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Application Reliability Analysis Of Density-aware Congestion Control In VANETs

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Abstract—Vehicle to vehicle wireless communication is regarded as a key component for improving safety on the road. There has been increasing interest in addressing the scalability issue with a large literature that has been proposed to mitigate packet congestion problem. LIMERIC is a well-known congestion control protocol which was adopted by the current ETSI standardization bodies to be applied in the future deployment of VANETs. In this study, the objective is to evaluate the application reliability of using the density information in this problem. In this paper, we compare LIMERIC to LIMERIC-D to provide an answer to the question whether density estimation can improve the performance of the congestion control strategies regarding application reliability. The simulation results show the effectiveness of the use of the density information to improve the performance of congestion control protocols in VANETs.

I. INTRODUCTION

Within the next few years, Vehicular Ad-hoc Networks (VANETs) is set to become an important component in Intelligent Transportation Systems. This technology would play a major role in improving road security through promising safety applications and protocols [1].

Applications of VANETs have different requirements on communication [2]. In contrast to comfort applications, safety applications have a strict delay, minimum reception probability, and transmission range constraints. Dedicated short-range communication (DSRC) is proposed to support these applications. This band consists of seven channels of 10MHz that includes one control channel (CCH) and six other channels (SCHs) [3]. A CCH is used exclusively for road safety messages and service announcements, while the other channels are service channels (SCH).

The periodic exchange of beacons or CAMs (Cooperative Awareness Messages) in CCH would help each vehicle to support cooperative applications, including road safety applications. These beacons carry status information about the vehicle position, its speed, and direction safety [4]. For the well-functioning of the safety applications, a set of strict requirements regarding beacon reception frequency and latency have to be met. These requirements can change from an application to another, and they are strongly depended on the environmental conditions of vehicles as well [5]. In a dense network, a large number of vehicles broadcast beacons messages at a high frequency, the CCH channel will easily congest. In this conditions, achieving a high QoS required by the safety applications is still a significant challenge for the radio channel

available for VANETs [6]. Therefore, the CCH can rapidly become congested if no congestion control policies are applied [7], [8]. This crucial issue makes congestion control an active research area in VANETs. Many congestion control protocols have been proposed to ensure effective control of the radio channel [7], [8]. These protocols mainly aim to reduce packet loss rate with equitable access to the radio channel for the vehicles.

LIMERIC [9] is a well-known congestion control protocol adopted by the current ETSI standardization process. LIMERIC-D [10] is an enhanced version of LIMERIC using the density estimation. LIMERIC-D uses SLDE module to be more adaptive to traffic state. SLDE permits to estimate the number of neighbors accurately within the maximum transmission range with a minimum amount of overhead while using regular beacons, the communication range could be reduced by up to 90% in a high-density scenario [6].

In this paper, we compare LIMERIC [9] to LIMERIC-D [10] to provide an answer to the question whether density estimation can improve the performance of the congestion control strategies regarding application reliability. To evaluate the protocols based on the requirements of safety applications, we use widely accepted metrics for the evaluation of the application reliability: awareness range (AR) [11], awareness probability (AP) [11], and Inter-Reception Time (IRT) [12].

The main contributions of the paper are:

- We introduce SLDE, a density estimation strategy for VANETs.
- We show that the density information could be used to enhance the functioning of LIMERIC.
- We perform simulations to analyze the application reliability of LIMERIC and compare it with LIMERIC-D (an enhanced version of LIMERIC).

The remainder of this paper is organized as follows: Section II summarizes the most prominent research papers regarding message-rate congestion control strategies in VANETs. LIMERIC-D is presented in Section III. Section IV describes Segment-based Local Density Estimation(SLDE). The performance analysis and the evaluation of LIMERIC and LIMERIC-D are presented in Section V. Finally, the conclusion is given in Section VI.

II. RELATED WORK

Ensuring high quality of service while ensuring fairness are central concepts in congestion control VANETs. Several methods have been proposed to support this concept for congestion control by adjusting the transmission power, and messaging rate. In this paper, we are interested messaging rate since it is adopted by the standardization bodies. In [13] the authors proposed a protocol, called Adaptive Traffic Beacon (ATB), to disseminate messages efficiently through an adaptive beaconing. The beaconing rate is adapted based on the following set of metrics: packet collisions, Signal-to-Noise, and the message utility. The authors in [7] proposed a distribution strategy to control channel based on the adjustment of the vehicle's transmission power. The latter is continuously adjusted based on some specific information such as the detected neighboring vehicles and the estimated carrier sensing range. The authors in [14] studied the negative impacts of radio shadowing generated due to stationary and mobile obstacles. They also showed how these impacts could be beneficial to effectively control the channel load via a dynamic beaconing. For this issue, they proposed a dynamic beaconing protocol, called DynB. This latter uses two control variables: the channel busy time (CBT) and the number of neighbors based on the received beacons. These variables are used to control the beacon interval to make it as close as possible to the desired value. The authors in [8] proposed a congestion control protocol called PULSAR that adapts the transmission of beacons according to the technique known as Additive Increase Multiplicative Decrease (AIMD). This technique uses the channel busy ratio (CBR) locally calculated and the maximum CBR calculated by the neighboring vehicles. The beaconing rate is adapted according to the maximum CBR between the local and one hop CBRs. If the resulting CBR value is greater than CBR_{max} , then the beaconing rate frequency is decreased by a multiplicative factor. Otherwise, the rate is increased by an additive factor. The multiplicative and additive factors are modified based on whether the beaconing rate of the vehicle is above or below beaconing rates of the neighboring vehicles.

A. LIMERIC

Linear MESSAGE Rate Integrated Control (LIMERIC) linearly adapts the beaconing rate of each vehicle based on the frequently measured channel load and a target channel load [9]. The beaconing rate of a vehicle j at a specific time t is calculated using the following equation:

$$r_j(t) = (1 - \alpha)r_j(t - 1) + \beta(r_g - r(t - 1)) \quad (1)$$

Where r_g is overall target beaconing rate, $r(t - 1)$ is the measured overall beaconing rate by the vehicle in the previous time window, $\alpha = 0.1$ and $\beta = 1/150$ are system parameters. Practically, the CBR is used instead of the channel load. In the above equation, r_g and $r(t - 1)$ will be replaced by target channel busy ratio (CBR_t) and the measured channel busy ratio CBR_c , respectively.

The current ETSI standardization [15], [5] process adopted a congestion control protocol that combines LIMERIC [8] and PULSAR [9]. In fact, the linear equation of LIMERIC is used for controlling the congestion based on PULSAR's CBR information exchange. Recently INTERN (INTEgRation of congestion and awareness control) protocol is proposed [16]. The main goal INTERN is to manage the transmission parameters according to the requirements of the applications. This protocol is based on LIMERIC, PULSAR, and the awareness control design policy proposed in [17].

III. LIMERIC-D

One of the most influential parameters in LIMERIC is the targeted level of channel busy time (CBT_t). In LIMERIC-D [10], we have adapted the CBT_t to reach the maximum usage of the available bandwidth. For this goal, the CBT_t will be adapted by a calculated a factor (delta) that satisfies the following equation:

$$\begin{aligned} CBT_c &= CBT_t \\ CBT_t \times \frac{\beta K}{\alpha + \beta K} * \delta &= CBT_t \\ \delta &= \frac{\alpha + \beta K}{\beta K} \\ CBT_c &= CBT'_t * \frac{\beta K}{\alpha + \beta K} \\ CBT'_t &= CBT_t \times \delta \end{aligned} \quad (2)$$

The new calculated targeted level of channel busy time (CBT'_t) is used instead of CBT_t to ensure more efficient channel utilization. Therefore, the adaptation of the beaconing rate of a vehicle i at a specific time t is calculated using the following equations:

$$r_i(t) = (1 - \alpha)r_i(t - 1) + \beta(CBT'_t - CBT_c) \quad (3)$$

$$r_i(t) = (1 - \alpha)r_i(t - 1) + \beta(CBT_t \times \frac{\alpha + \beta K}{\beta K} - CBT_c) \quad (4)$$

The estimated number of vehicles is calculated using Segment-based Local Density Estimation (SLDE) which is presented in the next section.

IV. SEGMENTED LOCAL DENSITY INFORMATION (SLDE)

In this section, we introduce Segment-based Local Density Estimation (SLDE) density estimation strategy [18]. Within the maximum transmission range, SLDE allows VANETs applications to collect an accurate estimation of the number of neighbors with minimum overhead.

In order to facilitate reading, we describe the essentials of the SLDE strategy through the scenario shown in Figure 1. N_0 is the estimator vehicle (EV). The N_{-2} , N_{-1} , N_1 and N_2 are the reference vehicles (RVs). Each RV has a specific color to identify its actions and information. EV uses all received density histograms (DHs). The density histogram (DH) is an array that contains the densities of the segments within the

maximum transmission range of a specific vehicle. For each segment in EVs range, EV uses the density of the nearest RV to the center of that segment. It is important to note that there are two ways of receiving the density segments information either directly (solid lines) or included in other DH (dashed lines). This is because the received DHs are sent through the same estimation process. Therefore, the source of the density information of one segment can be computed using another RV. For example, the density of segment S_{i+2} estimated by N_2 can be received directly or included in the DH of N_1 .

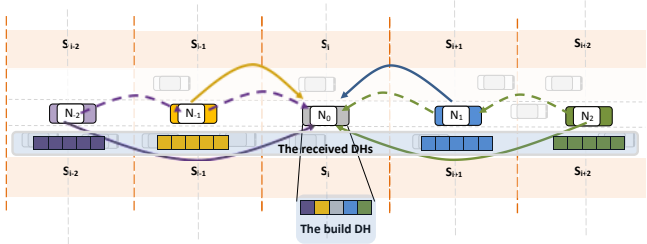


Fig. 1: Simple scenario shows the functioning of SLDE

We describe, in the following, the three principal components of SLDE: **fixed segments**, **data fusion**, and **density propagation**.

In SLDE, vehicles use preloaded digital maps to find the identity of each segment. Through these maps, each segment has a unique identity that is usable by all vehicles. This allows for more accurate density estimation by using the shared information directly. As results, SLDE permits lower estimation errors.

The fusion of the received density information is based on selecting the most accurate information for each segment in the maximum transmission range. This is done during density histogram (DH) construction. The nearest Reference Vehicle (RV) to the center has a higher probability of detecting the vehicles in that segment. This is why the estimator vehicle uses the valid data of the nearest Reference Vehicle (RV) for each segment. In the case of no reception of DH that has better accuracy, the estimator vehicle will use the received normal beacons. Therefore, after the construction DH, the estimator vehicle will have accurate densities estimation for the different segments.

The density propagation is an important element to make the accurate density information available in a short time. In SLDE, there are two ways to start the propagation of density information. First, when a vehicle passes through the center of a segment; second, when a vehicle receives a DH.

To ensure more accuracy in the density estimation, SLDE uses a segment to segment propagation when it is possible. For that, the next RV is the nearest vehicle to the center of next segment. SLDE use two methods to select the next RV. First, each vehicle receiving DH sets a timer that corresponds to the distance to the center of the segment (TimeToWait). After the reception of DH, and once the timer expires, the corresponding vehicle responds by sending its DH if no DH

is shared yet from its segment. After sharing new DH by the selected RV, the timers of all other vehicles of the same segment are canceled, and their responses are suppressed. The equation 5 is used to calculate *TimeToWait* period:

$$TimeToWait = \frac{Dx, segment}{SL/2} * LTEB \quad (5)$$

Where:

Dx, segment: The distance between the vehicle and the center of its segment (m).

SL: Segment length (m).

*LT**EB*: Lifetime of an extended beacon(s).

The time to wait is calculated to ensure that the nearest vehicle to the center waits for less (Equation 5). The smallest value is 0 when the vehicle is in the center ($Dx, segment = 0$). The greatest value is the lifetime of an extended beacon when the vehicle is on the border of a specific segment ($Dx, segment = SL/2$). The other method is by including in DH the next three RVs (RV_1, RV_2, RV_3) in the next segment. This information is to ensure that DH is reconstructed in each segment. This permits to increase the accuracy by including the accurate information of the corresponding RVs. The RVs are sorted based on their distance to target segment center to make the delay time as short as possible. The *TimeToWait* calculation is changed to make the chosen RV wait less, and the vehicles outside the target segment wait more (Algorithm 1).

Algorithm 1: SLDE TimetoWait calculation

```

Data: DH of  $RV_j$  with  $RV_1, RV_2$  and  $RV_3$ 
if  $Segment(RV_i) \neq NextSegment(RV_j)$  then
    TimetoWait  $\leftarrow$  TimetoWait + ( $|Segment(RV_i) -$ 
         $Segment(RV_j)| * \alpha$ );
else
    if  $i = RV_1$  then
        TimetoWait  $\leftarrow$  0;
    else
        if  $i = RV_2$  then
            TimetoWait  $\leftarrow$  TimetoWait*0.3;
        else
            if  $i = RV_3$  then
                TimetoWait  $\leftarrow$  TimetoWait*0.6;
            end
        end
    end
end

```

The density information is still valid when received within ΔT period. If no DH is received in this period, the vehicle of that segment sets a timer that corresponds to the distance to the center of the segment (TimeToWait); the same process when they receive DH. Additionally, if the sending RV sent an extended beacon more accurate than the last sent extended beacon, it will be sent even if the density information still valid. This is to propagate the accurate extended beacons as fast as possible to make their information available before becoming outdated.

V. PERFORMANCE EVALUATION

In this section, we carry out a simulation study for evaluation of application reliability of LIMERIC and LIMERIC-D using three main metrics: awareness range (AR) [11], awareness probability (AP) [11], and Inter-Reception Time (IRT) [12]. The simulations are performed using ns-2.35 network simulator [19] and an overhauled Mac PHY-model is used [20]. This model is adapted to the characteristics of IEEE 802.11p, which is used in the inter-vehicle communications. In addition, the probabilistic Nakagami propagation model is used to ensure more realistic simulations. The parameters of this simulation are listed in Table I.

The simulation scenario consists of a three-lane highway of 1 km in length. The highway is straight without entrances or exists. The metrics are evaluated by the vehicles situated in the observation zone Fig. 2.

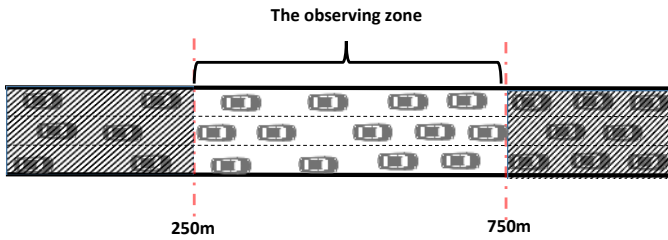


Fig. 2: Simulation scenario

The scenarios we use for this evaluation simulates traffic of varying density: 150, 200, and 250 vehicles per km, collecting data points from up to 20 independent runs for each scenario to ensure the statistical significance of results.

Parameter	Value
Frequency	5.9 GHz
Data rate	6 Mbps
Carrier Sense Threshold	-96 dBm
SIFS time	32 us
Slot time	16 us
Preamble length	40 us
PLCP header length	8 us
Noise floor	-99 dBm
SINR for preamble capture	4 dB
SINR for frame body capture	10 dB
MAC	802.11P
Packet size	400 byte
Beacon generation	10 beacons/s
Radio propagation	Nakagami
Number of vehicles	150, 200, 250
Road length	1 km
Simulation time:	20 seconds
beaconing adapting interval	0.2 second
α	0.1
β	1/150
Segment size	100m
ΔT	0.9 second

TABLE I: Simulation configuration.

In the following, we start first by the evaluation of both protocols in terms of beaconing rate and CBR exploiting. Then we evaluate the impact of this finding on application reliability using .

A. Message Rate and CBR evaluation

Considering different vehicular densities, Fig. 3 shows the mean beaconing rate of all vehicle in the observing zone for LIMERIC and LIMERIC-D in each iteration. As it can be observed, LIMERIC-D allows better beaconing rate in different density scenarios. As it can be observed in Fig. 4, this is mainly due to the efficient exploitation of the available bandwidth using density information in LIMERIC-D without exceeding the maximum allowed CBR.

B. Inter reception time (IRT)

Inter-Reception Time (IRT) is the average amount of time between two subsequently received beacons between the sender and the receiver [12]. It is also known as Beacon Information Age [21] or Update Delay [22]. This metric evaluates the queuing time and the number of consecutive packet losses that have a great impact on the stability of the safety applications.

Fig 5 shows the IRT for LIMERIC and LIMERIC-D with 95% confidence interval. Considering different vehicular densities, LIMERIC-D has lower IRT in various density scenarios. This is a direct result of allowing higher rates while respecting the maximum allowed CBT.

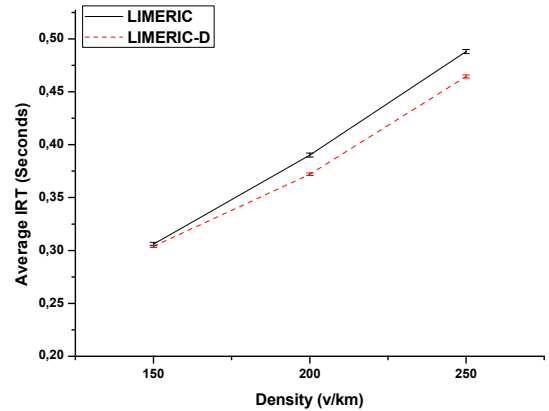


Fig. 5: Average Packet inter-reception time (IRT) of LIMERIC and LIMERIC-D with 95% confidence interval

C. Awareness probability

Awareness probability (AP) is the probability of successfully receiving at least n packets in a time window T [11]. It is known as Neighborhood Awareness [21]. We also find Application reliability metric which is the probability of successfully receiving at least one packet during tolerance time window T . In this evaluation, we consider a time window of 1 second and two different values for n : 3 (AP-3) and 5 (AP-5).

Fig 6 shows the AP-3 and AP-5 for LIMERIC and LIMERIC-D with 95% confidence interval. As it can be observed, For both protocols, the application reliability is getting lower as the density of vehicles increases. However, LIMERIC-D has higher AP in various density scenarios comparing with LIMERIC. This is also the result of allowing higher rates while respecting the maximum allowed CBT.

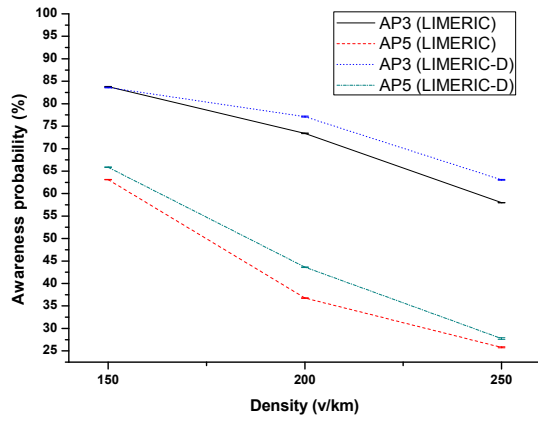


Fig. 6: Average Application probability (AP-3 and AP-5) of LIMERIC and LIMERIC-D with 95% confidence interval

D. Awareness reliability

Awareness reliability is the maximum distance at which the Awareness Probability (AP) is greater than or equal to a certain threshold [11]. In this evaluation, we consider a time window of 1 second and two thresholds: 30% (AR-3) and 50% (AR-5) with 95% confidence interval. As it can be observed in Fig. 7, both protocols allow approximately the same awareness

range. Moreover, the awareness reliability is getting lower as the density of vehicles increases. In contrast to IRT and AP metrics, there was no impact on the awareness range. This is mainly because in a difference in awareness probability for the long distances was not too high, and as results, it does not allow to enhance the awareness reliability.

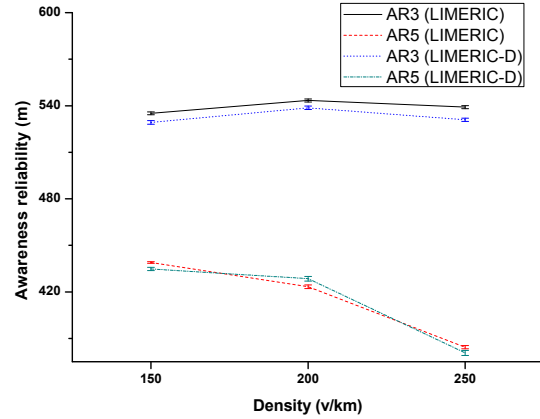


Fig. 7: Average awareness reliability (AR-3 and AR-5) of LIMERIC and LIMERIC-D with 95% confidence interval

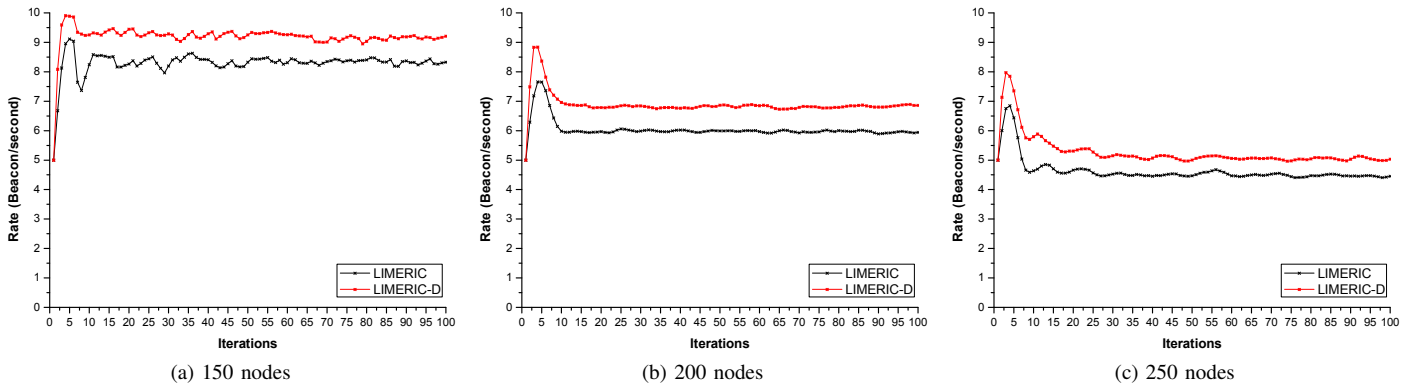


Fig. 3: Beaconing rate evaluation

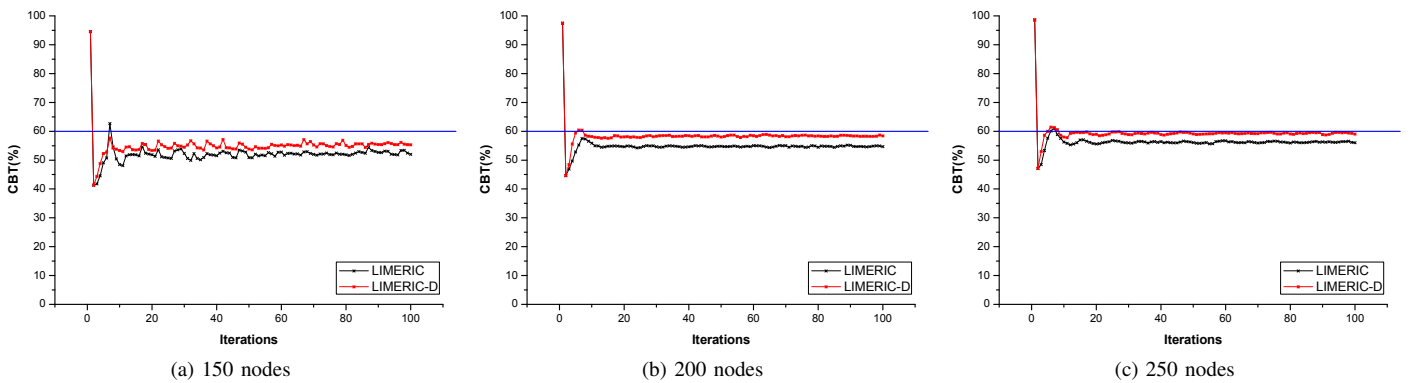


Fig. 4: Channel busy time evaluation

VI. CONCLUSION

LIMERIC is a well-known congestion control protocol adopted by the current ETSI standardization process. LIMERIC-D is an extension of LIMERIC using the local density estimation. In this paper, we have reviewed and analyzed LIMERIC and LIMERIC-D to evaluate the impact of using the density information on the performance of congestion control protocols. The results show that LIMERIC-D outperforms LIMERIC allowing better application reliability. LIMERIC-D has less Inter-Reception Time (IRT) and higher Awareness Probability (AP). However, there was no impact on the Awareness Range (AR). Also, LIMERIC-D allows higher beaconing rates for vehicles. We have shown that use of the density information in VANETs could improve the performance of congestion control protocols. As future work, we will evaluate other applications of the density information, and also examine the use of other neighborhood metrics.

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