grow at the same pace as the number of vehicles, traffic congestion has become a pressing issue in the largest cities around the world. It creates a number of neg- ative issues for the society, such as, the increase in the number of car accidents, negative effects on economic development and neg- ative impact on the environment [2,3]. According to a U.S. Department of Transportation report, there are three main sources for congestion [4]. The first one is related to traffic-influencing events, such as incidents, working zones, and bad weather. The second one is related to traffic demand, which means fluctuations in normal traffic and special events. The last source is related to the road infrastructure features, which repre- sent the traffic control devices and physical bottlenecks. Moreover, the report also shows that bottlenecks are responsible for 40% of the overall congestion, followed by incidents, such as car accidents with 25%, bad weather with 15%, work zones with 10%, and poor traffic signal timing and special events with 5% each one. Since controlling the weather is not a reality and building new road in- frastructure is a slow process, modern societies need to rely on new technologies to avoid congestion and its related problems.One such technology is the Traffic Management System (TMS), In order to overcome the aforementioned limiting factors of re- lated TMSs solutions, we propose ICARUS (**I**mprovement of traf- fic **C**ondition through an **A**lerting and **R**e-ro**U**ting **S**ystem), which relies on VANETs to offer a lightweight and distributed solution for controlling and reducing traffic congestion in urban environ- ment, i.e. the vehicle sends its position and retransmits the in- formation only when it receives an alert. After receiving a traf- fic event from an alert generation system, ICARUS operates under two main phases: *i)* Information Dissemination and *ii) Re-routing.*

In the Information Dissemination phase, the vehicle disseminates the

alert message to all vehicles in the affected geographical area. Due to frequent changes in the network topology and density caused by the high mobility of vehicles and the short-range communica- tion of VANETs, this phase presents many challenges. For instance, the broadcast storm problem, which takes place whenever multi- ple vehicles attempt to transmit simultaneously [16], causing high data traffic, network congestion, packet collisions, service disrup- tion and extra delay at the medium access control (MAC) layer. Another challenge is related to the resynchronization effect caused by the multichannel operation of the IEEE 802.11p standard [6,17]. Indeed, all data dissemination protocols for VANETs that assign dif- ferent waiting delays to rebroadcast (desynchronization) in an at- tempt to avoid the broadcast storm problem are vulnerable to this resynchronization effect [18,19]. In summary, these challenges limit the use of existing data dissemination protocols in VANETs [20]. This work is organized as follows. Section 2 discusses the liter- ature related to congestion minimization in urban environments. Section 3 describes ICARUS. Section 4 presents the performance evaluation results. Finally, Section 5 concludes the study and dis- cusses some future work.

II.RELATED WORK

We discuss the related work according to the phases of ICARUS. Therefore, we first describe approaches related to data dissemination, and then we present solutions for congestion detection and re-routing in VANETs. We discuss the relevant algorithms for data dissemination in the Section 2.1 and the strategies to identify congested areas and re-routing in Section 2.2.

Data dissemination

Flooding is the simplest way to perform data dissemination, however it leads to the well-known broadcast storm problem when the network is dense. Many data dissemination solutions have been proposed in the literature to overcome such problem. These solutions mainly focus on packet forwarding strategies that employ different parameters, such as position, distance, local topology and expected delay. Some of these solutions are described hereafter.

Adaptive Information Dissemination (AID) [21] is a distributed statistically-based broadcast suppression protocol for VANETs. In AID, each vehicle counts the number of redundant messages received from its neighbors. Based on the inter-arrival time between message receptions, a vehicle decides whether to rebroadcast a message or not. For instance, in a high-density traffic scenario, after receiving some redundant retransmissions for a given message, a vehicle may decide not to rebroadcast it, assuming it was already transmitted by many other vehicles. The protocol does not use any neighbor information or any kind of infrastructure. However, it works only on networks with no partitions.

Distance Based Relay Selection (DBRS) [22] is a simple and efficient strategy used to disseminate information in a network. Upon receiving a data packet, the vehicle holds it for a time interval inversely proportional to the distance to the destination vehicle. Thus, it is preferable to use vehicles situated further from the transmitting vehicle to disseminate information. When a vehicle scheduled to retransmit a packet overhears the retransmission of this same packet from another vehicle, it cancels its own retransmission to avoid the broadcast storm problem. This approach is efficient in handling the broadcast storm problem, however it is prone to two other problems. The first one refers to the high delay, since there is no guarantee of the existence of vehicles close to the communication radius (the ones that will transmit with the lowest delay). The second problem refers to the coverage that can be low, since vehicles will cancel their retransmission indiscriminately upon hearing the retransmission of the same packet.

Data Dissemination Protocol in Vehicular Networks (DRIVE)

[23] performs data dissemination on both dense and sparse networks. In a dense network, DRIVE selects only the highest priority vehicle within the transmission range of the sender vehicle to continue the dissemination process. The highest priority vehicles are located in a region known as the sweet spot, the same employed in the GEDDAI protocol [24]. In a sparse network, whenever a network partition is detected by a source vehicle, DRIVE employs the recovery zone concept. Vehicles outside the area of interest are used to disseminate data about the event within the area of interest. Those vehicles outside the area of interest (AoI) form a recovery zone. The main purpose of using a recovery zone is to perform data dissemination for vehicles separated by network partitions that are within the AoI.

Congestion detection and re-routing

The related proposals available in the literature focus on identifying congested areas reactively. This typically happens by collecting data from vehicles and roads, processing them to determine the slowest/fastest roads and which ones are congested. With this information, vehicles are rerouted considering the best route for each one of them. Pan et al. [7] propose a centralized system to acquire in real time the vehicle geographic position, speed and direction to detect traffic jam. Once detected, vehicles approaching the traffic jam are re-routed based on three different algorithms. First, Dynamic Shortest Path (DSP) proposes a route to the shortest path with the lowest travel time, but this algorithm has a shortcoming, which is the possibility to move the congestion to another spot. Second, Random *k* Shortest Paths (RkSP) chooses randomly a route among *k* shortest path routes. The goal of this algorithm is to avoid switching congestion from one spot to another one by balancing the re-routed traffic among several paths. Third, Entropy Balanced *k* Shortest Paths (EBkSP) improves RkSP considering the impact that each one of the *k* routes has on the future of the traffic density. The results show a decrease in the average travel time of 36% to DSP, 41% to RkSP and 45% to EBkSP to the tested scenarios. These schemes do not implement a real-time mechanism to infer when a congestion occurs, only detecting it in the next re-routing interval. Furthermore, these schemes perform the data collection in a centralized way.

Brennad et al. [11] propose a TMS that collects traffic information in real-time and attempts to detect and manage traffic congestion. In such solution, a set of RSUs is distributed through the map in order to provide full coverage of a city. Under this scheme, each RSU is responsible for managing the subset of vehicles and detecting congestion only within its coverage area. Moreover, such proposal includes a congestion control mechanism, which periodically performs the re-routing of all vehicles according to the traffic information collected in a previous step. Similarly to [7], this scheme does not detect congestion as soon as its occurs, since it only detects traffic jams during the next re-routing phase.

III. ICARUS

In this section, we describe ICARUS – a TMS that uses data about traffic events to alert vehicles inside an Area of Interest (defined by the application) using our proposed vehicle-to-vehicle data dissemination protocol. The main goal of ICARUS is to redistribute more effectively the road traffic to minimize vehicle congestion in urban centers. In addition, unlike most solutions found in the literature, ICARUS does not require that all vehicles periodically send a message to a central server, which might bring forth very serious impacts on the communication network capacity. To this end, only the set of vehicles inside the Area of Interest (AoI) that will pass through a congested area send messages to a central server.

Definition 3.1 (Problem definition). Considering a VANET environment where the road network is a directed and weighted graph$G = (V, E)$, where the set $V = \{v_1, v_2, \ldots, v_i\}$ corresponds to the set of intersections (vertices), while the set $E = \{e1, e2, \ldots, ei\}$ corresponds to the set of road segments (edges). Moreover, $W = \{w1, w2, \ldots, wi\}$ is a set of weights representing the traffic condition $\forall e | e \in E$. Let $N = \{n1, n2, \ldots, ni\}$ be a set of vehicles (nodes), $R = \{r1, r2, \ldots, ri\}$ a set of routes $\forall n | n \in N$, where $\forall r \subset E^2 | r \in R$. Let TE = $t1, t2, \ldots, ti$ be a set of traffic events. When a vehicle nj receives a traffic event tj, it creates an alert message MSG which is composed by the set of roads that may potentially be affected by the traffic event, thus characterizing a congested area CA. In other words, the affected area is composed by the set of adjacent roads of the traffic event location. Moreover, MSG is used to warn the vehicles inside the AoI, while CA is the set of affected roads that regards a specific traffic event tj identifying a congested area, CA $\subset E^2$. On the other hand, when a vehicle nj inside the AoI receives a message MSG, it verifies if $rj \cap CA$ (i.e., the vehicle verifies if its route will pass through a congested area). Finally, if necessary, an alternative route is computed for the vehicle *nj* to avoid the con- gested area CA.

The ICARUS structure and how each module interacts is presented in Fig. 1. ICARUS receives information about traffic events from other systems, such as congestion detection, accident notifi- cation and congestion prediction (e.g., OBD 2 system[1]) Thereafter ICARUS can extract information from traffic events to characterize a congested area, create and disseminate a message to alert all vehicles within an AoI using a V2V data dissemination protocol. Furthermore, the data dissemination needs to address the broad- cast storm problem by minimizing the packet collisions during the transmissions, which will also lead to a low overhead, short delays and high coverage. Finally, upon receiving an alert, a vehicle can make a real-time decision by verifying if it will pass through a congested area and, if necessary, the vehicle can change its route us- ing a re-routing algorithm to avoid the congested area. It is worth noticing that ICARUS can be proactive or reactive, depending on the Traffic Event (see Fig. 1). For instance, if the congestion predic- tion triggers an event with the imminence of congestion, ICARUS acts pro-actively. On the other hand, for an unpredictable event, such as an accident, ICARUS acts reactively.

To address the broadcast storm problem and maximize the coverage, ICARUS uses the concept of a sweet spot.

Definition 3.2 (Sweet Spot)**.** A sweet spot is defined as an area in which its vehicles are best suited to continue performing data dissemination. In other words, among all vehicles that received data to be forwarded, the transmission of a single vehicle within the sweet spot is sufficient to perform the data dissemination effi- ciently. Vehicles located within the sweet spots are more likely to spread the information further and reach a larger number of neigh- bors that could not be reached by the previous transmitter [23]. It is worth noticing that, as shown in [23], the use of a sweet spot is also able to handle the network partition problem, however, such problem is out of the scope of this paper.

To minimize the number of collisions by avoiding the synchronization introduced by the IEEE 802.11p standard [6,25], ICARUS implements a desynchronization mechanism that verifies if the computed waiting time to retransmit will lead to a transmission when the control channel is active. If this is the case, ICARUS adds an extra delay to allow the vehicle to transmit in the service chan- nel. The extra delay is at most 50 ms (the time the IEEE 802.11p standard uses to swap from the control channel (CCH) to the ser- vice channel (SCH)). In this scenario, if a transmission is scheduled when the control channel is active the extra delay is added to al- low the transmission to occur during the SCH.

Furthermore, it is important to stress that ICARUS employs an AoI to each traffic event in order to warn only the vehicles close to the traffic event. In this way, ICARUS prioritizes the vehicles that have higher probability to pass through a traffic jam i.e. the vehi- cles that should be re-routed. However, the traffic event may affect vehicles farther than the AoI, but is not necessary to alert them at this moment, once that the traffic jam may disappears before the vehicle arrives at the congested road. Otherwise, if the traffic jam still exists, the vehicles will be alerted as soon they enter in the AoI. At last, AoI reduces unnecessary transmissions outside the AoI contributing to reduce the broadcast storm problem.

Fig. 2 describes the steps taken by ICARUS. It starts when a ve- hicle *nj* receives an alert message MSG. Vehicle *nj* verifies if it is inside of the AoI (label "A" in Fig. 2). If it is not the case, vehicle *nj* verifies if the received MSG is already scheduled to be rebroad- cast (label "C" in Fig. 2) to decide if it cancels the scheduled MSG and/or discards the received message MSG. Otherwise, vehicle *nj* verifies if it will pass through the *CA* (label "F" in Fig. 2). If it is the case, an alternative route is computed for vehicle *nj* to avoid the congested area *CA*. The algorithms (Dijkstra, A* and Probabilistic k-Shortest Path) to calculate an alternative route are explained later. Moreover, vehicle *nj* checks whether it is the first time it received the message MSG (label "B" in Fig. 2). If so, vehicle *nj* computes the waiting time to rebroadcast and continues the dissemination pro-cess based on the *sweet spot* and its position (label "D" in Fig. 2). Moreover, after calculating the waiting time, vehicle *nj* verifies if the CCH will be active in the computed waiting time (label "E" in Fig. 2). If it is not the case, the vehicle schedules the retransmis- sion for the computed waiting time. Otherwise, the vehicle adds an extra delay to the computed waiting time to avoid transmit- ting the message when the control channel is active, i.e., it avoids transmitting the message when the SCH is active. Finally, the ve- hicle schedules the retransmission for the computed time (waiting time plus an extra delay).

To compute an alternative route and re-route the vehicles to avoid a congested area, the re-routing mechanism of ICARUS im-plements three different routing algorithms (Dijkstra, A* and Prob- abilistic k-Shortest Path) to avoid the congested areas. These are shortest path algorithms, however each algorithm uses different metrics to select a route.

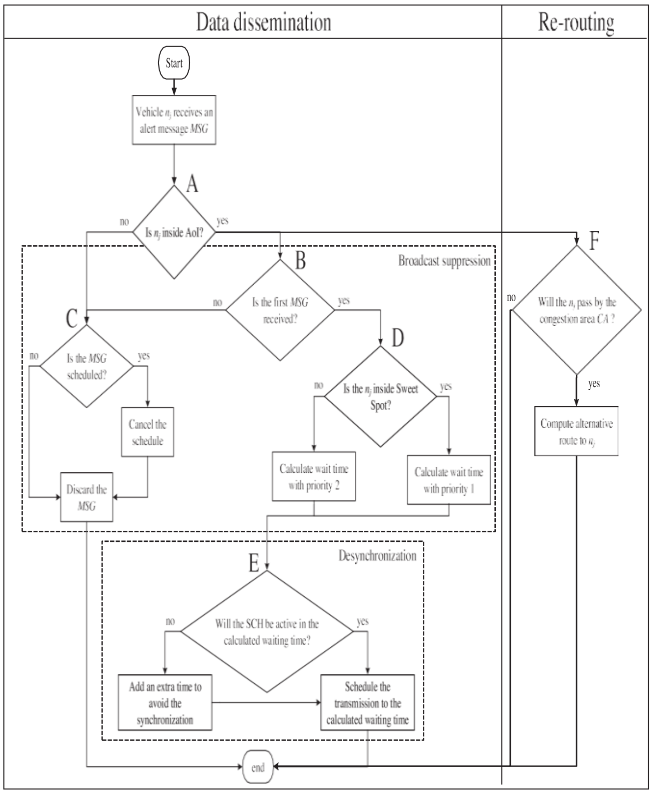


Fig. 2. Procedures of ICARUS.

1- *Dijkstra:* finds the path with the lowest length cost from the current vehicle position to its destination. Dijkstra is one of the optimal algorithms based on the labeling method. However, the algorithm only uses the length of each road as re-routing met- ric, thus as the traffic becomes denser, Dijkstra algorithm may causes a new traffic jam in a different area (i.e. it can creates a new congested area), because in dense scenarios many vehicles will be routed to the same route.

2- *A ∗:* is a variant of Dijkstra's algorithm and the its time com- plexity depends on the heuristic. Like [27] , in our implementa- tion, A ∗uses the traffic condition in each road to calculate the shortest path. Hence, A ∗restricts the search space and reduces the computational time. In a road traffic application, the search space is restricted to the area where traffic congestion occurs [28] . A ∗uses the traffic condition between the current location and the destination as a heuristic function. This heuristic func- tion reduces the probability of occurring a new congestion in a different area.

IV. PERFORMANCE ANALYSIS

The assessment of ICARUS is divided into two parts: data dis- semination, and congestion avoidance and re-routing. First, the data dissemination evaluation compares the data dissemination mechanism of ICARUS with four solutions presented in the liter- ature: Flooding, AID [21] , DBRS [22] and DRIVE [23] . Second, the congestion avoidance and re-routing evaluations are further di- vided into four distinct evaluations: (i) we evaluate the literature solutions DSP and RkSP in our simulation scenario, in order to identify the best parameter values for these protocols for a later comparison with ICARUS; (ii)we compare ICARUS performance un- der three different shortest path algorithms: Dijkstra, A ∗and prob- abilistic *k* shortest path; (iii) we compare ICARUS with literature solutions in a congested scenario caused by a high traffic demand, and; (iv) we compare ICARUS with literature solutions in a con- gested scenario caused by accidents.

a. *Simulation tools*

To conduct the performance analysis, we have implemented ICARUS in the Network Simulator OMNeT++ 4.3 [30] . Moreover, we employ SUMO (*Simulator for Urban MObility*) [31] , version 0.17.0, to manage the mobility of vehicles. For the vehicular network, we use the framework Veins 2.1 [32] , which implements the IEEE 802.11p standard and the signal attenuation model caused by obstacles. Fi- nally, the EMIT model [33] , which is implemented in SUMO, cal- culates the CO emissions and fuel consumption of vehicles. EMIT is a statistical model simplified from the HBEFA formula [34] to compute instant CO emissions and fuel consumption based on ac- celeration and vehicle speed.

b. *Data dissemination evaluation method*

A realistic scenario is applied to the simulations, obtained from a real map using the OpenStreetMap tool [35] . The scenario is a 4 km 2 fragment of Manhattan, USA, with several blocks and two- way streets so the vehicles can move in opposite directions. The vehicle density varies from 300 to 700 vehicles/km 2 using three classes of vehicles: cars, buses and trucks, with proportion of 50% to cars, 25% to buses and 25% to trucks. Furthermore, to gener- ate the vehicles' routes, we use a random mobility model, so that for each replication and density, different routes are generated for each vehicle. Table 1 summarizes the simulation parameters and the associ- ated values used in our assessment. For instance, the transmission power is set to 2.2 mW. With this configuration, the communication range can reach 300 m using the two-ray ground propagation model [36] . Moreover, we set the parameter T of the re-routing algorithm equal to 1. As shown in [11] , when T assumes a big value, the vehicles tend to choose the same path during the re-routing phase, since different cars have similar probabilities of choosing the same alternative route. On the other hand, when T assumes small value, the cars tend to choose the path with the lower weights, thus leading to a better load-balancing of the road network. In fact, according to the simulation assessment presented in [11] , when T = 1 leads to the best results. Finally, for every anal- ysis, the results represent the mean of 33 replications with a con- fidence interval of 95%. After the simulation stabilizes, a vehicle in the center of the map of our simulation scenario generates 100 messages of 2048 bytes and starts the data dissemination process at a rate of 500 kbit/s to all vehicles within the AoI, which has 1 km of radius. For this evaluation, the messages correspond to an emer- gency warning to all drivers being disseminated using a multi-hop communication. We assess four metrics to evaluate the efficiency, scalability and reliability: (i) *Coverage* is the percentage of vehicles that receive 100% of the data messages being disseminated. It is expected that dissemination protocols achieve a delivery ratio of 100%; (ii) *Trans- mitted messages* is the total number of data messages transmitted by all vehicles in the network during the dissemination process. A high number of message transmissions is a strong indication that redundant messages are being disseminated, which may result in the broadcast storm problem; (iii) *Delay* is the average time it takes to disseminate the data messages from the source to all vehicles within the AoI. A low delay is of particular interest to time-strict applications, such as warning message dissemination; and, (iv) *Col- lisions* is the average number of packet collisions at the MAC layer per vehicle to disseminate all data messages. A high number of collisions indicates that a given protocol is not able to avoid the broadcast storm problem.

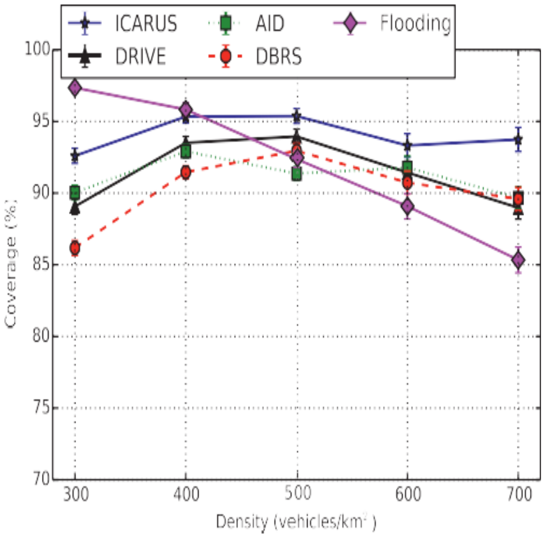
Table 1: Simulation parameters

parameters	**value**
Transmission power	2 .2 mW
Wireless range	300 m
Bit rate	18 Mbit/s
Scenario	$4\ \text{km}^2$
AoI	1 km
Number of simulations	33
Confidence interval	95%

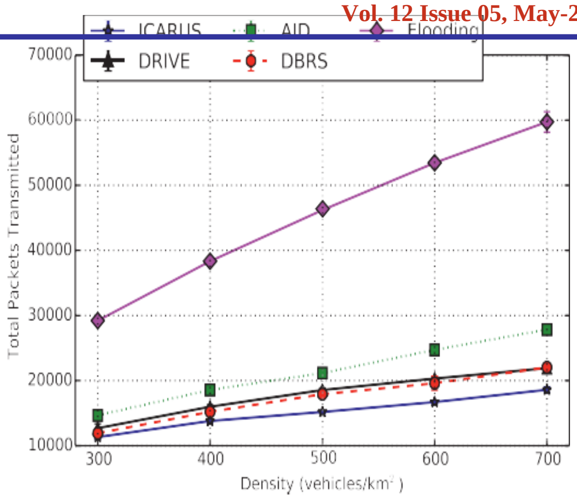
V. Data dissemination results

In this section, we discuss the ICARUS data dissemination mechanism. ICARUS was compared with AID [21] , DBRS [22] , DRIVE [23] and Flooding. We evaluated all protocols under normal and high traffic conditions. The densities used for the simulation were 300, 400, 500, 600 and 700 vehicles/km 2 . Fig. 3 presents all data dissemination results for the simulated scenario. Fig. 3 (a) shows the coverage result for all protocols un- der different traffic densities. For lower densities, Flooding is the only protocol that has a coverage up to 97% in the AoI. This comes from the fact that Flooding essentially rebroadcasts the packet to all vehicles and, in low density, the messages collisions are still a few (see Fig. 3 (d)), thus increasing the chance of reaching the best coverage. For the remaining protocols under low densities, only ICARUS has a coverage up to 95%, while the other protocols present a performance from

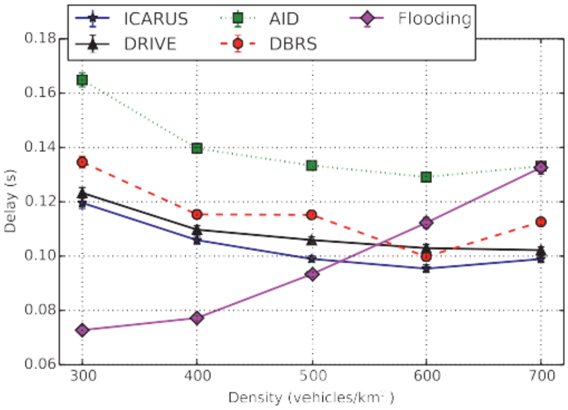
85% to 93%. However, as the traffic density increases, the data traffic in the network increases as well (see Fig. 3 (b)). Such increase in the network traffic leads to more packet collisions, thus leading to a worse coverage for all protocols. On the other hand, ICARUS's efficient broadcast suppression mech- anism minimizes the packet collisions, which keeps the protocol's coverage up to 95%. Fig. 3 (b) presents the total number of data packets transmitted. As expected, Flooding is the protocol with the highest overhead. Indeed, in Flooding, all vehicles rebroadcast the message once, thus resulting in redundant retransmissions. ICARUS, by using the pro- posed broadcast suppression mechanism, disseminates about 68% less packets when compared to Flooding. Moreover, ICARUS disseminates less packets than the other solutions. Therefore, this re- sult shows that ICARUS does not waste bandwidth with unneces- sary rebroadcasts. Fig. 3 (c) shows the average delay to disseminate data packets to intended recipients. As can be observed, for lower traffic densities, Flooding has a lower delay, followed by ICARUS. However, as the density increases, ICARUS takes less time to deliver the data packet to all recipients, due to the mechanism to minimize the number of packet collisions by avoiding retransmissions of collided packets. This shows that ICARUS is the best solution, among those evalu- ated, for applications with strict time requirements, such as alert message dissemination. Finally, Fig. 3 (d) shows the average number of collisions at the MAC layer to disseminate a packet. Flooding has the highest num- ber of packet collisions, which increases as the traffic density increases. This shows that Flooding cannot avoid the broadcast storm problem, especially at higher traffic densities. ICARUS has the low- est packet collisions for all densities, because it implements the desynchronization mechanism to minimize it. Compared to Flood- ing, ICARUS can reduce the number of average packet collisions by about 80%. Compared to AID, DBRS and DRIVE, ICARUS reduces packet collisions approximately 45%, 30% and 30% respectively.



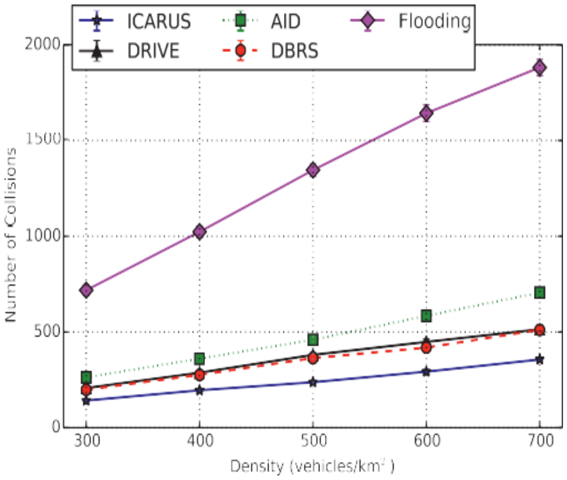
(a)Coverage



(b) Transmitted messages



(c) Delay



(d) Collision

VI. CONCLUSIONS

In this work, we proposed a novel Traffic Management System, ICARUS, to minimize the congestion of vehicles in urban centers using a vehicular network. The proposed solution aims to reduce the travel time, congestion time, fuel consumption, CO emissions and maximize the average speed of the vehicles during its trip. Simulation results show that the proposed solution reduces signif- icantly the travel time, fuel consumption and CO emissions. Since, for the travel time, a reduction of approximately 68% was pre- sented, fuel consumption showed savings of 48%, and, finally, CO emissions were reduced by 48%. .

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