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Research Article

Optimization of Transmission Signal Power through Observation of Congestion in VANets Using the *Fuzzy* Logic Approach: A Case Study in Highway and Urban Layout

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Vehicular *ad hoc* networks (VANETs) have unique features and rely on vehicle-to-vehicle (V2V) communication to mitigate adversities in traffic dynamics management and to support drivers providing safety alerts. Congestions, originating from an incident, frequently endanger traffic and, consequently, cause all kinds of losses. In this scenario, the paper herein proposes eFIRST, a robust solution to autonomous detection of the current congestion condition in order to disseminate safety alerts and to reduce problems with the interruption of traffic in a section of the highway. The approach is supported only by V2V communication and the local neighborhood identification records, which are brought together in a *fuzzy* strategy and in the adaptive adjustment of the transmission signal power. The estimate of local traffic conditions establishes the dynamic reach of transmission for the vehicle, supporting the connective maintenance. In these circumstances, the drivers receive an alert emitted soon enough for the proper response action. The results during simulations show how the elaborated solution leads to minimized delays, with low communication overload, besides relevantly mapping the congest levels and efficiently providing the event coverage to satisfactory propagation distances inside the area of interest for the dissemination. Promptly, the alert finds vehicles far from the traffic accident located at nearly 1/6 from the evaluated extension. In accordance with the intelligent protocols, this evaluation contributes providing grants for the ratification of *fuzzy* approximation as an adaptive strategy to fluctuations in vehicular density in different traffic basis.

1. Introduction

Currently, the amount of technological insertions has been increasing and has been characterized by the adoption of mobile devices, the pervasive computing, and the *ad hoc* communication. These elements provide the information ubiquity and lead to transformations. This insight supports the expectation of mobile communication in vehicles as a near reality and also triggers the elaboration of intelligent and safe transportation systems transportation systems (ITS) [1, 2], once the inconvenient traffic congestions cause frustrating experiences to drivers, perform a negative impact on economy, and harm the environment [3]. The initiatives with ITS benefit from the aspects underlying the innovations in processing technology, detection, and communication, contributing to the intention of providing resources to monitor traffic conditions in a region and helping to reduce congestions, as well as providing information and services for users of these systems, like drivers, and passengers [4].

A component that provides strength to ITSs engineering is the vehicle network known as *ad hoc* vehicular network (VANET) or simply *vehicular network*. This is a particular type of mobile *ad hoc* network (MANET), originated by the interaction of vehicles equipped with processing capacity, wireless communication interfaces, and several sensors, where all the nodes are effectively active in the communication process, although they are penalized by the uncertainty arisen from the traffic dynamics. In these spontaneously formed networks, the nodes have little or none previous infrastructure because they can send, receive, and forward data among them, communicate with the components aggregated to the network infrastructure (*Road Side Unit* (RSU)), or vehicle-infrastructure (V2I), creating a VANET [6, 7].

The uncertainties inherent in the traffic dynamics, which have an impact on the communication process, require attention [8]. The most known theories for dealing with imprecision and uncertainty are the theory of sets and the theory of probabilities respectively [9]. Although both are useful, these theories cannot always extract the richness from the available information. The classic theory of sets, which deals with classes and objects and their relation in a defined universe, cannot deal with the vague aspect of the information, and theory of probability is more suitable to deal with frequentist information than those provided by individuals, for instance [10–12].

With less austerity, the classic theory of sets can be seen as a particular case of the more general theory of cloudy sets, where the *level of relevance* of an element x in relation to a *fuzzy A* set is determined by a real characteristic function, which can take on endless values in the interval $[0, 1]$, or formally $\mu_A(x) : X \longrightarrow [0, 1]$.

The theory of cloudy sets and the theory of possibilities are intimately linked. Developed by Zadeh [9, 13], the theory of possibilities deals with the uncertainty of information in a similar way to the theory of probabilities. Alleged to be less restrictive, this theory can be considered more suitable for dealing with information provided by the individual than by probabilities. Effectively, even in the usual discourse, the notion of possibility is less restrictive than probability, since recognizing a certain event as possible does not mean that it is probable.

So, exceeding the formalization started by Zadeh [9] and employing the approach to the *fuzzy* systems, this paper materializes the solution Embedded Fuzzy Identification and Regulation System for Transmission *Embedded Fuzzy Identification and Regulation System for Transmission* (eFIRST) (in Portuguese: Sistema Embarcado de Identificação e Regulação Fuzzy para Transmissão) as a paradigm for embedded applications in VANET vehicles, which can count on answers elicited from the output *defuzzification* operations (Figure 1) of a *fuzzy* system. The levels of congestion or the traffic conditions detected allow a data dissemination strategy to promote adaptive actions as well as provide strength to the adjustment of transmission signal in vehicles, minimizing the fragility in communication due to the saturation of reserved channels (see *Dedicated Short Range Communications* (DSRC) [15]). Going a little further, the *fuzzy* system can contribute to the adaptation of other ITS applications to the vehicular traffic detected, in a similar approach [8, 16, 17].

2. Related Work

This section describes some of the approaches performed by the academic community that share particularities with the eFIRST. They consist of discussions that investigated issues relevant to the challenges imposed by data dissemination. The focus is on the aspects involving the formation of strategies adopted during dissemination. Such aspects describe the way the communication can be conducted in order to transmit a particular information, and also on protocols linked to ITS, used to minimize the congestions on highways or in urban routes.

2.1. Data Dissemination. The less complex strategy to conceive data dissemination in vehicular communication *ad hoc* networks is based on flooding. Inconveniently, this simplicity is inversely related to the capacity of collapsing and damaging the transmission channels. Among such challenges, taking on a homogenous distribution of communication nodes (vehicles), frequently implies on unsustainable supposition for VANETs, due to congestions, constraints and other adversities [18].

The approach herein (Section 4.1) advances towards the control algorithm, which develops adaptive strategy about number of neighbors, based on the attribution of dynamic reach by means of adjusting the transmission signal power. In its turn, the dissemination and the vehicle congestion problem receive deserved attention in the literature, considering some solutions proposed in order to optimize the flow of vehicles in the cities and highways.

The solution for detecting congestions elaborated by Bauza et al. [8] makes use of *fuzzy* logic for informing about location, extension and intensity of vehicle congestion. The authors present the *COperative Traffic congestion detECtion* (CoTEC) protocol, which in V2V communication cooperatively validate the conditions of traffic. In CoTEC, each vehicle continuously monitors the local traffic conditions and the *fuzzy* logic identifies the congestion condition, when it exceeds a predefined threshold (C_{th}). A situation of congestion detected locally activates the cooperative proceeding, which correlates the individual decisions. CoTEC uses *Cooperative Awareness Messages* (CAM) or *beacons* in *broadcast*, periodically transmitted, with information about speed and location in order to announce its presence to the neighbor nodes. The local traffic density is estimated through the reception of these messages. Thus, the congestion quantification *fuzzy* system makes use of the estimated traffic density and the vehicle speed as input parameters. The system output informs the level of traffic congestion or the corresponding intensity of traffic jam. The cooperative proceeding in the detection mechanism is based on *multihop* communication. Only the vehicles in the congestion take part of the process to retransmit control and updating messages. So, the dissemination of information for vehicles in an approaching situation is not satisfactorily contemplated.

The work of Araujo et al. [17] presents the *Cooperative vehiculAR Traffic congestion Identification and Minimization* (CARTIM), an identification and vehicular congestion reduction protocol. Strongly inspired and based on CoTEC [8], CARTIM aggregates a heuristic that makes use of politics to suggest new routes and, thus, reduce the congestion levels. According to Araujo et al. [17], it is a proposal aware of viable context for heterogeneous scenarios as highways and urban highways. CARTIM relies on a system based on *fuzzy* logic, and on a heuristic that longs for reducing the journey time for

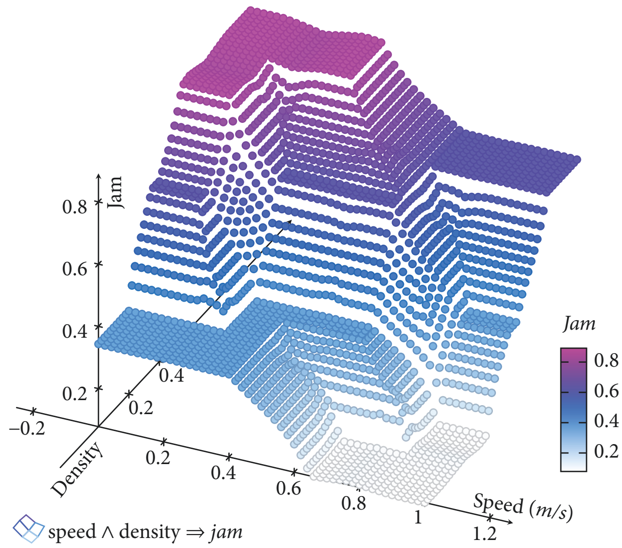


Figure 1: Surface in the *fuzzy* domain mapping congestion. Built with Matplotlib [14].

drivers. To this effect, the reduction of the journey time is a consequence of the proposal for altering the routes, with subsequent improvement of the vehicle traffic flow, in case of a congestion. Similar to CoTEC, the authors describe the logic of the proposal elaborated in three components: (i) local estimative of vehicular traffic, (ii) cooperative validation of traffic congestion, and (iii) a heuristic to minimize the traffic congestion. For updating, the information is shared by means of periodic exchange of *beacon*s, in V2V communication. Similar to what was formalized in CoTEC development, CARTIM also supports itself on its own control messages, but in bigger quantity, it implies a bigger overload for the communication channel.

With a proposal towards the same direction, but based on the work about an artificial neural network (ANN) trained in advance, Meneguette et al. [1] addresses the strategy called INCIDEnT (*INtelligent protocol of CongestIon DETection*) [1], with the aim at aggregating an alert mechanism so the driver can identify and avoid congested highways. However, the intense dynamics inherent to any VANET [19, 20] weakens the ANN response capacity, which tries out the capacity of narrow adaptation. In this approach, the convergence for determining the weighting of ANN synapses occurs prior to the integration of the strategy to the vehicle. Differently, this proceeding compromises the strategy performance.

Contrary to what is verified with strategies based on the adaptation capacity, but still meeting the purpose of detecting and minimizing traffic congestions for ITS, FOX, developed in Brennand et al. [4], describes a mechanism in real time that devotes attention to the task of optimizing the flow and the movement of vehicles in urban centers. FOX relates scalability as well as conditions for minimizing the vehicle congestion and, consequently, reducing the journey time, the consumption of gas and the emission of CO_2. However, different from the other heuristics referred in this section, FOX presumes and lodges itself on a whole RSU infrastructure previously established.

3. Fuzzy Logic

This section contextualizes the *fuzzy* logic system of eFIRST as a proposal of a solution for disseminating alerts and controls in congestion situations in the road environment. The minimization of inconvenient arisen from these incidents and the orientation of traffic flow by means of a collaborative information transference proceeding among vehicles cooperate in order to justify the elaboration of this strategy based on a computational intelligence technique (IC) [1, 8, 17, 21].

In the traditional approach, probability theory can be used to formally represent information in stochastic decision environments, then it describes the uncertainty associated with the randomness of events. In a similar perspective, the *fuzzy* sets (or cloudy sets) theory tries to represent the uncertainty associated with vague or inaccurate information [9]. The theory of cloudy sets, when used in a logic composition, like the systems based on knowledge, is known as cloudy logic, diffuse logic or *fuzzy* logic. This approach is especially interesting when the mathematical model is subject to uncertainties [22, 23]. The base of rules of a cloudy system is composed by a set of production rules like *If* ⟨*assumption*⟩ *Then* ⟨*conclusion*⟩. This kind of statement defines response actions, like the domain mapped in Figure 1, based on several value intervals that state variables of the problem can undertake [10]. These value intervals are modeled by cloudy sets called *linguistic terms*.

In the VANET context, due to the high underlying dynamics, there is a great uncertainty associated to the traffic. Among other aspects, these networks are subject to unexpected overloads in some moments, and disconnection in other moments. As a consequence, they challenge the precise analytical modeling. Therefore, *fuzzy* systems are presented as a convenient approach to deal with issues like identifying the dimension of the vehicular congestion and adjusting the power of the transmission signal, for instance.

Even without exhausting the discussions and concepts, the works elaborated by Gomide et al. [12], Zadeh [13], Dubois and Prade [24], Mendel [25], Bittencourt [26] bring the basic definitions of the cloudy sets theory. Moreover, similar to the operations performed in *crisp* sets, concepts like *complement* (*denial*), *intersection*, *union* and *implication* are approached in this theory, besides some of the properties associated to these operations.

3.1. Cloudy Systems. Different from the conventional systems with paradigms represented by algebraic or differential equations, based on a mathematical model, a *fuzzy* system uses logical rules (Table 1). These rules together form a foundation, with the aim of describing inside a routine, the human experience, intuition and heuristic to perform the same process [13].

A *linguistic variable* [13, 24] can be closely defined by a quintuplet $(X, T(X), \Omega, G, M)$, where

(i) X is the name of the linguistic variable;

(ii) $T(X)$ is the set of names for linguistic values of X, that is, the set of terms used by the variable X;

(iii) Ω is the universe of discourse of the linguistic variable X;

(iv) G represents the grammar of syntax rules in order to generate X values as a composition of terms $T(X)$, logical connectives, modifiers and delimiters;

(v) M is the semantic rule, a function that associates a relation of relevance for each $T(X)$ element by means of a *fuzzy* set in Ω, representing its meaning.

Figure 2 illustrates the linguistic variable X: *speed* described by means of cloudy terms $T(X)$: {*Slow*, *Moderated*, *High*, *Very high*}. The level with which a value x_0 (Figure 2) in Ω: 0 *to* 200 km/h satisfies the linguistic term A: *High* is the pertinence of x_0 in A, expressed like $\mu_A(x_0)$: [0, 1] (for example, in Figure 2 $\mu_A(x_0) = 0.7$).

3.2. Fuzzification Interface. The *fuzzification interface* identifies the input variable values, which characterize the system state (state variables) and normalize them in a universe of standardized discourse. These values are then *fuzzificated*, with the transformation of *crisp* input in cloudy sets so they can become *linguistic variable* instances.

3.3. Knowledge Base. The *knowledge base* consists of a database and a base of rules, as presented in the synthesized matrix representation which is summarized by the Table 1 with a reduced set of rules, in order to characterize the response strategy and the goals for each situation mapped on the tackled problem, the identification of the congestion condition for instance. The *databases* store the definitions related to discretization and normalization of discourse universe and the definitions of the membership functions to the cloudy terms. The *base of rules* is formed by a set of structures that are written in the following way: *If* ⟨*assumption*⟩ *Then* ⟨*conclusion*⟩, as for example (Algorithm 1):

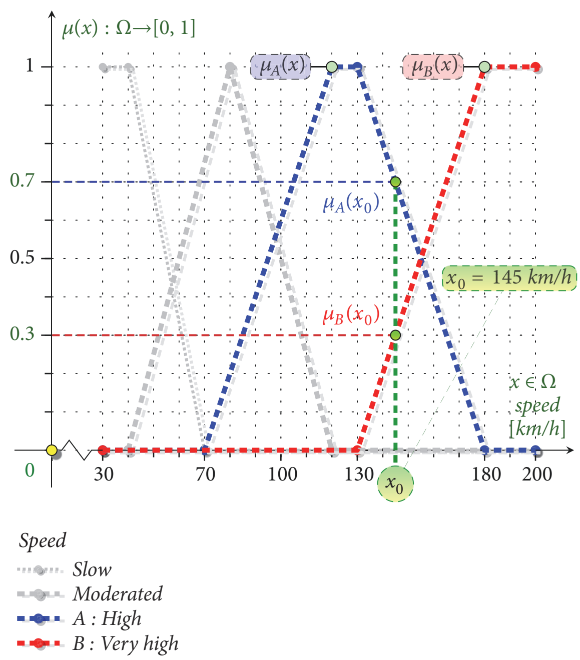


FIGURE 2: The *speed* variable described by means of a set of *linguistic terms* and the level of relevance for x_0. Adapted from [27].

These rules, in addition to the input information, are processed through an *inference proceeding*. As a consequence, this proceeding infers the response actions according to the state of the system. The entire mapping of the combinations of variable terms guarantees the existence of at least one rule to be transmitted to any input. In the same way, the consistency is essential to avoid contradictions and the interaction among the rules, managed by the implication function, in order to get around the cycle situations.

On this basis, the assumptions of the rules are related by the logical connectives, provided by the *conjunction operator* ($\wedge$) calculated with the *minimum* (*min*) for the intersection and the *disjunction operator* ($\vee$), calculated with the *maximum* (*max*) for joining two *fuzzy* sets [9, 28].

3.4. Inference Proceeding. Briefly, the process of inference of a *fuzzy* system consists in

(a) verifying the level of compatibility between the facts and the conditions in the assumptions of the rules;

(b) determining the level of global compatibility of each rule assumption;

(c) determining the conclusion value, based on the level of compatibility of the rule with data and constant response action in the conclusion;

(d) aggregating the values observed as conclusion in several rules, representing the final answer.

As a result, for the moment the *fuzzy* system evaluates the *speed* identified in Figure 5(a) by means of the reference $x_0 = 70\ km/h$ and simultaneously for the local vehicle *density* $y_0 = 40\ veh/km/lane$ considered in Figure 5(b), the

Table 1: Simplified set of logical rules to characterize local *congestion*.

			Traffic density [*vehicles*/*km*/*lane*]			
	Congestion level	. . .	Low (B)	Mean (M)	High (A)	Very high (Ma)
	Parked (P)	. . .	moderate	severe	absolute	absolute
	Very slow (Ml)	. . .	weak	moderate	severe	severe
	. . .	. . .	. . .	. . .	. . .	. . .
	Slow (L)	. . .	free	weak	moderate	moderate
	. . .	. . .	. . .	. . .	. . .	. . .
Speed [*km*/*h*]	Moderated (M)	. . .	free	*weak*	*weak*	moderate
	High (A)	. . .	free	*free*	*free*	weak
	Race car (Rc)	. . .	free	free	free	free

. . . Rules omitted for convenience of example. Italic cells identify the activated rules as illustrated in Figure 5.

If <Speed is Slow> And <D*ensity* is High>
Then <Congestion is moderate>

Algorithm 1: Rule structure.

If <Speed is Moderate> And <D*ensity* is Medium>
Then <Congestion is weak> Or
If <Speed is Moderate> And <D*ensity* is High>
Then <Congestion is weak> Or
If <Speed is High> And <D*ensity* is Medium>
Then <Congestion is free> Or
If <Speed is High> And <D*ensity* is High>
Then <Congestion is free>

Algorithm 2: Activated rules.

If $< \mu_M(x_0) >$ And $< \mu_M(y_0) >$ Then $< \mu_f(z) >$ Or
If $< \mu_M(x_0) >$ And $< \mu_A(y_0) >$ Then $< \mu_f(z) >$ Or
If $< \mu_A(x_0) >$ And $< \mu_M(y_0) >$ Then $< \mu_l(z) >$ Or
If $< \mu_A(x_0) >$ And $< \mu_A(y_0) >$ Then $< \mu_l(z) >$

Algorithm 3: Membership functions in the implication.

observation in Table 1 in accordance with the correspondence of these variables with the terms that describe them, allows to segregate the set of the four rules activated in this opportunity (Algorithm 2):

With the *congestion* sustained as variable z to build the consequent of the expressions and taking care to provide the relation of union among the rules, by means of the connective *OR* (*max*), it is possible to observe the replacement of the respective membership functions that evaluate the implication relation in the conditional statements as follows (Algorithm 3):

In the task of obtaining the membership function of the *fuzzy* $\mu_{n^*}(z)$ (to the set n^* does not correspond a label in defined *linguistic term*) set, dynamically determined for each one of the activated rules, the expression connects

$$
\begin{aligned}
&\mu_{n^*}(z) = (\mu_{T(x)}(70) \wedge \mu_{T(y)}(40)) \wedge \mu_n(z) \\
&\vdots \\
&\mu_{f^*}(z) = (\mu_M(70) \wedge \mu_M(40)) \wedge \mu_f(z) \vee \\
&\mu_{f^*}(z) = (\mu_M(70) \wedge \mu_A(40)) \wedge \mu_f(z) \vee \\
&\mu_{l^*}(z) = (\mu_A(70) \wedge \mu_M(40)) \wedge \mu_l(z) \vee \\
&\mu_{l^*}(z) = (\mu_A(70) \wedge \mu_A(40)) \wedge \mu_l(z)
\end{aligned}
$$

Algorithm 4: Membership function in the consequent of the rules.

both antecedents in the premises using the connective *And*, translated in the operator as *min* and then represented as $\wedge$. Therefore, through the identification of the respective membership functions (Algorithm 4):

The evolution of further substitution by propagating the degrees of membership of the variables in the respective terms that describe them in each rule, provides the representation of (Algorithm 5):

Proceeding the combination of the rules by means of the operator *max* application, the compatibility of the respective *fuzzy* set in the consequent of the expressions reflects the contribution of each activated response (see Figure 5(c)) in the composition of the output *fuzzy* set (Algorithm 6) in the contextualized moment.

This simplified combination of expressions determines the boundary of the *fuzzy* answer set, for the situation under consideration, when adding the adhesion values applied to the sets identified as conclusion in the activated rules (Figure 5(c)). In its turn, Figure 3 illustrates the *fuzzy* set of interest, determined in the Algorithm 6, as a result of the *max* operation.

3.5. Defuzzification Interface. The *defuzzification* interface is used to get only one precise answer, from the support cloudy set ($Su(Z)$) that is a result of the *inference process*

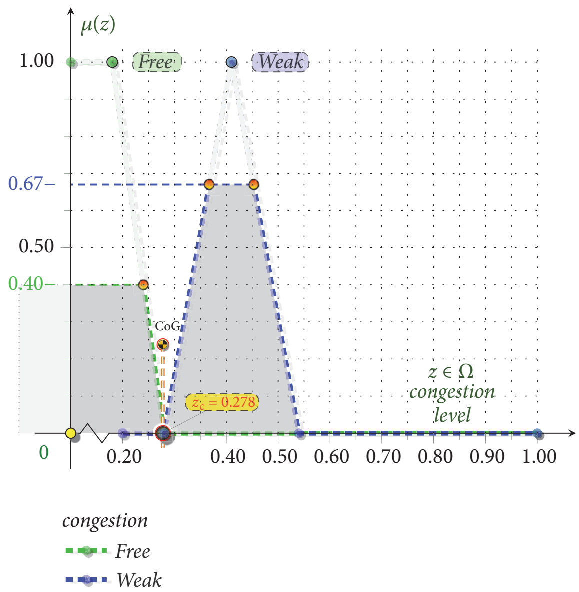


Figure 3: Discrete value of response obtained in the *defuzzification* by means of CoA, used as method for determining the CoG.

$$\mu_{f^*}(z) = (0.75 \wedge 0.67) \wedge \mu_f(z) = 0.67 \wedge \mu_f(z) \vee$$
$$\mu_{f^*}(z) = (0.75 \wedge 0.25) \wedge \mu_f(z) = 0.25 \wedge \mu_f(z) \vee$$
$$\mu_{l^*}(z) = (0.40 \wedge 0.67) \wedge \mu_l(z) = 0.40 \wedge \mu_l(z) \vee$$
$$\mu_{l^*}(z) = (0.40 \wedge 0.25) \wedge \mu_l(z) = 0.25 \wedge \mu_l(z)$$

Algorithm 5: Membership in the consequents.

described in Section 3.4. The operation comprises the domain identification of the output variables in a correspondent discourse universe, and with the inferred cloudy answer, a *nonfuzzy* answer is developed.

The selection of the *defuzzification* method is directly related to the system characteristics and the respective behavior of response. The literature [24, 25] provides several solutions for the *defuzzification* of the output set *fuzzy* $Su(Z)$. Among these solutions, and also used in this evaluation, the center of gravity method (CoG) is responsible for determining the *crisp* value (not *fuzzy*) in the output of the system as the CoG of the possibility distribution function of the response variable. The referred value corresponds to the average of the areas of all the $Su(Z)_i$ sets that represent the levels of membership of a *fuzzy* answer subset, as a reference to the one represented in Figure 3, in order to satisfy the implications synthesized in Algorithm 6 (Section 3.4).

With the CoG solved by means of the *Center of Area* (COA) in order to offer the arithmetic average among the centers of gravity of the areas representing the levels of membership of each *fuzzy* subset, the z_c *crisp* value is inferred as the centroid of the *fuzzy* $Su(Z)$ set composed of the combination of all the contributions from the consequents of the activated rules (Figure 3). This fact allows to conclude this output as the value in the universe that divides the area under the membership function curve in two equal parts. The fractional addressing

$$\mu_{f^*}(z) = 0.67 \wedge \mu_f(z) \vee$$
$$\mu_{l^*}(z) = 0.40 \wedge \mu_l(z) \vee$$

Algorithm 6: Application of the *max*($\vee$).

of this task is obtained with the performance of sufficient proceedings to

(i) determine the abscissa in the centroid coordinate for each consequent activated in the inference;

(ii) calculate the area established between the level of membership and the abscissa for each consequent activated;

(iii) calculate the centroids weighted average in relation to the respective areas.

In (1), which formalizes the calculation of the centroid by means of the CoA for the discrete domain, the numeric value z_c expresses the CoG of the distribution of output possibility provided by the *fuzzy* inference engine:

$$z_c = \frac{\sum_{i=1}^{N} z_i \cdot \mu_{Su(Z)}(z_i)}{\sum_{i=1}^{N} \mu_{Su(Z)}(z_i)} \tag{1}$$

where the component $\mu_{Su(Z)}(z_i)$ represents the areas of a membership function, as, for example, for the term *free* or the term *weak* in Figure 3, modified by the respective *fuzzy* inference result, that is, the level of membership associated to the $i - th$ *fuzzy* set (consequently, 0.4 for *free* and 0.67 for *weak*, as provided in Figure 3) and, z_i reflects the centroid position of the individual membership function for the $i - th$ *fuzzy* set (in this case *free* and *weak*). In the particularized sum with (1), the limit N accommodates the amount of linguistic terms (sets) that contribute in the composition of $Su(Z)$. For operations performed in the continuous domain, the sum in the discrete domain that characterizes (1) appears in full written in the form of the integral shown in (2).

$$z_c = \frac{\int_{x_{min}}^{x_{max}} x f(x)\, dx}{\int_{x_{min}}^{x_{max}} f(x)\, dx} = \frac{\int_{z_{min}}^{z_{max}} z \cdot \mu_{Su(Z)}(z)\, dz}{\int_{z_{min}}^{z_{max}} \mu_{Su(Z)}(z)\, dz} \tag{2}$$

for which z represents the value of the linguistic variable at the *fuzzy* system output and the limits z_{min} and z_{max} in their turn, define the contribution intervals of each term activated on this linguistic variable (see (3)).

Among the most widespread approaches, the *defuzzification* by means of the CoA method effectively calculates the value of the best adhesion to the multiple linguistic terms activated in the output, as shown in Figure 3. From this perspective, (3) finds assistance and support as an expansion of (2), for it reflects the area (the values of z are mapped to the interval $[0, 1]$ in Figure 3, but for convenience (3) is solved for the interval $[0, 100]$, so then the results $z_c = 0.278$ and $z_c = 27.7663$, respectively) represented by the combination of activated terms contributions in the composition of Figure 3, later confirmed as consequent in Figure 5.

$$z_c = \frac{\int_0^{24} 0.4z dz + \int_{24}^{28} (2.8 - 0.1z)\, z dz + \int_{28}^{36.71} ((z - 28)/13)\, z dz + \int_{36.71}^{45.29} 0.67 z dz + \int_{45.29}^{54} ((54 - z)/13)\, z dz}{\int_0^{24} 0.4 dz + \int_{24}^{28} 2.8 - 0.1 z dz + \int_{28}^{36.71} ((z - 28)/13)\, dz + \int_{36.71}^{45.29} 0.67 dz + \int_{45.29}^{54} ((54 - z)/13)\, dz} \quad (3)$$

$$z_c = 27.7663$$

In VANET, information is easily accessed and works as input like *(i)* the speed of the vehicle (similar to the illustrated in Figure 2) and *(ii)* the vehicular density observed on the road, represented through *fuzzy* sets. So, the performance of an inference proceeding makes it possible to obtain *(iii)* the intensity of the congestion, as the *fuzzy* set of the system response.

In its turn, applications embedded in VANET vehicles can benefit from the responses of the *defuzzification* proceeding of these outputs by means of the *fuzzy* system, which results on the mapping of the respective interest variable domain, as for example the congestion surface in Figure 1. This response surface has its structure supported in the *defuzzification*, performed by means of CoA, of all possible combinations of values informed with the input variables. The levels of congestion and the traffic conditions allow a data dissemination strategy to provide adaptive actions to improve the identified conditions. In a similar way, it also makes possible the autonomous adjustment of the transmission signal power in each vehicle as congestion intensity function, at the moment of the alerts communication, in order to ensure the scalability implied to the formation of VANET.

4. Performance Evaluation

This section presents the methodology adopted to elaborate the evaluations, performed with *fuzzy* eFIRST solution proposed to adaptation, the development and operation framework, the tools and conditions of traffic. Moreover, it also discusses the results achieved with the simulations performed.

4.1. Methodology. The variations of *fuzzy* eFIRST strategy performed were implemented with the network simulator OMNeT++ 5.0 (OMNeT++ (*core, without IDE*), https://omnetpp.org/) [29]. As an ally, the network *framework* Veins 4.5 (Veins, http://veins.car2x.org/) [30] is the component responsible for providing the communication architecture resources and the standard technology IEEE 802.11p [31], embedded in all VANET nodes. As the realistic mobility (or traffic) model is essential for precise results in evaluations of data dissemination algorithm, SUMO 0.28.0 (SUMO, http://www.dlr.de) (*Simulation of Urban MObility*) [32] was adopted as a tool to support the traffic simulation scenario and to provide vehicular mobility.

To complete the instrumental and support the uncertainty treatment operations, the fuzzylite 6.0 (FuzzyLite, http://www.fuzzylite.com) (*The FuzzyLite Libraries for Fuzzy Logic Control*) library was used. This library admits the integration to the codification language set in the simulation environment and provides interfaces for the implementation of all the components of a system based on *fuzzy* logic, as discussed in Section 3 [33]. In order to perform the experiments and to proceed with the evaluations of the proposed heuristic, 33 repetitions of each simulation were performed in a way that each point represented in the graphics in Section 4.4 corresponds to the average value of these repetitions, preserving the level of confidence 95%.

Figure 4 shows a gap in a section of the highway, about 6 kilometers of extension, observed during evaluation performance in Section 4.4. The section of the road illustrated in Figure 4 corresponds to the configuration of region used to provide a car accident, responsible by the induction of congestion situation. The multiple lane highway has three traffic lanes in two opposite directions, authorized changing lanes and center divider. The established speed limits are specific for each lane, with restrictions of 80, 100 and 120 km/h. On the lateral end it is slower, in the middle with better flow. Due to this particular characteristic, the composition of vehicle flow inserted in the simulation, to provide mobility, satisfies three groupings with arrangements represented by the dimensions, acceleration/deceleration and speed threshold, as follows:

(i) light vehicles (up to 120 km/h): passenger car, truck, *sport utility vehicle* (SUV);

(ii) intermediate vehicles (up to 100 km/h): truck, SUV and microbus;

(iii) heavy vehicles (up to 80 km/h): microbus, bus, truck.

In order to reflect realistic conditions with small inhomogeneity according to Highway Capacity Manual (HCM) [33], all the simulations lodge a regular density flow for the period of observation and respect the guidelines established for each lane. This way, the central lane, which supports speed up to 120 km/h, works preferably, with smaller vehicles, for they reach higher speed. The evaluations are guided so they can explore specifically six different traffic conditions in this section of the highway, with densities varying from 500 to 4000 vehicles per hour (specifically: 500, 1000, 1500, 2000, 3000 and 4000 vehicles/h).

The traffic generated is divided into 70% of light vehicles with ≈ 4.5m length, 15% of intermediate vehicles with ≈ 14m and the remaining is composed of heavy traffic (≈ 18.15m). These groupings are instantiated first in the opposite ends of the respective lanes. However, the vehicles use configuration that provides exemption of restriction to any internal lane change necessary during the route.

Table 2: Simulation parameters for highway setting.

Parameters	Values
Number of vehicles	500, 1000, 1500, 2000, 3000, 4000 vehicles/h
Length of highway	$\approx 6.25\ km$
Interference model	Two-Ray Path Loss Models [5]
Transmission power (max.)	$20\ mW$ (range of up to $\approx 886m$)
Alert message time	$80s$ (relative to the starting time)
Simulation time	$280s$
Time to live	$40s$
Bit rate	$6\ Mbit/s$
Beacon frequency	$1\ Hz$
Number of runs	33
Confidence interval	95%

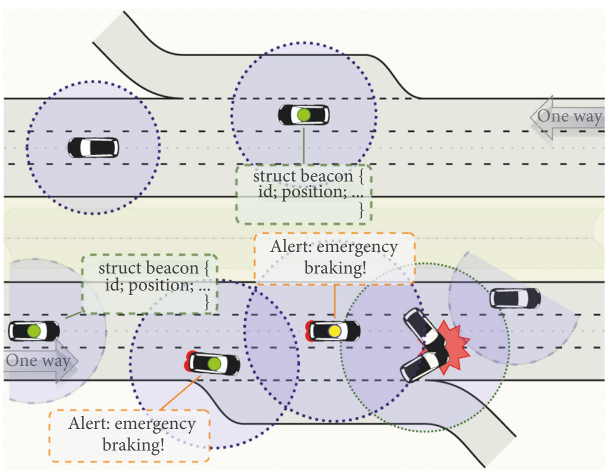


Figure 4: Vehicles approaching the place of the accident receive emergence alert by means of V2V communication to avoid the congestion situation.

Table 3: Time of accident for each traffic.

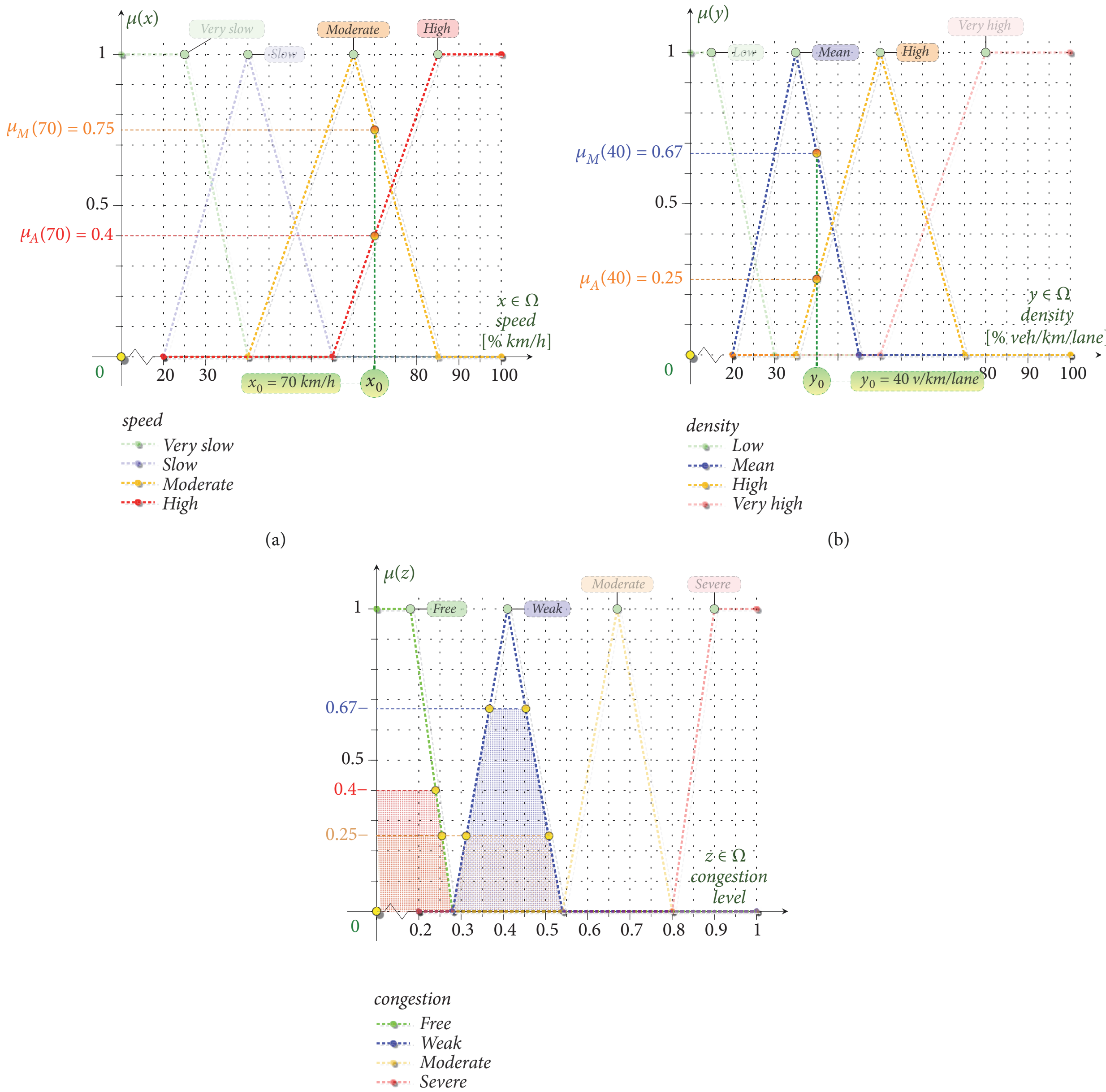
Traffic condition (vehicles/h)	Moment of accident/alert
500	$158s$
1000	$127s$
1500	$116s$
2000	$112s$
3000	$106s$
4000	$103s$

In order to ensure a regime in stable traffic conditions, with measuring free of interferences, the records corresponding to the 10 initial seconds are dismissed (*warm up*) from the driving range of each simulation. Notwithstanding the considered period of 280 seconds (Table 2), which is enough to evaluate the protocol of transmission during the performance of alert message dissemination strategy. So, once the adequate variation is reached in the density and speed of the nodes, at 80 seconds in relation to its own departure time, an incident is induced by a certain vehicle (Table 3). The event triggers the production of only one alert message, originated in the first vehicle involved, and this circumstance will compromise at least one lane of the highway. As a consequence, a congestion is initiated in the region of the unexpected event.

The drivers approaching the intervention area (Figure 4) are notified with the alert transmitted by means of *multihop* communication. The message to be transmitted will carry the information with the identification of the interdicted lane, which characterizes an incident on the road, particularly, the accident prepared for the case investigated in this approach. So, taking into consideration the limit of the warning time, the task consists of delivering the assistance information for the most vehicles that are on the route of the accident, with the purpose of giving the driver enough conditions to avoid the event.

Used to define operation properties that reverberate in the simulations, the relevant attributes and their respective values, as abstracted from other experiments previously performed, are summarized in Table 2. In this table, the main configuration parameters of Veins component, which implement the communication technology, describe the bits tax (*in Mbps*) in MAC layer, the maximum power available for transmission (*in mW*) and consequently, the respective near reach of communication ($886.6m$) when submitted to the noise caused by the Two-Ray Interference Model [5], among other definitions.

Inferring congestion is a challenging proceeding, since it involves conclusion about partial or qualitative information, for example, the network sparsed by low vehicular density. Then, inherent uncertainty and inaccuracy support the election of a decision system based on *fuzzy* logic for dealing with the indications that identify the levels of traffic congestion, in reference to what Bauza et al. [8], Binglei et al. [21] presented, evaluations that based on the same foundations, also attack the problem with the reception of Zadeh's [9] theory. As in Section 3, the state variables, preeminent in any decision-taking system based on *fuzzy* logic, support themselves in *fuzzy* sets that break a domain in value intervals (Figure 2).



(c)

Figure 5: Inference proceeding in the congestion detection *fuzzy* system.

These sets, the *linguistic terms* presented in Figure 5 [34], prolong themselves over the speed and density inputs and, similarly, show the consequent level of congestion.

In this perspective, the embedded *fuzzy* system is responsible for developing the input instances admitted in any moment, in Figures 5(a) and 5(b) noticed as x_0 and y_0, which allow raising the correspondent level of conformity (μ) in reciprocity to a certain set. The relevance verified among these facts and the conditions in the assumptions of the rules summarized in Table 1, conveniently represented as *linguistics terms* in Figure 5, converge to a global compatibility response of each rule assumption. The response action in the conclusion of each rule is implicated according to the respective relevance of this convergence. Finally, aiming at extracting the value of response considered by the *fuzzy* system, (2) is applicable on the combination of sets conceived in conclusion in the rules issued as evaluated inputs.

Without compromising relations to the limits established for the highway, the speed observation has no obstacles. With protected consistency, the information is native to the simulation framework, and for that reason its access is immediate, once it derives from the own model of adopted vehicle provisioned with GPS. On the other hand, the characterization of vehicle density in the neighborhood is a result of indirect verification. The extension of this measure is provided by means of estimate that considers the count of received *beacon*s, settling an immediate relation with the reach of communication (V2V). The identification of origin, retained in each *beacon* message, provides an approaching of the quantity of vehicles gathering in the same coverage area. Thus, the vehicle itself updates its density dynamics, in a time interval, followed by an individual evaluation of the quantity of neighbors that are close to the current route in relation to the road capacity.

Wang and Mendel [11], Zadeh [13], Mamdani [28] classical approach is enough to provide the adjustments and adaptations intended to the incorporated *fuzzy* system, with respect to the variations originated from the insertion context of each vehicle. By caution, a conservative composition to model the consequence of the rules structures the *congestion* orientation for the interval $[0, 1]$ by means of the linguistic terms *free*, *weak*, *moderate* and *severe*, as reflected in Figure 5(c) with the relevance functions (*fuzzy* sets), which completely comprises the foundation of inference rules. Therefore, the *fuzzy* system embedded in the vehicle benefits from the entirety of these rules (*if/then*), from which the assumptions comprehend the *fuzzy* propositions that deal with *speed* and vehicular *density* inputs, previous described, and associates them according to the mapping of responses expressed on the surface of Figure 1. The interpretation linked to the congestion positions in the range of this surface externalizes, for instance, *high speed* with *low density* situations implying *free* traffic (sparse network) or, in opposite circumstances, many neighbor vehicles in the same section of the highway (*very high density*) and reduced *speed*, identifying a *severe* congestion moment.

All the endeavors implied in this evaluation converges in order to provide a solid strategy to transmit a message with safety alarm detect the order of the congestion and even provide actions to minimize or avoid the inconvenience resulting from this event. Due to the alert dissemination, the severity of the congestion registered in *fuzzy* treatment is conveniently taken into consideration, to condition the power of the transmission signal in V2V communication. The recognized conditions of local traffic provide information about the densification of vehicles in the neighborhood. A sparse neighborhood induces to a greater investment in the transmission power, with the intention of supporting the dissemination reach and continuity. In a similar way, in the situations close to the capacity burnout of the highway, it is important to mildly reduce the signal power when transmitting the alert in order to instigate the V2V communication to reach only reduced regions, as a part of the strategy. The reduction of the signal is compensated with the administration of precedence to the retransmissions, avoiding compromising the channel of communication or weaken the dissemination, and with the aim at reducing data collisions.

Respecting the respective limits ($[0, 20] mW$) and proportionally to the maximum value admitted for the transmission signal power, Figure 6 shows the adaptation behavior of the power as a complement function of the congestion detected in the *fuzzy* inference. The construction of the corresponding domain follows what is formalized in (4),

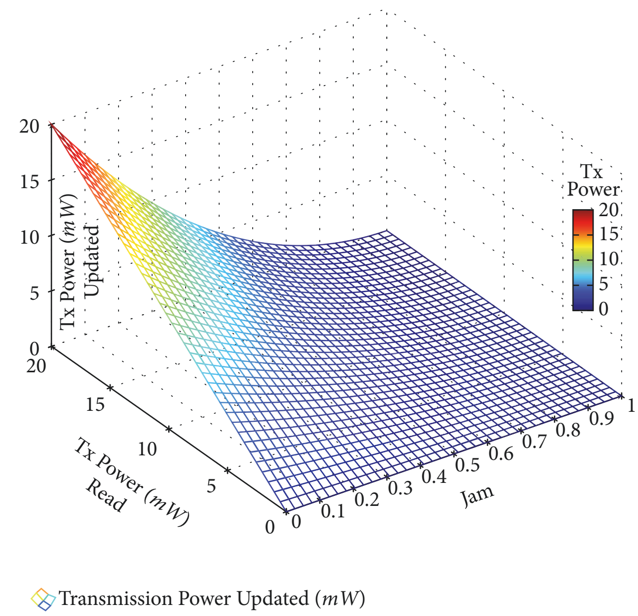


Figure 6: *Fuzzy* calculated transmission power (mW).

which allows measuring the highest values of transmission power associated to the traffic with less density.

$$TxPower_{updated} = Power_{max} \cdot \left(1.0 - Jam_{fuzzy}\right)^2, \quad \forall Jam_{fuzzy} \in [0, 1] \tag{4}$$

Thus, in (4), the $Power_{max}$ component reproduces the superior limit for the power of the transmission signal as operation parameter and, Jam_{fuzzy} consists of the discrete response obtained for the level of congestion, mapped for the interval $[0, 1]$.

The approaches represented with the codification, in Algorithms 7 and 8, provide an abstraction of the implementation to obtain the levels of congestion, and of the transmission signal power updating, with the implicit natural quantification of (4).

4.2. Algorithms for Detection of Congestion and Adjustment of Transmission. The cornerstone of the adopted strategy harmonizes the ability to adapt to traffic conditions, granted to vehicles with the embedded *fuzzy* solution (eFIRST), which in its turn, benefit from the V2V communication [6, 7]. The resources to detect the congestion levels on the road and the subsequent adjustment of the transmission signal power as a function of this element are expected in all the vehicles and are used periodically. This proceeding ensures the possibility of reflecting instantaneous information, with the updated situation, related to the current situation of the road for the vehicles in the neighborhood. This is also a way to regulate and protect any inconsistent or rash inference, encouraging a coherent and reliable convergence for the response of traffic conditions.

Each vehicle gathers a set of local values for properties like the direction, location coordinates, speed and other

```
// Fuzzy inference system
// Initial setting
updateNeighbors ⟵ getNeighborhood ();
currentSpeed ⟵ getSpeed ();
currentDensity ⟵ getDensity (updateNeighbors);
// Fuzzification
// Input variables
fzSpeed ⟵fuzzification (currentSpeed);
fzDensity⟵fuzzification (currentDensity);
// In: membership functions
foreach membershipFuncIn[i] ∈ getRuleWith (↩
        fzSpeed, fzDensity) do
    // Fuzzy inference engine with set of rules
    membershipFuncOut[i] ⟵fuzzyInference (↩
        membershipFuncIn[i]);
done
// Out: membership functions
foreach fzOut[i] ∈ membershipFuncOut () do
    // Defuzzification with Eq. (2)
    FzTraffic ⟵ defuzzification (fzOut[i]);
done
if ( fzTraffic <= 0.28) then
    congestion ⟵ setFreeLevel (fzTraffic);
else if (fzTraffic <= 0.54) then
    congestion ⟵ setWeakLevel (fzTraffic);
else if (fzTraffic <= 0.8) then
    congestion ⟵ setModerateLevel (fzTraffic);
else
    congestion ⟵ setSevereLevel (fzTraffic);
end
return (congestion);
```

Algorithm 7: Classification of the local congestion level.

characteristics for the traffic condition in the current section observed (road or urban highway). The information related to other sections are also sent, since the previous knowledge due to the previous processing, if available, provides to the vehicle the capacity to set a location and the congestion level of other sections of the road, which are part of the route until the last destination. In the *fuzzy* system, with preserved content, the *beacon*s identified individually in the reception are recorded in order to support the determination of the vehicular density, which is used in one of the inputs. The mechanism to infer the levels of local congestion is reproduced in Algorithm 7, which with the suitable rules for the domain of the problem, deals with the input variables as well as the output *fuzzy* variables, by means of the membership functions. The traffic conditions, associated to the membership functions activated in the consequent of each evaluated rule, involves the processing of (2) to complete the defuzzification proceeding. The propagation of *beacon*s ensures the dissemination of information about the level of congestion for the current coordinates of the vehicle and surrounding routes, but it tends to generate an overload in the network causing *broadcast storms* [19]. Despite that, it also provides the anticipation of other sections of the road with busy traffic in the driver's experience.

Data dissemination required by a particular vehicle, instigated in any event, is also supported by eFIRST *fuzzy*

// Transmission power update
// See: Eq. (4)
txPower ⟵ setUpdateTxPower (congestion);

distFromSrc ⟵ getDist↩

$$\left(\sqrt{\left(snd_x + rcvd_x\right)^2 + \left(snd_y + rcvd_y\right)^2}\right);$$

stdDelay ⟵ $\dfrac{distFromSrc}{getTxRangeRadius(txPower)}$;

fzDelay ⟵ setDelayFor (congestion);

// Time to schedule the next transmission
delay ⟵ stdDelay + fzDelay;

Algorithm 8: Calculate the wait time to schedule the transmission based on the level of congestion.

```
beaconCnt = 0;

while (true) do
      newBeacon ⟵ getBeaconMsg (beacon);
      msgBeacon ⟵ setDecapsulate (newBeacon);
      beaconCnt++;
end

if (isInsideRoI (msgBeacon.getDistFromSrc ( ) ) ) ↩
   then
      if ( (check (ttl, msgBeacon.getTimestamp ( ) ) ) >↩
       0) and (getHops (msgBeacon) < Threshold) ↩
   then
            sendBeaconEvt ⟵ setUpdateMsg (msgBeacon) ↩
   ;
            scheduleAt ( interval.beacon ( ), sendMsg (↩
   sendBeaconEvt ) );
      else
            cancelAndDelete (msgBeacon);
      end
end
```

Algorithm 9: Mechanism of *store-carry-forward*.

strategy. Once the incidence of relevant information for dissemination is evaluated, the propagation of a message ensures the distribution of the referred information to the vehicles inside the geographic location of the *Region of Interest* (ROI). When the message is received, the coordinates of the current position are examined in order to ensure that the vehicle is in the ROI (Algorithm 9). They are evaluated in relation to the distance from the origin of the dissemination (Algorithm 8). The retransmission scheduling of the updated message occurs only in a positive case, respecting the level of congestion observed at the same moment. In a different way, the message is simply discarded, similar to the proceeding adopted when the duplicated information is confirmed. In Algorithm 8, the level of effective congestion orientates the updating of the power used with the transmission signal in the vehicle, and it also determines the delay time for scheduling the retransmission. This is the mechanism responsible for regulating the elements (vehicles) active in the data dissemination strategy, in order to reduce the problem of *broadcast storms* [6, 7, 19, 35].

The attribute signalized as TTL in Algorithm 9, which defines the availability or, specifically, the *time to live* (TTL) of a message, delimits the capacity of the vehicles to deal with the inconveniences of the sparse network. The lack of *beacon*s in the reception allows the conclusion of the momentary fragmentation of the network. In a defensive attitude, the vehicles use the *store-carry-forward* communication model, limited by the TTL, in order to reduce the effects of this fragmentation. Consequently, the vehicle transports the message stored for

```
(1) // Reception of information beacon
(2) forall (receivedMsg (beacon) ) do
(3)       if (newBeacon ⟵ getBeaconMsg (beacon) ) ≠ ↩
          NULL) then
(4)           msgBeacon ⟵ getDecapsulatePkg (newBeacon↩
           );
(5)           new src ⟵ createMsg (msgBeacon);
(6)           src.roadId ⟵ getCurrentRoadId (msgBeacon↩
           );
(7)           src.coord ⟵ getCoord(msgBeacon);
(8)       end
(9) done
(10)
(11) coord ⟵ getCurrentCoord ( );
(12) roadId ⟵ getCurrentRoadId (coord);
(13) roadIdToAvoid ⟵ getCongestedRoad (src.coord, src↩
           .roadId); //Edge id to avoid
(14)
(15) if (roadIdToAvoid ≥ getModerateLevel (congestion) ↩
           ) then
(16)       setRoadId.timetotrip (roadIdToAvoid,∞); // ↩
           Travel time to assume
(17)       warnTripEdges ⟵ getPlannedRoadIds (roadId, ↩
              roadIdToAvoid);
(18)
(19)          if (warnTripEdges == true) then
(20)             newTripEdges ⟵ searchRouteId(coord, ↩
              prune (roadIdToAvoid) );
(21)             newRoute ⟵ setShortestPath (newTripEdges↩
              );
(22)             setChangeRoute (newRoute);
(23)       end
(24) end
```

Algorithm 10: Method of *beacon* reception.

a period that corresponds to the remaining TTL, reaching other regions of the road or urban highway, in different traffic conditions.

Another component, Algorithm 10, demands greater attention with the frustration deriving from the compromised traffic situation due to an unexpected event like an accident involving vehicles on the road. The first lines (*lines* (1) – (10)), in Algorithm 10, show the set of actions triggered with the reception of any *beacon*, which later, culminate in the route switching mechanism. The instantaneous traffic measurement, in the section of the road with the current position coordinates, is confronted by the context received from *beacon* messages. The weak identification associated to the congestion level, registered in the *beacon*, in accord with severe traffic conditions, authorizes the route updating previously established. Every section of the road which is degraded by traffic is penalized. This penalization is reflected in cost equivalent to a time interval longer than the simulation period. Thus, these sections of the road become impracticable for the driver, so the vehicle verifies updating in nearby sections and initiates the selection of alternative routes for the same destiny, with a reasonable cost.

The exploratory evaluation conducted in this experiment is considerably based on metrics monitoring, briefly described in Section 4.3.

4.3. Evaluation Metrics. The route evaluated, according to the *fuzzy* strategy previously determined, is submitted to what was observed in the response metrics for the dissemination process, as follows:

(i) *Collisions:* it measures the number of collisions registered during data dissemination. It is directly related to the network degradation.

(ii) *Delay:* the values reduced for this metrics are, mainly, aimed at the safety alert dissemination. It corresponds to the average time necessary for the message to reach all the vehicles in the ROI, measured from the vehicle that originated the message.

(iii) *Coverage:* it is a ratio that corresponds to the number of vehicles that effectively receives data from a transmission during the dissemination, in relation to the total number of vehicles in the relevance zone (ROI). It is expected that reliable data dissemination solutions reach around 100% of coverage.

(iv) *Total of transmissions:* it is the total quantity of data messages transmitted inside the ROI, provided by the sum of transmissions performed by each vehicle during dissemination. This metrics is related to the problem with *broadcast storm*, for high values are a strong evidence of redundant transmissions.

(v) *Distance of message propagation:* the maximum average distance reached by data disseminated inside the ROI, from the origin vehicle. Reliable solutions of data dissemination commit themselves with distances of message propagation, approximately equivalent to the size of the ROI.

Section 4.4 presents some of the response curves outlined under *fuzzy* strategy, which uses the uncertain information, in order to aggregate adaptation to the detection of congestion conditions during the route developed in the evaluation scenarios.

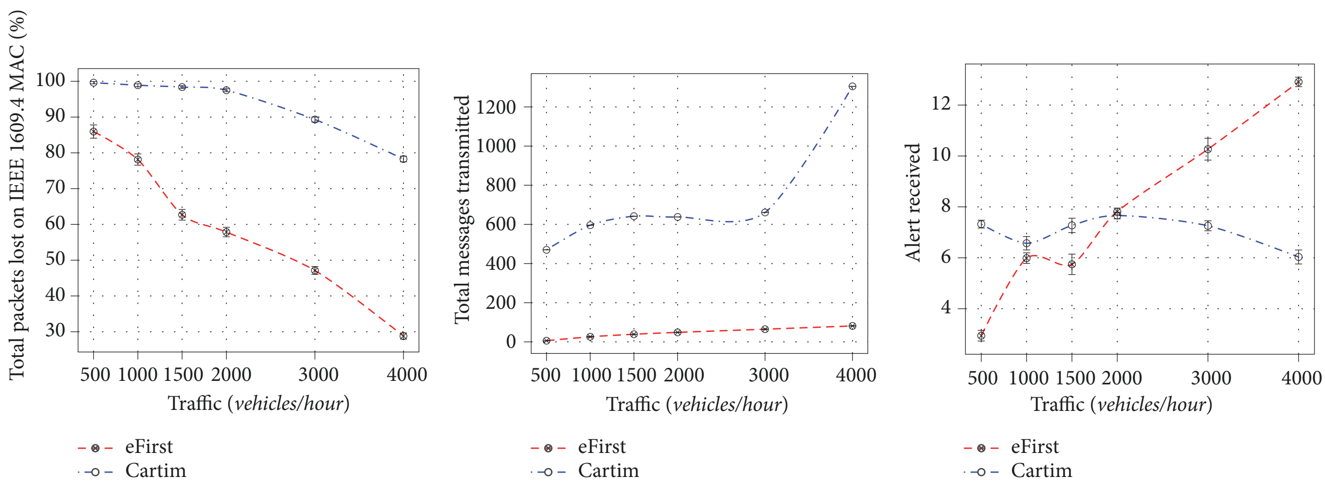
4.4. Curves of Outcome Evaluation. This subsection concentrates the discussions about the *fuzzy* eFIRST approach outcomes for trials on the road or on urban highway routes, presented as response curves for the metrics followed during data dissemination process. An accident among vehicles (Table 3), defined as to compromise the free traffic in one of the directions, generates the demand for the distribution of an alert message related to this event to the local vehicular neighborhood. Allen to this disturbance, the quantity of vehicles produced and lodged on the ordinate axis, which establishes the traffic regime, obeys a normal distribution along the simulation period. The eFIRST adaptive strategy performs with the reasonableness and support from the observations prompted in convergent works [1, 7, 36]. In this way, the identification of behavioral responses, in the evaluation of the eFIRST strategy in highway layout, accommodates the dissemination of an alert message to restrain the congestion situation and then, the curves provided by this approach resort to direct confrontation with the analogous strategy CARTIM [17], for which identical operating conditions are imposed in the simulations.

The characterization of the movement, between the sparse traffic conditions and heavy traffic conditions, receives the consolidation in Figure 7. The curves that represent the percentage of losses related to the IEEE 1609.4 MAC layer (Figure 7(a)), the quantity of alert message retransmissions in Figure 7(b) and, reciprocally, the number of messages with the alert of accident in Figure 7(c) supports a stronger dissemination behavior with the neighborhood intensification, according to the conception expectations of eFIRST. The tendencies registered in the graphics grouped in Figure 7 summarize the propagation in different moments when *ad hoc* networks were formed, from the insufficient establishment of communication links in the initial regime, with approximately 500 vehicles per hour, and its respective consequences, until a more comfortable situation in order to make the alert dissemination persevere, with a more intense traffic. Although distant, Figure 7(a) shows that the profile raised for implementation with eFIRST follows a trend similar to CARTIM, an evaluation in which both present more degradation with scarce traffic. However, unfavorably the dissemination operation with CARTIM in Figure 7(b) implies the retransmission of a number of messages in order of magnitude well above that reported by the eFIRST strategy. An equilibrium region for the two strategies can be identified with traffic of 2000 vehicles in Figure 7(c), segmenting their performance so that, in accordance with this metric, sparse network formation is appropriate for coping with the CARTIM and in the opposite situation, eFIRST responds more properly.

For the records that satisfy the lowest flow of vehicles, arranged on the abscissa in Figure 8(a), the high percentage of lost alert message that is reported on the ordinates axis derives from a sparse network situation, coerced by the unavailability of vehicles in the neighborhood. Out of the transmission signal reach, the vehicles do not distinguish the messenger with the alert data from other background noise. The downward mitigation that occurs on the observation curve (Figure 8(a)) indicates, as expected, the stabilization of these losses with a bigger quantity of active elements, in order to increase the formation of regions with facilitated communication. For the eFIRST, these losses reduce and stabilize with a flow of, approximately, 1500 vehicles per hour inserted in the investigation road, observing the associated confidence intervals. When confronted, both strategies in Figure 8(b) report moderate losses for regions affected by neighborhood deprivation, a natural consequence of the lack of opportunity for dissemination. There is a condition of greater harmony between the strategies in the transition to dense traffic, which is interrupted at the end of the abscissa, around the 4000 vehicles, with the divergence reflected by the CARTIM, in a tendency that characterizes its inability to deal with traffics of that order.

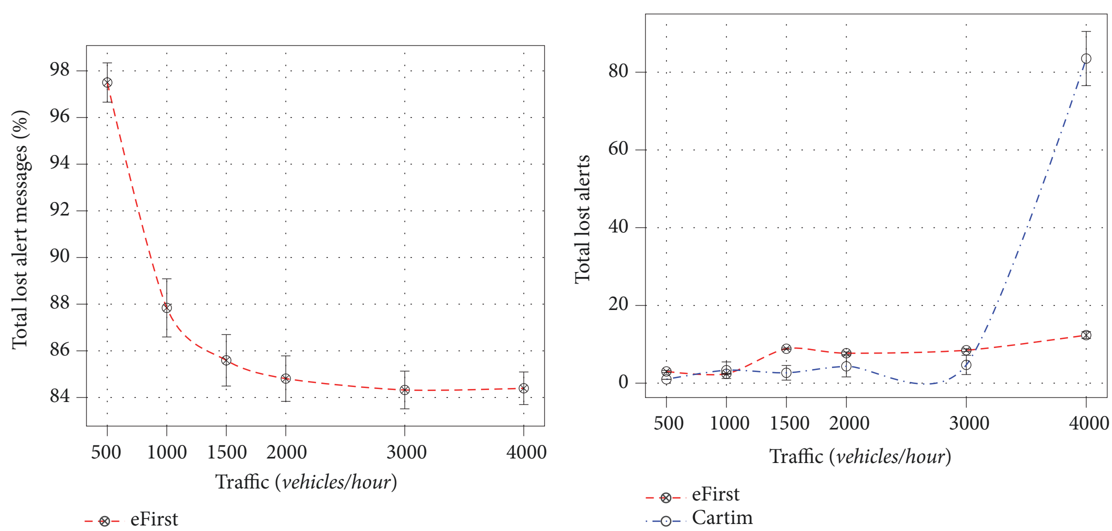
With the profile of the curve for the quantity of collisions verified during data dissemination, in Figure 9, according to the expectations, the inclination is rising and advances in tendencies opposite to what was raised in Figure 8(a). In the absence of a strong strategy for controlling and supporting this process, the increase of collisions, which establishes direct relation with the network degradation, would only be aggravated and would go up to the limits with the saturation of vehicles in the monitored section of the road. However, in the eFIRST, even for the conditions with a higher traffic concentration, with 4000 vehicles per hour, the collision situations are moderate with consistency, and are lodged in the dissemination process, without involving any expressive degradation to communication. The strategies evaluated do not differ from each other in behavior in a significant way for this metric. Even the traffic fluctuations echoing meaningless effect on the CARTIM over the abscissa, the eFIRST also do not include numbers that deserve any attention, even if the highest density (4000 vehicles) is observed, which, with more intensity in CARTIM, reveals the approximation to the operation threshold for both strategies

The coverage curve in Figure 10, provided with the eFIRST strategy, is exposed in a unique behavior, reaching more expressive results for traffic regime, approximately between 1000 and 2000 vehicles per hour. Notably, having only 500 vehicles distributed in the period of one hour, does not contribute for forming communication networks sufficiently



(a) Losses (b) Forwarded alerts (c) Received alerts

Figure 7: Highway, (a) lost packages in the IEEE 1609.4 MAC layer, (b) total quantity of alert messages transmitted, and (c) average number of alerts received per vehicle of interest.



(a) Percentage of lost (b) Number of lost alerts

Figure 8: Highway, (a) percentage of lost alert messages; (b) absolute number of lost alerts.

connected to ensure the propagation. This adversity is also aggravated by the fact that the alert message does not neglect the maximum TTL established (Table 2), besides eFIRST lodging the approximation to the preference zones [19, 36, 37] for all alert message received. In this approach, the vehicle verifies if it appears in the referred region and, accordingly, the dissemination mechanism induces the alert referral only by means of further vehicles, in relation to the transmission range.

The circumstances of the event, which emits the alert, respond to the location coordinates reached at 80 seconds in relation to the initial moment of the route, which is reflected in times of Table 3. The availability of alternative outlets on the road in positions somewhat favorable converges from this dynamic. Thus, a contextualization of the evaluation conditions ensures relevance to the discussion of this metrics, given that the section of the road chosen for the simulations, has approximately ≈ $6250m$ length, formed by three lanes in each direction and with own speed regime, so that the ROI dimension is presented as an unlikely challenge. According to Figure 10, even if it is not absolutely, the inconvenience of the omission of any trigger for moderation or containment echoes the inferred response in an evaluation scenario unfavorable to the dissemination strategy developed in CARTIM. As opposed to eFIRST, which is completely regulated by propagation guidelines that qualify only the vehicles of interest, obfuscated with losses and collisions, the CARTIM seeks minimally to reach some neighborhood, regardless of condition, safeguarded the vehicles that have advanced beyond the incident on the highway.

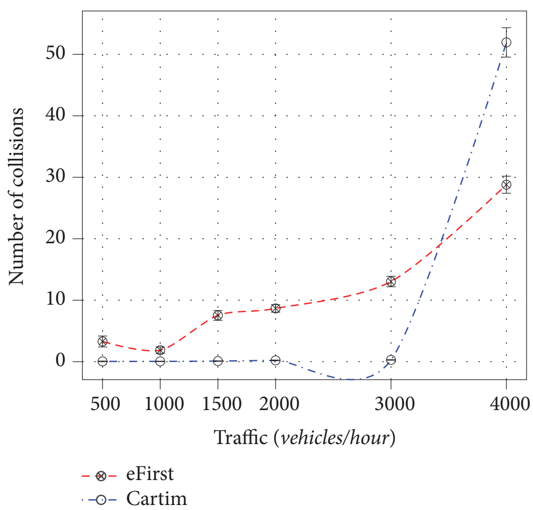


FIGURE 9: Highway, collisions during transmission.

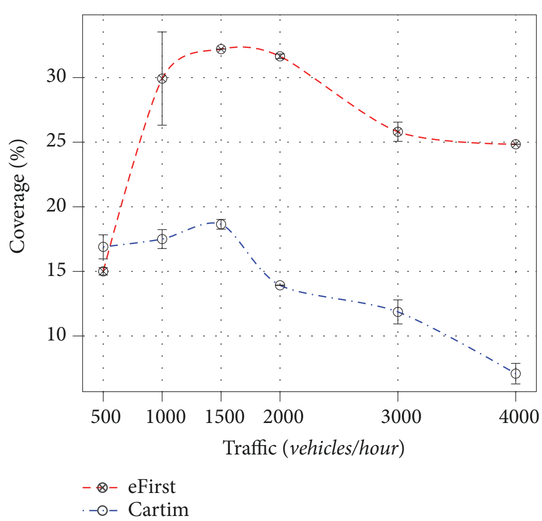


FIGURE 10: Highway, ROI coverage.

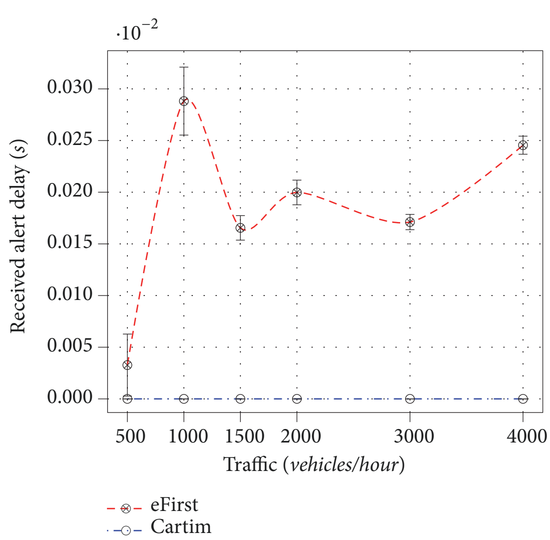


FIGURE 11: Highway, delay verified with the alert receipt (*s*).

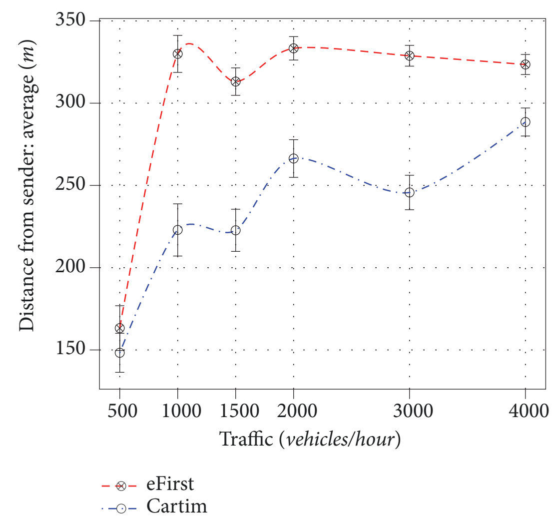


FIGURE 12: Highway, maximum average distance for a hop in V2V communication (*m*).

As a consequence of the alerts propagation promoted among vehicles immediately adjacent, the delay records for the CARTIM are irrelevant. While in the eFIRST, in terms of magnitude order, in Figure 11 all the observations for the delay, noted with the reception of the alert message, are lodged in an interval of satisfactory values for safety warnings. Reaching the biggest number of vehicles in the section of interest of the road, in a sufficiently reduced time, provides to the driver an immediate response before the negative event. Distinctively, for 500 vehicles per hour, which characterizes a sparse network, it is not possible to guarantee the availability of some element within the transmission signal range in a regular position to continue the dissemination in the region. Aiming at minimizing this situation, the vehicles operate with the maximum power for the transmission signal. With a more intense traffic and the identification of a consolidated neighborhood, the eFIRST *fuzzy* strategy provides the proper adaptation for the transmission signal power, aiming at avoiding collisions. The transition between the sparse and heavy network conditions reveals light evidence for traffic with 1000 vehicles per hour in Figure 11, given the disagreement with the delay in heavier traffic.

The different origins (vehicles) responsible for the continuity of alert dissemination process, contribute with leaps of average distance described in the curve in Figure 12. The regimes of intense traffic, ensured by the prerogative of greater availability of V2V communication, in eFIRST respond according to the mechanism that induces the forwarding of alerts through vehicles with a further location [37], in relation to an initial transmission reach. In other situation, with road without neighborhood to increase the formation of *ad hoc* networks, the retransmission is delegated to scarce vehicles that circumstantially expose themselves to the region with the signal reception. Thus, further distances are compromised in both CARTIM and eFIRST strategies, as a consequence of poor opportunities in positions convenient for transmission.

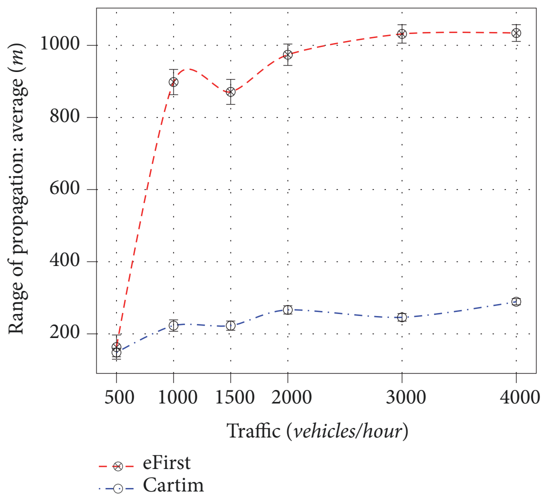


FIGURE 13: Highway, distance of the alert message displacement in the section of the road (m).

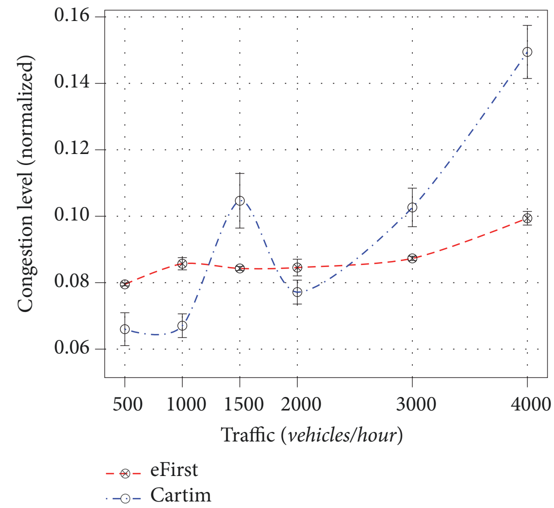


FIGURE 14: Highway, *fuzzy* response for the inferred level of congestion.

Native to the strategy, another approach that, in eFIRST, supports the behavior in favor of hops in greater distances, results from the power adaptations of the transmission signal in *fuzzy* inference for the local traffic.

Available after the generation of a sole alert message, triggered in the vehicles involved in the road disturbance, Figure 13 calls the attention for the dissemination convergence over a neighborhood located at $\approx$ 1000m, adopting eFIRST strategy as the one of greater interest. This extension implies $\approx$ 1/6 of the section observed, even with the traffic considered between light and moderate, and in due course, it coincides with the information incited by the coverage curve in Figure 10. In a complementary manner, it also justifies a satisfactory dissemination, although the delivery is consolidated far from the ideal convergence, with 100% of the expected vehicles (Section 4.3). Although supported on a conservative approach, the eFIRST *fuzzy* adaptation strategy, for the transmission signal power inferred directly from the congestion response, extracts property enough from the traffic regime and conducts the alert to sections of the road that offer reaction conditions relevant for drivers. As an adversity, in the lack of vehicles in the neighborhood, the eFIRST *fuzzy* strategy and CARTIM react in a similar and presumable way with an innocuous effect on the traffic unavailability. This omission is easily minimized with the simple repetition of alert message in a controlled period in order to support the dissemination, protecting the transmission channels, though. As a particularity, the distinct discordance to the extension of the alert message displacement, with a notable advantage for the eFIRST strategy, results from the conciliation between the selection of appropriate vehicles in the preference zones and the adaptive *fuzzy* regulation for the transmission power, while the CARTIM strategy, without more elaborate dynamic artifacts, operates at disadvantage, since it is limited to adjacent neighbors only.

The curve for the identification of congestion, contextualized in Figure 14, summarizes the *fuzzy* evaluation for the instantaneous condition of traffic in the observation region of the road. The own speed reading and the evidence of vehicle saturation, measured by means of neighborhood records, feed the *fuzzy* inference engine in eFIRST strategy. The conclusion obtained with the defuzzification (see (2)) rescues, from the evaluation of the input association rules, the response in Figure 14 regulated to the interval $[0, 0.2]$ for the congestion level. The event, which interrupts the lane in one direction, effectively reflects itself in a complete congestion in maximum density conditions of traffic, but there are also precarious traffic signals even with the reduced insertion of vehicles in the period of evaluation. For this last verification, the disturbance is due to the inexistence of immediate options for the reception of the alert that allows to by-pass, through alternative route, the compromised route. The initiative of the accident, in any case, induces congestion in some scale to any situation with established traffic, although the dynamics of the strategy provides enough control and reaction conditions in extension (Figure 13) in order to mitigate the inconvenience, as elicited in implementations with eFIRST.

With singular interactions due to a neighborhood lacking reasonable traffic, the transmission signal power remains prominent, looking forward to giving some persistence to the dissemination. Moreover, the high mobility of vehicles and the short-range transmissions, would intensify unstable topology networks subject to disconnections. In relation to these factors, there is still the effect of fluctuations in the nodes density that integrate any vehicular *ad hoc* network. So, the traffic incidence, in a higher volume, stimulates the *fuzzy* inference engine in order to intervene as the adaptation mechanism, with the advantage of adjusting the transmission power. The power movement can be verified by means of the curve represented in Figure 15, with the declination that exposes the tendency of value reduction of this metrics. The express restraint of the intervention delegated to the *fuzzy* strategy, about the signal power manifested in the alert transmission, adds resistance to the modifications in a very disproportional order. The modest variation interval,

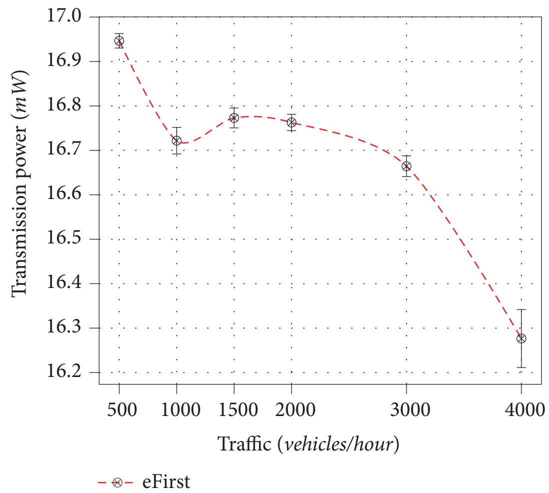


FIGURE 15: Highway, adjustment of the transmission signal power as a function of the traffic conditions observed.

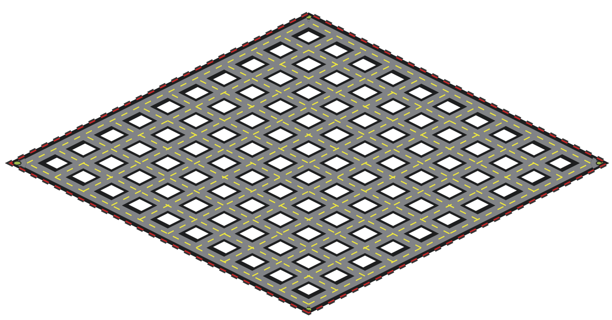


FIGURE 16: Urban layout in Manhattan *grid*.

registered in mW, shows the propagation of a sole alert in an interval of time sufficient to reach far regions (Figure 13), in a quite reduced neighborhood and with traffic not impacted by the affected road.

The urban layout (Figure 16) also receives similar attention, with evaluations performed based on a realistic mobility model, an indispensable feature to ensure coherent and accurate outcomes when performing data dissemination algorithms. In this task, the urban mobility simulator SUMO [32] provides consistent mobility models that consider the road conditions, the conditions of speed in traffic, the vehicle and obstacles density, for example. The urban layout is supported in a typical *Manhattan* scenario, characterized by the advanced structure of a grid-shaped topology, as represented in Figure 16. The region is sized in a plan a little bigger than 5000x5000m^2 and segmented in even blocks with extension of approximately 500x500m^2, where the intersections on the map represent the crossroads, with no traffic light.

The vehicular traffic used in the evaluations is randomly generated and is composed according to what is described in Section 4.1, homogenizing light, intermediate and heavy vehicles. In order to ensure an adequate variation in nodes density and speed, as well as to preserve measurements free of interferences, an interval of 600 seconds of traffic is applied in each simulation. This time is considered long enough to evaluate the transmission protocols during the dissemination heuristics performance. From this period, the records corresponding to 10 initial seconds of *warm up* are segregated and discarded from the performance interval of each simulation. For the communication in the physical and data link layers, the vehicles with embedded *software* benefit from the IEEE 802.11p standard and include a *simple obstacle shadowing* propagation model for the radio signal. Each vehicle in the scenario respects a route with minimum distance of 4.5km, reserving the right to a random destiny.

With support from previous works ([6, 7, 35]), where situations of deterioration are identified in the performance of several dissemination strategies as a consequence of vehicular density increase, in the evaluations herein five distinct sets of traffic are explored, with extent to achieve comfortable conditions and extend the observation to critical concentrations of vehicles. Thus, an interval of vehicles sufficient to integrate the densities signaled in the saturation of dissemination strategies is assumed, reaching the context of vehicle saturation for the evaluation scenario. This prudence is developed to meet the purpose of transiting from sparse networks to completely connected networks, what can be provided with traffic densities ranging from 250, 500, 1000, 1250, and 1500 vehicles each and with vehicles that develop their trajectory on the horizontal and vertical routes of the grid model in Figure 16.

During evaluations, the induction of congestion situation happens at 150 seconds from the moment of departure, when any vehicle obstructs a road by abruptly suspending its movement. This episode conveniently meets the specific purpose of originating a single message with a warning alert, to elicit the implementation of the dissemination strategy. In continuity, the vehicle arbitrarily transmits that event to the surrounding areas. Thus, by obstructing the traffic by instigating a congestion, it also triggers the process of dissemination to all vehicles in the region of interest (ROI).

In order to characterize the behavior of the eFIRST adaptive *fuzzy* strategy in urban trajectory, the results produced as a result of the development of the dissemination of an alert message for imminent congestion are presented and discussed, in accordance with this described situation. Based on reasonableness, previously explored strategies such as AID, DBRS and SRD [6, 7, 36] are released from this exposure, since the vehicular traffic interval applied in this study is too unfavorable, restricting their reach. For a fair equivalence, the curves constructed with the eFIRST adaptive strategy are compared to the results obtained with the implantation of the approach performed by the CARTIM algorithm [17], in situations of viable contrast and with the same simulation conditions.

The stable trend externalized through the response to the congestion level, defined for the interval $[0, 1]$ in Figure 17, regulates the cooperative behavior pursued with the application of the eFIRST adaptive *fuzzy* strategy. The *fuzzy* inference engine shows itself as robust enough when consistently facing the local obstruction of a road, due to the fact that it provides alternatives, clears and balances the traffic in the compromised region. During all the vehicular density

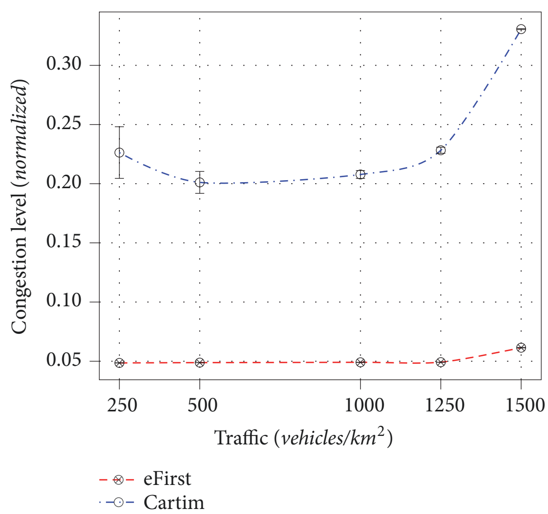


FIGURE 17: Urban, *fuzzy* response for the congestion level.

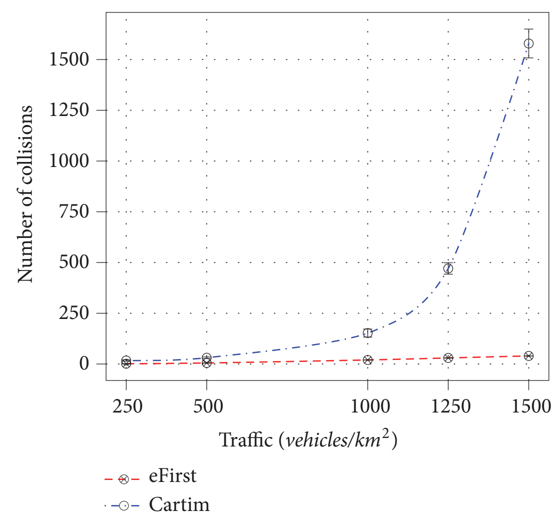


FIGURE 18: Urban, *fuzzy* response for the quantity of collisions during transmission.

interval evaluated, the eFIRST strategy supports satisfactory conditions of traffic and preserves ephemeral values for the levels of congestions detected with cumulative participation of the neighborhood, without incurring any expression errors. With less intensity than the CARTIM strategy, inevitably at the saturation limit of vehicles for the described scenario, the upward movement in the congestion curve becomes accessible, which also implies an observation threshold for any approach.

The adaptive nature of the eFIRST strategy is positively reflected in the collaborative regulation of recorded congestion (Figure 17), indifferent to the increase in vehicular density and, consequently, the number of collisions determined during the alert dissemination is kept minimized during all the interval of observation in Figure 18. In a much less comfortable circumstance, the opposition CARTIM strategy does not follow this regular behavior, with persuasive evidence of incapacity to accommodate a more intense vehicular traffic, clearly elicits an upward trend to unrestrained imbalance for increased collisions. Without support to the dissemination process, the increase in collisions establishes immediate relation with the degradation of the network. In the eFIRST, however, even for the peripheral records with the highest concentration of traffic arranged on the abscissa of Figure 18, the collision readings are moderate, consistent to preserve the integrity of the communication channels.

The eFIRST strategy signals adhesion to a bold conduct, essentially in response to a native feature of operation. The eFIRST promotes the associated dissemination of the warning for the event (obstructed road) to the vehicles of interest, together with the orientation to perform the correction on the route, when a palliative solution such as a turning or alternative itinerary is accessible. The coverage metrics outlined on the flat area of Figure 19 catalyzes and corroborates this perception.

A significant segment of the convenient vehicles, which integrate the impacted route, are stimulated to implement the eFIRST adaptive response strategy. In Figure 19 it is possible

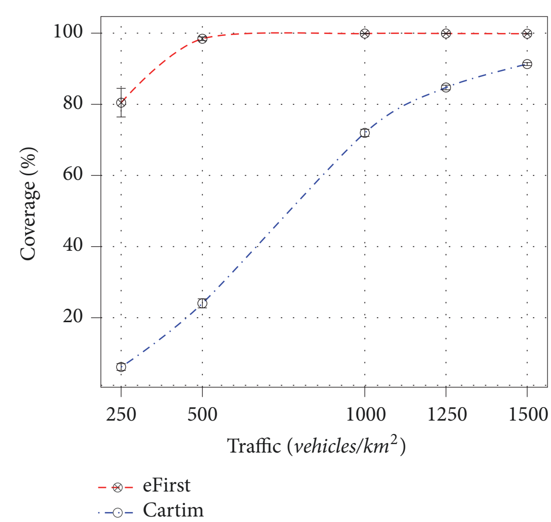


FIGURE 19: Urban, *fuzzy* response for the vehicles coverage in the neighborhood.

to note that there is an expressive impact on the coverage outcomes for the initial traffic regimes, where a little more than 80% of the 250 vehicles in the urban scenario receive the information about the incident on the road. This range of coverage intensifies the implementation of the strategy, preceding the incident and providing sufficient response time in order for the vehicles in conditions to show a reaction. In the CARTIM strategy, the coverage curve trajectory evolves in a less accentuated profile due to the constraint imposed by the use of thresholds that transform local congestion estimates into effective cooperative traffic alert messages (CTA).

A particularity shared by both, CARTIM and eFIRST, refers to how to accommodate the level of congestion of a route as a precursor to dynamically regulate the alert dissemination, which ceases the propagation with signs of discontinuation of severe congestion conditions. More aggressively, the latter is still protected with more moderation, since the alert message also does not violate the established TTL.

Balancing the purpose of aggregating broad coverage and keeping the dissemination delay low, despite the fluctuations in the density of the nodes integrating the VANET, eFIRST optimally extends the approach with zones of preference, initially elaborated in Villas et al. [19] and later also adopted by Meneguette et al. [36]. For each message received, according to this approach, the vehicle verifies if it is in the zone of relevance, which implies enough criteria to decide whether to discard it or not. The low delay forwarding, coming from the vehicles that meet the referred principles, contributes to mitigate the *broadcast storm* problem, since they support the cancellation of the equivalent transmissions by the other vehicles. The suppression mechanism established with preference zones is consolidated by reducing unnecessary redundant transmissions, and also by stimulating retransmissions on vehicles further from the origin of the alert. The dynamics in the dissemination heuristic is based on this assertion. Then, the immediate consequence of this approach dominates the typical response of eFIRST, which remains concentrated in distant regions around 450*m* as shown in Figure 20, in relation to CARTIM which, without analogous artifice, operates in a disadvantaged and insistent manner, notably resigned to the vicinity of 50*m*.

With intervals statistically equivalent to the average range of propagation, the effect of distinct vehicular densities on this metrics can be inferred as innocuous, ruled by eFIRST protocol that reacts indifferently to these variations during simulations. In the strategy developed by eFIRST, the difference in the range of propagation is a consequence of the artifice used to ensure wide coverage in low traffic density (Figure 19). Outstanding messages, preserved as a network partition is detected, are retransmitted by vehicles that receive a *beacon*. It works as a trigger; the *beacon* triggers this operation mechanism that conveniently takes advantage of the elements within range in order to perpetuate the dissemination process. Unquestionably, this strategy can present delays in sparse network, but it also provides wider coverage with balanced losses.

The relationship of interest in the propagation process that is established between the number of messages transmitted and the quantity actually received by the vehicles can be measured with the aid of Figure 21. The constructions of the curves for both heuristics in the figure assure the evidence of upward variations occurring in the delivery rate, expressively in function of the different traffic regimes, and correlatively in all the simulations carried out, but with a steeper slope in the behavior described by the implementation of the eFIRST. The respective slopes reflect an initial difference of about 12.5% in performance with the partitioned network variation to approximately 25% in dense traffic conditions.

The eFIRST adaptive response strategy responds with better relation to delivery rate in the simulations considered, followed in a very distant interval by the observations generated with the CARTIM, which presents more modest and discrepant results. For evaluations characterized by the formation of sparse networks, where the traffic involving 250 and 500 vehicles is part of the environment, without an adequate adjustment, the strategy developed in CARTIM implies a higher implementation cost, with a minor delivery result and with a penalty in the coverage, indicated by Figure 19. In a more comfortable position, in the eFIRST that uses a more responsive approach, the autonomy for adaptive regulation developed mainly on the transmission power, provides a satisfactory and substantial use of the alerts generated. The aggregation of the embedded *fuzzy* inference engine, responsible for the continuous evaluation of the available neighborhood, supports the adequacy of the operational parameters of the eFIRST strategy, in order to guarantee a better use response in the delivery rate. This fact reflected in the evaluation curve of this metric (Figure 21), which presents a tendency of stabilization in the region of a little over 30% for the highest vehicular densities evaluated.

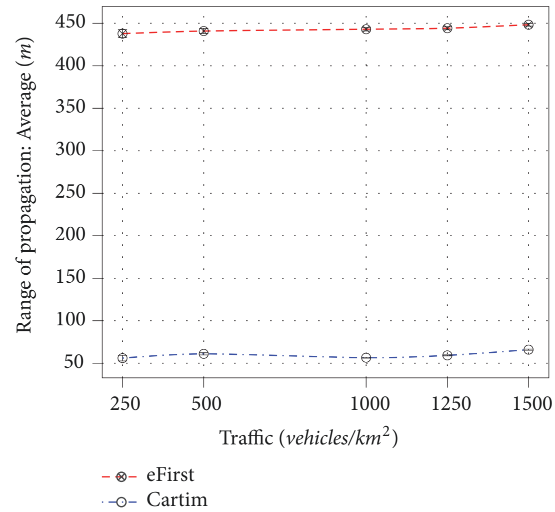


FIGURE 20: Urban, *fuzzy* response for propagation distance of the alert message in urban layout.

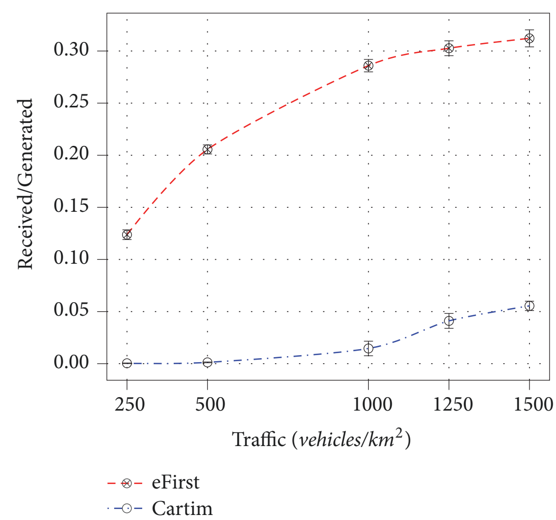


FIGURE 21: Urban, *fuzzy* response for the use relation between alerts generated and actually received.

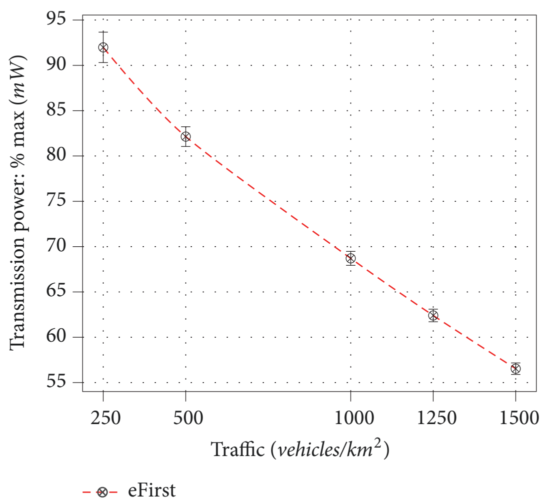


FIGURE 22: Urban, *fuzzy* response for the adjustment of the average transmission power.

The autonomous adequacy performed on the operating parameters involved in the transmission power adjustment, which provide the downward slope characterization in Figure 22, reflects the direct relationship established with (4) and mapped in Figure 6. The local speed and the congestion level identified in the neighborhood supply the *fuzzy* inference in the eFIRST strategy, the consequent regulation occurs on the beacons of the maximum power of the admitted transmission signal. Thus, in the regular incidence conditions of network partitions, there is the pursuit of adjustments for transmission power that, although oscillating around an average value, also accommodate larger ranges, as an inherent reaction to eFIRST. At the opposite end, the solid network formations, with wide neighborhood, allow the immediate harmonization of the adjustments that stimulate lower transmission power, to accommodate the intensification of the retransmission offer. The attenuation intensity derived from the consequent in the eFIRST adaptive response strategy and reflected as a percentage of the maximum transmission power in Figure 22, converges with autonomy without supervision, however conservative intervals are provided to promote the adequacy reaction in the power response. Thus, even at high vehicular densities, it remains higher than 55% of the established power range, in analogy to that previously discussed for the highway layout with Figure 15.

5. Final Considerations

The elaboration of strategies for disseminating data efficiently, in different working conditions in VANET, is still considered as a devious and complex research itinerary. The distinct adversities require attention to deal, simultaneously, with challenges with delay restrictions, communication overload restrictions, instable topology, mobility, frequent disconnections, high vehicular density, and, at the other end, insufficient vehicular traffic.

In the contextualized study, protocols were referred in order to perform the message dissemination and also to identify congestion, with responses suitable to deal with isolated problems, but due to their behavior, showed the evident need to add autonomy to their own approaches [1, 17, 18]. Thus, the whole development of *fuzzy*eFIRST strategy discussed keeps to a tendency of wider approaches, with adjustments, which consider different sources of local and contextualized information and which commits itself with problems from different origin. The process of alert dissemination adopts response assumptions consolidated on previous opportunities [7, 19, 35, 36], but without abandoning precaution, it trusts unconditionally the cooperative approach and particularly, the *fuzzy* system embedded in each vehicle, which associates the respective capacity of adaptation provided by means of the inference rules basis.

The traffic regimes, either for unexpected situation or for traffic in regular conditions are dealt with according to the linguistic terms associated in rules and then, mapped in the response domain for the congestion level. Therefore, the system integrates all the decision mechanism, which provides individual autonomy for the vehicles. Different from what is verified with strategies based on artificial neural network (ANN) [1], once the training for determining the importance of the synapses is workable, for sure it will compromise the strategy development. As the *ad hoc* networks topology experiments intense dynamics, the vehicle is penalized with a limited interval of time to obtain the traffic records, process and retransmit an alert. In its turn, the convergence time of the ANN learning proceeding and the processing demand are aspects that become obstacles to the mechanism of embedded nonsupervised learning and force the training implementation in advance.

6. Conclusion

This paper has described the eFIRST, an adaptive strategy, based on an autonomous *fuzzy* system, which uses V2V communications to cooperatively share context information and information about identification records of local neighborhood. Embedded in each vehicle, this strategy provides a solution to detect the current congestion situation in a compromised section of the road. Therefore, the metrics identifies the traffic conditions in the regions near the vehicle and then returns this information supporting a proportional response in power for the transmission signal.

The results recorded for the eFIRST adaptive strategy during the simulations show how the elaborated solution leads to minimized delays, with low communication overload, besides relevantly mapping the congest levels and efficiently providing the event coverage to satisfactory propagation distances inside the area of interest for the dissemination. Promptly, the alert finds vehicles far from the traffic accident located at nearly 1/6 from the evaluated extension. In accordance with the intelligent protocols, this evaluation contributes providing grants for the ratification of fuzzy approximation as an adaptive strategy to fluctuations in vehicular density in different tracings and traffic regimes.

Future works are motivated by the perspective of investigating the contributions with the estimate of local density, according to described in [18], and the planned insertion of *Road Side Unit* (RSU) in the evaluated region.

Data Availability

The vehicular communication raw data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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