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RESEARCH ARTICLE

Toward an Efficient Data Dissemination Protocol for Vehicular Ad-Hoc Networks

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ABSTRACT Data Dissemination protocols are used for several vehicular applications, varying from warning messages to real-time video delivery. The majority of literature solutions consider the distance from the sender to choose the vehicle to forward the message. Basically, the solutions introduce a delay in the forwarding procedure, which is inversely proportional to the distance from the sender vehicle. In order to improve the forwarding procedure, this work introduces the concept of Road Covered Area to improve the overall data dissemination process and we describe how to calculate the road covered area by a node transmission. We present the D&RCA, the combination of Distance and Road Covered Area strategies to enhance the re-transmission during communication. Instead of considering the distance, we propose a function to combine the distance and road covered area to introduce a small delay before re-transmissions. We compare the proposed protocol with literature solutions considering the metrics of number of collisions, network coverage and communication latency for different density of vehicles in the network. When the network has 700 vehicles/km², the data dissemination latency and number of collisions of the proposed D&RCA is, respectively, 1.24 and 1.32 times smaller than the literature solutions. When we increase the density of vehicles, all evaluated solutions present a network coverage above 90%.

INDEX TERMS Communication protocol, data dissemination, road covered area, vehicular ad hoc network.

I. INTRODUCTION

We are currently seeing a growing number of applications being developed to manage urban areas. Such application vision assists the management of a city and brings benefits to citizens such as intelligent transport systems (ITS) [1], [2]. ITS aims to provide citizens with safer, more pleasant, and efficient mobility. Thus, these applications need a data dissemination mechanism among users, vehicles, and edge computing that proves access to the internet [3]. The design of data dissemination protocols for these applications plays

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an important role, as the topology of a network involving these applications can change drastically over time. So if you consider a rush hour, there are many vehicles and people on the same road [4]. On the other hand, at late night, few vehicles travel along the same road. Thus, the design of data dissemination protocols is challenging and is one of the essential tasks in Vehicular Ad-hoc NETworks (VANETs). A VANET is a type of ad-hoc network where vehicles can communicate to provide a number of applications to passengers and drivers, such as entertainment, driving assistance and traffic information systems.

Developers of these applications must consider the inherent characteristics of VANETs, in which the topology of

vehicles is highly dynamic, and disconnections are not exceptional [5], [6]. The problem of data dissemination in VANET consists of sending data from a source vehicle to one or more destination vehicles using the vehicle communication environment [7]. This process must be executed considering the quality of service requirements of the applications, such as high coverage rate, short information delivery delay, and low network overload [8]. The data dissemination is the basis for implementing several applications, such as warning and alert messages, vehicular traffic management systems, cooperative management, dissemination of advertising, games, dissemination of videos, among others [9].

Communication protocols face several problems during data dissemination due to the dynamic behavior of VANETs. One of the main problems is caused by the variation of vehicle density in the vehicular scenario, compromising the performance of solutions that work only in specific scenarios, such as dense or sparse ones [10]. The highly dynamic topology of the scenario also imposes several data communication challenges, such as an adaptive approach to execute under different communication conditions [11]. A number of literature works deal with these communication issues using a distance-based forward technique, where all nodes that received a data dissemination message wait for a delay before re-transmission. The delay is calculated based on the distance from the sender, where the most distant node forwards the message before the others, thus canceling unnecessary re-transmissions [9]. However, a simple distance-based forward technique presents some disadvantages due to the number of message collisions. When only the distance is considered in the delay calculation, a number of vehicles may be scheduled to forward the message in the same wireless access time slot in the 802.11p medium access control mechanism. Thus, it is important to study alternative, simple and easy-to-use mechanisms to overcome the message collisions during the data dissemination process.

The objective of this work is to propose an efficient data dissemination protocol for vehicular networks. To overcome the limitation of literature works, the proposed solution introduces the concept of road covered area, where the vehicle estimates the road covered area in its re-transmission. The motivation to study and to propose the road coverage area for data dissemination in vehicular networks is related to the network coverage and messages collisions. Due to the layout of an urban center, where vehicles move considering the street infrastructure and a street has a number of neighboring streets, the farthest vehicle from the sender might not cover as much as possible neighboring vehicles compared to the use of the road covered area. The road covered area is calculated by the intersection of the vehicle communication range and the road shape where it is located. The proposed solution combines the distance-based technique with the road covered area to estimate the delay to re-transmit the message. Besides being located as far as possible from the sender node, the vehicle should also cover as much of the road as possible to have the smallest delay for re-transmission. The proposed

solution was designed to decrease the number of collision messages while keeping high values of covered vehicles and a small latency value to perform the data dissemination. We compare our solution with the previously discussed literature solutions regarding different numbers of vehicles in the scenario and data dissemination metrics.

The major contributions of this investigation are as follows:

- We present a data dissemination protocol for vehicular ad-hoc networks;
- The solution introduces a strategy for re-transmission delay in distance-based data dissemination protocol, where the delay is calculated using the distance and road covered area by a node transmission;
- We present in detail how the road covered area can be calculated in dynamic scenarios;
- The proposed data dissemination protocol overcomes the limitation of literature works, and it was designed to execute under different traffic density, considering real map road features, such as number of lanes, width and length of roads, traffic light, and others.

This work is structured as follows. Section II presents the related works focusing on data dissemination protocol. Section III presents the proposed data dissemination protocol, while Sections IV and V present the performance evaluation and the conclusions.

II. RELATED WORKS

There are several works in the literature dealing with the dissemination of data between vehicles [12], [13], [14], [15], [16], [17], [18], [19], [20]. Solutions for data dissemination in vehicular ad-hoc networks use different metrics to choose the next relay node. Data communication in VANET is influenced by a number of factors, such as: mobility patterns, vehicle density on the roads, speed limits, vehicle' direction imposed by the road infrastructure and others. The mobility of vehicles is also influenced by the drivers' behavior and their routines. In this scenario, [21] studied the mobility pattern in vehicular ad-hoc networks and its relation to Social Networks, where the study of mobility patterns using a social analysis can improve different services in the networks, including the data dissemination process.

In [22] the authors studied the use of meta-surface in vehicular ad-hoc networks to improve the vehicles' connectivity, which is directly related to data communication solutions. Meta-surfaces can be used to coat any material/surfaces (including vehicles, buildings, traffic lights etc) in order to turn on the environment as a part of the communication process. The meta-surfaces can be used to redirect the communication signals from a source to specific targets without creating new wireless waves.

Some works in the literature use the Vehicle-to-Everything (V2X) communication paradigm to improve data dissemination among vehicles by using cellular infrastructure [23], [24], [25]. The authors in [23] proposed the Trajectory Based Dissemination (TBD), which uses the cellular network infrastructure to obtain the network knowledge regarding the

density of vehicles in the city road infrastructure. When a vehicle wants to disseminate a message to a target region of the network, it retrieves the density matrix from the cellular network and the vehicle finds the densest roads to disseminate the message to the target region. Reference [26] elaborate a literature review of Cellular V2X (C-V2X) solutions considering the sidelink interface. The literature review includes a number of solutions for LTE-V2X and 5G-V2X considering as communication links the Vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), vehicle-to-infrastructure (V2I) and vehicle-to-network (V2N). The authors also discuss the sidelink specification, evolution and resource allocation, besides different algorithms for LTE-V2X and 5G-V2X autonomous modes.

The authors in [27] and [28] present the Fast Multi-hop Broadcast Algorithm (FMBA), a distributed protocol for fast data communication. FMBA is a decentralized communication protocol for vehicular scenarios and uses periodic *hello* messages containing the vehicle's positions. The solution relies only on vehicle-to-vehicle communication and works as follows. All vehicles during their journey broadcast a periodical *hello* message to create a neighbor table. A vehicle starts the data dissemination process by sending a data dissemination message and, upon receiving the message, a vehicle compute an addition delay to execute the forwarding procedure. The addition delay is estimated based on the vehicle's position and the contention window of the MAC protocol. Thus, the farthest node will re-transmit the message first. The main goal of FMBA is to cover the entire area with the smallest number of re-transmissions. However, the FMBA may decrease the data dissemination metrics such as coverage due to increased messages collision during the broadcasts. The main difference between FMBA and this work is the addition delay estimation, where FMBA considers only the distance between the sender-receiver and our proposal jointly consider the distance and the Road Covered Area. Moreover, our proposal considers the time slot duration in the addition delay estimation besides the contention window of the MAC protocol.

An Efficient multi-directional Data Dissemination Protocol (EDDP) for urban environments is presented in [29]. EDDP data dissemination protocol is based on vehicular communication and offers a multi-directional data dissemination flow to mitigate the network partition problem. EDDP relies only on local vehicle data to indicate the best vehicle to re-transmit a data dissemination message. The solution combines a distance-based delay with road condition (vehicular density) observed by the vehicle to decrease the number of re-transmissions. However, the authors did not mention how the vehicle estimates the local traffic condition and the impact of wrong traffic estimation. Thus, it is also necessary to use a traffic estimation communication protocol to find the local traffic condition. The proposed D&RCA also considers the distance between nodes in the additional delay estimation, however, it considers the Road Covered Area metric besides the density of vehicles on the road.

Moreover, the Road Covered Area can be estimated locally and without message exchanges, however, a communication protocol is necessary to estimate the density of vehicles on the road.

The Data dissemination pRotocol In VEhicular networks (DRIVE) [30] uses on-hop neighbor information to execute data dissemination under sparse or dense environments. DRIVE employs the concept of sweet spot, where the sender node defines the area of eligible vehicles to re-transmit the message. Thus, only vehicles located inside the sweet spots of the sender are able to re-transmit the message. The problem of using such an approach is the definition of sweet spots. To find the best vehicle to re-transmit the message, defining a sweet spot with a small area is necessary. However, this can resume the data dissemination process due to the network partition problem. Since only the vehicles inside the sweet spot are eligible for transmission, balancing its area considering the network coverage and communication delay is necessary. It is important to note that the sweet spot is a way of considering the road covered area during re-transmissions by limiting the position of vehicles that are able to re-transmit the data dissemination message. Thus, vehicles located outside the sweet spot area have a small road covered area and are not eligible for re-transmissions. The DRIVE's strategy limits the vehicles for re-transmissions and then estimates an additional delay based on the distance of the sender-receiver vehicles, where the proposed D&RCA jointly considers the distance and the Road Covered Area.

Bao et al. [20] proposed a V2V communication protocol called Efficient Clustering V2V Routing Based on PSO (Particle Swarm Optimization) in VANETs (CRBP). Therefore, the CRBP collects information such as vehicle position, speed, and direction to form the clusters and choose a leader from each formed cluster. Then, the particle filter is used to select the relay vehicles between the origin and destination of the message. However, the leading vehicle in the cluster is responsible for merging the collected data and computing the route within its cluster. Thus, the system depends on the leading vehicle to spend as long as possible active. This compromises the working of the protocol since there will have to be a new leader choice and the particle filter algorithm has to be computed again for the new network characteristics.

Costa et al. [17] proposed a data dissemination protocol based on complex network metrics, called DDRX. In DDRX, vehicles maintain local knowledge of their 1- and 2-hop neighbors used to build a subgraph. Using intermediation centrality and degree centrality, the DDRX selects the best vehicles to relay the message. DDRX provides data dissemination with low overhead and network delay, maximizing coverage and minimizing the number of packet collisions. As complex network metrics were used, more data processing and more control messages were needed than LEARN. In this case, it is necessary to know the nodes with two hops away. This solution is also compromised in more spaced networks and does not consider the destination's location, thus having to spread the message across the entire network.

A data dissemination protocol based on Clustering and Probabilistic Broadcasting (CPB) is presented in [31]. The proposed algorithm creates different clusters considering the vehicles moving in the city road structure and the cluster creation considers the driving directions and geographic locations of vehicles. Inside a cluster, each cluster member estimates a forward probability taking into account the message redundancy reduction while ensuring reliability and coverage. However, due to the probability mechanism to forward messages, a number of unnecessary messages are transmitted aiming to increase coverage of vehicles. In [32] the authors also use a cluster-base schema named Cross Layer Autonomous Route Recovery (CLARR) data dissemination protocol. The proposed solution is focused on selecting the most reliable relay vehicle inside the cluster to forward the message. Also, the proposed solutions aim to deal with the network partition problem during low density of vehicles and the broadcast storm for scenarios with a high density of vehicles.

Tesfa et al. [33] present an effective and efficient adaptive probability data dissemination protocol (EEAPD) for vehicular ad-hoc networks. The proposed solution combines a delay and probability approach in order to forward the data dissemination messages. EEAPD is based on the density of vehicles and a beacon algorithm is used to discover the number of vehicles on a specific road. The proposed solution was designed to be used for a number of application requirements, such as low end-to-end delay, packet delivery and low bandwidth consumption. In this scenario, the proposed solution is able to execute in an adaptive environment and could be also executed with no beacon exchange. The solution uses the concept of link load to reduce the number of messages during data dissemination. EEAPD was compared to literature works presenting better results regarding packet delivery and end-to-end delay. However, due to the use of a beacon algorithm to discover the density of vehicles on the road, the number of messages increases fast when the number of vehicles in the scenario also increases.

Considering all above solutions, it is important to point out that the C-V2X solutions uses the cellular network infrastructure and implements the V2V, V2P, V2I and V2N communications. By using the cellular network infrastructure, C-V2X solutions may improve the data dissemination performance, especially due to the orthogonal resource allocation. Considering the scenario of this paper where a vehicle disseminates a message to the entire network, a C-V2X approach will use the cellular network to disseminate the message instead of only the V2V communication. A critical issue of C-V2X solutions for data dissemination is the need of the cellular infrastructure always on to disseminate the message to the entire network. Thus, the vehicles that are located where there is no cellular coverage will not receive the message from the cellular infrastructure. In this case, it is important to design efficient solutions to be used in different scenarios and conditions to jointly increase the overall network performance with C-V2X solutions.

It is also important to emphasize that a number of literature works deal with the communication issues, such as vehicle density, highly dynamic topology, short-lived connections, vehicle mobility and others by using different data dissemination metrics. These metrics include social and complex network features [17], [21], probability-based schemes [33], geographical schemes [34], distance-based schemes [28], [30], among others. However, none of the literature solutions explore the road covered area during the data dissemination process. The social and complex network solutions for data dissemination requires periodical *hello* messages to create a network topology, which increases the number of messages to perform the data dissemination. Thus, the data dissemination delay will also increases due to the access medium control. The C-V2X solutions require cellular infrastructure and the use of a communication infrastructure is not needed in the proposed D&RCA. Thus, to have a fair comparison among the data dissemination solutions, D&RCA is compared to FMBA, EDDP and DRIVE, which are the most similar literature approaches. These solutions use only V2V vehicular communication to perform data dissemination and the simulation section presents a comparison among them. The surveys [7], [35], [36], [37] present extensive and up-to-date data dissemination protocols and algorithms for vehicular ad-hoc networks.

III. D&RCA: DISTANCE & ROAD COVERED AREA DATA DISSEMINATION PROTOCOL

This section presents the proposed protocol for data dissemination for warning and alert messages. We consider a multi hop data dissemination scenario where a specific vehicle sends a warning message for the entire vehicular network using only vehicle-to-vehicle communication, i.e., the vehicle performs a broadcast message for all vehicles in the network. We assume (i) vehicles are equipped with an On-Board Unit (OBU) with processing, memory, and communication capabilities; (ii) vehicles are able to estimate the distance between the sender and receiver nodes based on vehicles' positions calculated using GPS or using Time Of Arrival (TOA), Angle Of Arrival (AOA) or Receive Signal Strength Indication (RSSI) among others techniques. In this work, we assume the vehicles are equipped with a GPS receiver; (iii) vehicles have the city map stored in the On-Board Unit containing the street/road specification and information, such as size, geometry, number of lanes, ids etc.

The proposed protocol is a delay-based approach, where a node delays its forwarding procedure based on the distance from the sender and road covered area, and the smallest delays are calculated for greater distances from the sender and greater road covered area. The bandwidth usage has a great importance on data dissemination protocols in vehicular environments, and our solution tackles this issue by reducing the number of message collisions and thus improving the overall network bandwidth usage. The protocol was designed to execute in urban or highway scenarios. Table 1 describes the important notations. The following sections describe

TABLE 1. List of important notations.

Term	Description
AC	Access Categories
CW	Contention Window
CWmin	Minimum Contention Window Value
CWmax	Maximum Contention Window Value
AIFSN	Arbitration Inter-Frame Space Number
P	Area of the polygon defining the road shape
C	Area of the circle defining the communication range of a vehicle transmitting a message on the road P
A	Intersection area
RCA	Road Covered Area
r	Vehicle communication range,
y_1	Distance from the vehicle to the upper limit of the considered road
y_2	Distance to the lower limit of the same road
D	Distance estimation between sender-receiver
N	Set of vehicles

in detail the wireless network model, environment and parameters, followed by the road covered area calculation and the proposed data dissemination protocol.

A. WIRELESS NETWORK MODEL, ENVIRONMENT AND PARAMETERS

The proposed protocol was designed to execute in the Wireless Access in Vehicular Environments (WAVE) [38]. The WAVE environment uses the 5.850-5.925GHz band, the Dedicated Short Range Communications (DSRC), and it is based on the IEEE 1609 and 802.11p protocols. These protocols are based on Enhanced Distributed Channel Access (EDCA) to support different intelligent transportation systems and applications with different quality of service levels. EDCA uses the CSMA/CA, where the node willing to send a message should sense the wireless medium and it employs four different Access Categories (AC).

The Access Categories have different Contention Window (CW) and Arbitration Inter-Frame Space Number (AIFSN) time slots, which are: (i) AC0 for background traffic with CWmin = 15, CWmax=1023 and AIFSN=9; (ii) AC1 for best effort traffic with CWmin = 15, CWmax=1023 and AIFSN=6; AC2 for video traffic with CWmin=7, CWmax=15 and AIFSN=3; and AC3 for voice traffic with CWmin = 3, CWmax=7 and AIFSN=2. AIFSN is used to compute the Arbitration Inter-Frame Space (AIFS), the time a node must sense the wireless medium before transmission. If the wireless channel becomes busy before AIFSN[AC], the node selects a random backoff from the interval [0,CW[AC]], where the first interval starts with CWmin and doubles at each attempt to transmit if the channel is busy. CWmax is the maximum allowed time slot. The Access Categories AC0 and AC1 are considered in the proposed data dissemination protocol.

In the considered vehicular wireless network context, all vehicles are equipped with an On-Board Unit with processing, memory, and communication capabilities. Thus, the OBU implements the WAVE architecture. In order to estimate the road covered area by a vehicle transmission, we

simplify the wireless environment and we set the communication range to 250m. However, the network designer could use any specific values of communication range to better represent the application requirements and the hardware available.

B. ROAD COVERED AREA CALCULATION

Let P be the area of the polygon defining the road shape and let C be the area of the circle defining the communication range of a vehicle transmitting a message on the road P . The intersection area $A = P \cap C$ defines the Road Covered Area (RCA) by the vehicle transmission, i.e., all other vehicles inside A will be covered by its transmission. The larger the area A , the greater the number of covered vehicles during a transmission. Figure 1 illustrates how the RCA is calculated. The gray vehicle in the center of a Cartesian plane calculates its RCA considering it will forward the message and only the vehicles inside the communication range of the sender will receive the message (vehicles with a green flag).

The computation of the road covered area A by the transmission of the gray vehicle, where four vehicles will receive the message, can be estimated considering r , which defines the vehicle communication range, y_1 that is the distance from the vehicle to the upper limit of the considered road and y_2 that is the distance to the lower limit of the same road. Given the circle equation to define the communication range $x^2 + y^2 = r^2$ of the vehicle, thus $x = \pm\sqrt{r^2 - y^2}$. The intersection area A covered by the vehicle transmission considering the road polygon is the sum of the intersection areas above and below x-axis, defined by Equation 1.

$$A = 2 \int_0^{y_1} \sqrt{r^2 - y^2} dy + 2 \int_{-y_2}^0 \sqrt{r^2 - y^2} dy \quad (1)$$

Considering the first integral $2 \int_0^{y_1}$ of A , we have:

$$\begin{aligned} 2 \int_0^{y_1} \sqrt{r^2 - y^2} dy &= 2 \int_{\theta=0}^{\pi/2} \sqrt{r^2 + r^2 \sin^2 \theta} r \cos \theta d\theta \\ &= 2 \int_{\theta=0}^{\pi/2} \sqrt{r^2(1 - \sin^2 \theta)} r \cos \theta d\theta \\ &= 2 \int_{\theta=0}^{\pi/2} r \cos \theta r \cos \theta d\theta \\ &= 2r^2 \int_{\theta=0}^{\pi/2} \cos^2 \theta d\theta \\ &= 2r^2 \int_{\theta=0}^{\pi/2} \left(\frac{1}{2} + \frac{1}{2} \cos 2\theta \right) d\theta \\ &= r^2 \int_{\theta=0}^{\pi/2} (1 + \cos 2\theta) d\theta \\ &= r^2 \left[\theta + \frac{1}{2} \sin 2\theta \right]_{\theta=0}^{\pi/2} \end{aligned} \quad (2)$$

Using the following trigonometric and related transformations $y = r \sin \theta$, $dy = r \cos \theta d\theta$, $y^2 = r^2 \sin^2 \theta$, we have:

$$2 \int_0^{y_1} \sqrt{r^2 - y^2} dy = r^2 \arcsin \left(\frac{y_1}{r} \right) + y_1 \sqrt{r^2 - y_1^2} \quad (3)$$

Applying the same evaluation, the second integral $2 \int_{-y_2}^0 \sqrt{r^2 - y^2} dy = r^2 \arcsin\left(\frac{y_2}{r}\right) + y_2 \sqrt{r^2 - y_2^2}$ of A is:

$$2 \int_{-y_2}^0 \sqrt{r^2 - y^2} dy = r^2 \arcsin\left(\frac{y_2}{r}\right) + y_2 \sqrt{r^2 - y_2^2} \quad (4)$$

Thus,

$$A = r^2 \arcsin\left(\frac{y_1}{r}\right) + y_1 \sqrt{r^2 - y_1^2} + r^2 \arcsin\left(\frac{y_2}{r}\right) + y_2 \sqrt{r^2 - y_2^2} \quad (5)$$

After modeling the wireless network and describing the road covered area calculation, we present the proposed data dissemination protocol.

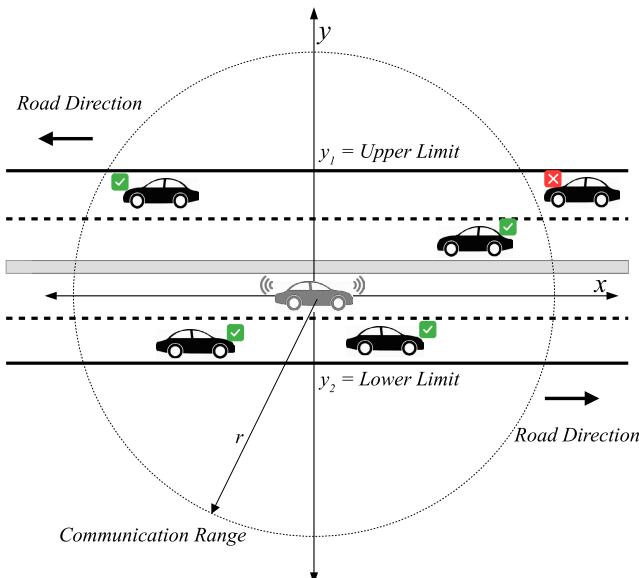


FIGURE 1. Sample calculation of the road cover area. The gray vehicle in the center of the figure estimates the road covered area considering the communication range and road limits of vehicles.

C. DESCRIPTION OF THE D&RCA DATA DISSEMINATION PROTOCOL

Algorithm 1 is executed when a vehicle starts the dissemination process. The **Data Dissemination** procedure receives as inputs the access category from application and the data to be disseminated to all vehicles in the network. It is important to note that our protocol was designed to disseminate data for AC0 or AC1 application categories. The first action is to create the data dissemination message and then to set the 802.11p header (Algorithm 1, lines 1 and 2). After, the vehicle creates a unique message ID, gets its location (S_x, S_y) , and gets the time T_0 the data dissemination started (Algorithm 1, lines 3 – 5). Then, the message is updated with this information and with the application payload (Algorithm 1, lines 6 – 9). The unique ID is used to limit the execution of the forward procedure. Finally, the vehicle broadcasts the message to all neighbors.

Algorithm 1 Data Dissemination Procedure Executed When a Vehicle Starts the Data Dissemination Process

Input: AC: AC0 | AC1. Access Category from Application.
Data: Application Payload.

- 1 $Msg \leftarrow$ new BroadcastMessage().
- 2 $Msg.$ Set80211p-Header(AC).
- 3 $ID \leftarrow$ GetUniqueId(). // unique ID for the message
- 4 $(S_x, S_y) \leftarrow$ GPS(). // vehicle's location
- 5 $T_0 \leftarrow$ timestamp(). // the time the data dissemination was started
- 6 $Msg.$ SetId(ID).
- 7 $Msg.$ SetLocation(S_x, S_y).
- 8 $Msg.$ SetStartTime(T_0).
- 9 $Msg.$ SetData(Data).
- 10 $Broadcast(msg)$. // broadcast message for all vehicles inside its communication range

When a vehicle receives the data dissemination message it executes Algorithm 2. When a vehicle receives the data dissemination message it verifies if this message was already received before using the message ID and, in this case, the message is dropped (Algorithm 2, lines 1 – 3). Otherwise, it executes the following steps. The vehicle updates the list of received messages (Algorithm 2, line 4). After, the vehicle estimates its distance (D) from the sender node. The distance is converted to a value between 0 and 1, where 1 means the vehicle is positioned at *communication range* distance (r) from the sender, i.e., the vehicle is at the maximum distance from the sender. The vehicle estimates the RCA A by evaluating Equation 5. The vehicle converts the area to a value between 0 and 1 considering the maximum road covered area for the street/road length and width where it is located (Algorithm 2, line 7).

Using the distance D , and the area A , the vehicle calculates a *DelayFactor* (DF) using the equation defined in Algorithm 2, line 8. The DF also ranges from 0 to 1, where 0 means the vehicle is positioned as far as possible from the sender and has the greater road covered area. Figure 2 shows the DF behavior for different values of distance and road covered area. It is important to highlight that if the vehicle has a covered area close to 1 but is very close to the sender vehicle, its DF is close to 0.5 and, as soon as the vehicle moves away from the sender, the DF gets close to 0. The *DelayFactor* was designed to decrease quickly for values of distance and covered area close to 1.

After that, the vehicle computes the *AdditionDelay* (AD) using the equation defined in Algorithm 2, line 9, where $aTimeSlot$ represents the 802.11p time slot duration. Then, the vehicle waits AD before the re-transmission. After the delay AD , the vehicle verifies if it received a message with the same ID, and if yes, the forwarding procedure is canceled. Otherwise, the vehicle sets its position in the message sender location ($This_x, This_y$) and forwards it (Algorithm 2, line 11 – 16). It is important to highlight that when a vehicle

Algorithm 2 Forward Procedure Executed When a Vehicle Receives a Data Dissemination Message**Input:** Msg: Received message.

ReceivedIDs: List of all received messages.

```

11 if ReceivedIDs.Contains(Msg.ID) = True then
12   | Discard(Msg).
13 else
14   | ReceivedIDs.Add(Msg.ID).
15   | (Thisx, Thisy)  $\leftarrow$  GPS( ). // this vehicle's
16   | location
17   |  $D \leftarrow \frac{\sqrt{(\text{this}_x - \text{msg}.S_x)^2 - (\text{this}_y - \text{msg}.S_y)^2}}{r}$ 
18   |  $A \leftarrow \text{getRoadCoveredArea}()$ . // Equation 5
19   |  $DF \leftarrow \sqrt{\frac{e - e^{D/2}}{e - 1}} \times \sqrt{\frac{e - e^{A/2}}{e - 1}}$ .
20   |  $AD \leftarrow \lfloor \text{CWmax} \times DF \rfloor \times aTimeSlot$ .
21   | Wait(AD).
22   if ReceivedIDs.Contains(Msg.ID) = True then
23     | Discard(Msg).
24   else
25     | Msg.UpdateLocation(Thisx, Thisy).
26     | Broadcast(Msg).
27 end

```

detects an event, it executes the **Data Dissemination** procedure, and this action triggers the **Forward** procedure. The **Forward** procedure is executed by all vehicles in the network in the case they receive the message in order to perform re-transmissions.

The complexity analysis of algorithms 1 and 2 are as follows. The Big O notation provides an upper bound on the growth rate of the algorithm, and the complexity of Algorithm 1 is $O(d)$, where d is the number of algorithm's steps, and Algorithm 1 has 10 steps. The steps related to procedure calls `BroadcastMessage()`, `set80211p-header(AC)`, `getUniqueId()`, `GPS()` are executed by a constant factor. Since all other steps are executed by a constant factor, the final complexity of Algorithm 1 is $O(10)$, which is $O(1)$. The complexity of Algorithm 2 starts with a sequential search of the received messages (Algorithm 2, line 1) and, for the list of receivedIDs with a size of m , the search complexity is $O(m)$.

The sequential search is repeated in line 12, thus the complexity becomes $O(m+m)$, which is $O(m)$. The Road Covered Area calculations (Algorithm 2, line 7) has a complexity of $O(1)$ using equation 5. All other steps of Algorithm 2 have a complexity of $O(1)$. Considering all complexity analysis parts, the final complexity of Algorithm 2 is $O(m)$. The data dissemination process starts with the execution of Algorithm 1, but, as mentioned before, Algorithm 2 is executed every time a vehicle receives the data dissemination message. Considering a vehicular network with N vehicles, the complexity of the proposed data dissemination protocol is $O(1) + O(Nm)$, thus the complexity is $O(Nm)$. This analysis considers a scenario where all vehicles forward the data

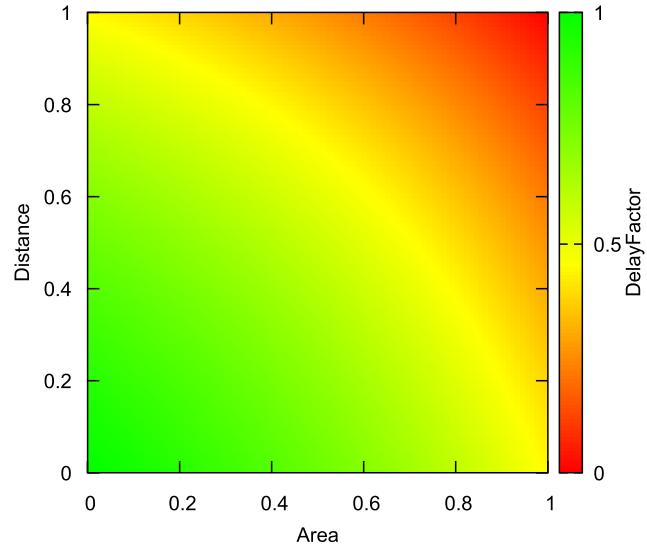


FIGURE 2. Delay Factor Distribution. Road covered area and distance from sender are scaled from 0 to 1, where 1 means the vehicle is as far as possible from the sender considering the communication range and has a road covered area equal to the maximum one considering the road configuration.

dissemination message once for a network coverage of 100%. Considering this complexity, the proposed data dissemination protocol is able to execute under OBUs with processing limitations, thus not impacting on the execution of the target application that requires data dissemination.

D. PARAMETERS CONSIDERATIONS

The proposed D&RCA data dissemination protocol has a number of parameters and assumptions that should be considered during its execution. First, the D&RCA was designed to support AC0 and AC1 applications, which include background services, such as hello messages for neighbor table construction, service discovery for vehicular networks applications, warnings messages or best effort data routing/communication. However, the D&RCA could also be applied to support video (AC2) and voice (AC3) applications in the case when a specific vehicle is streaming a video/voice traffic to the entire network. As we can observe in the Simulation result section, the data communication latency to disseminate one broadcast to the entire network reaches 0.11 seconds considering the D&RCA.

Two model parameters have a great impact on the performance of the proposed D&RCA. The first one is the *DelayFactor* (DF), where $DF \leftarrow \sqrt{\frac{e - e^{D/2}}{e - 1}} \times \sqrt{\frac{e - e^{A/2}}{e - 1}}$. Figure 2 shows the delay factor distribution for different values of area (A) and distance (D). The use of a different *DelayFactor* distribution has a great impact on data dissemination metrics, such as latency and number of collisions. The developed *DelayFactor* distribution was designed to select the vehicle that is far away from the sender and, at the same time, the vehicle has a high road covered area. It is important to point out that the distribution may not choose the vehicle

to forward the message that has the greater distance or road covered area, but it combines both metrics.

The *AdditionDelay(AD)*, defined in Algorithm 2 – line 9 as $AD \leftarrow \lfloor CWmax \times DF \rfloor \times aTimeSlot$, combines the *DelayFactor* with the wireless network model parameters, which are the maximum contention windows value (*CWmax*) and MAC time slot duration (*aTimeSlot*). Thus, the used medium access control solution has a great impact on the estimated addition delay and, to use a different protocol, the D&RCA should be reconfigured to work properly considering the above mentioned parameters.

IV. SIMULATION RESULTS

This section presents the simulation results. The proposed solution is compared to the FMBA [27], [28], EDDP [29], and DRIVE [30] vehicular and distributed data dissemination protocols. Section IV-A presents the scenario configuration and all used parameters to setup the simulations. Section IV-B presents the performance evaluation of the proposed protocols considering data dissemination metrics.

A. SIMULATION SETUP

We use the OMNET++/Veins/SUMO suit of vehicular and mobility simulators to conduct the performance evaluation. The road topology was downloaded from OpenStreetMaps, and we consider a 4km^2 region of downtown in New York with all real road features (number of lanes, width, length). In our simulation, we choose one vehicle at random to disseminate a message to the entire network. The results correspond to the average of 33 different simulations with different random number generators for a confidence interval of 95% with a Z score of 1.96.

The network framework Veins 5.2 was used to simulate the behavior of the protocols. Veins implements the Physical Layer, IEEE 802.11p and IEEE 1609.4 DSRC/WAVE and the Two-Ray Interference Model for path loss [39], [40], [41]. We set the Channel frequency to 5.890e9Hz, Bit rate to 18 Mbit/s, Transmission power to 1.6 mW, which leads to a communication range of approximately 250m under the Two-Ray interference and propagation model.

The communication range defines the maximum distance a vehicle can receive the transmitted message. From the 802.11p we consider $aTimeSlot = 13\mu\text{s}$ and the Access Category AC1. A Gaussian distribution was used to simulate the GPS error in the distance and road covered area calculation with the mean equals 5m, and the variance equals 2m. These values were estimated considering [42]. Table 2 describes the main parameters of the simulation.

We evaluate the data dissemination considering different numbers of vehicles/ km^2 to obtain results regarding the following performance data dissemination metrics:

- *Message Collision*: which measures the total number of collisions during the data dissemination process. When a message is sent by a vehicle, all vehicles that receive the message schedule the forwarding procedure. If two or more vehicles re-transmit the message simultaneously,

TABLE 2. Simulation parameters.

Parameters	Value
PHY Transmission Power	1.6 mW
Communication Range	250 m
Channel Frequency	5.890e9 Hz
Bandwidth	10 MHz
Bit rate	18 Mbit/s
<i>aTimeSlot</i>	$13\mu\text{s}$
Access Category	AC1
Message Size	50 bytes
Number of Executions	33
Confidence Interval	95 %
Scenario	4km^2
Number of Vehicles	100 to 800 vehicles/ km^2
GPS Error (Gaussian Distribution)	$\mu = 5\text{m}$ and $\sigma = 2\text{m}$

there is collision and all vehicles re-schedule the forwarding procedure. It is important to point out that a vehicle transmission might have one or more collisions, since when the vehicles re-schedule the forward, another collision could happen, however, with a lower probability. The total number of collisions is summarized considering the entire data dissemination process as illustrated in equation 6, where NC_v is the number of collisions at node v .

$$\text{Number of Collisions} = \sum_{v \in N} \sum_{i=0}^{\max_v} NC_v \quad (6)$$

- *Network Coverage*: which measures the number of vehicles that received the data dissemination message. When a message is sent by a vehicle, the number of vehicles that received this message is recorded. we reach a 100% of network coverage if the number of recorded messages is the number of vehicles in the network. However, due to message collision, the network partition problem [43], or the wrong choice of the forward node during the data dissemination process, usually the network coverage is not 100% as expected. The network coverage is computed considering equation 7, where $RECV_v$ represents if the vehicle v received the data dissemination message.

$$\text{Network Coverage}(\%) = \frac{100\%}{|N|} \sum_{v \in N} RECV_v \quad (7)$$

- *Communication Latency*: which is the average time for all vehicles to receive the message. When a vehicle receives a message, it records a timestamp t named $time_t^v$. The difference between all received timestamps and the time of the data dissemination process started t_0 represent the average communication latency, computed as:

$$\text{Communication Latency}(s) = \frac{1}{|N|} \sum_{v \in N} (time_t^v - t_0) \quad (8)$$

B. PERFORMANCE EVALUATION

Before showing the data dissemination metrics, we compare the road coverage area of all evaluated solutions. For this,

we executed each solution and we applied equation 5 for all nodes that forwarded messages during the data dissemination process. Figure 3 shows the road coverage area for all solutions and it is possible to observe that none of the solutions is able to cover the entire road map. This is due since there will always be a road area without vehicles and thus, without a transmission coverage or due to a packet collision. Since the proposed solution is the only one which considers the road coverage area during the data dissemination process, it is straightforward that it will achieve better results. However, for a number of vehicles/km² equals to 300, the road coverage area of D&RCA is 1.07, 1.09 and 1.15 greater compared to the DRIVE, FMBA and EDDP respectively. DRIVE and FMBA present similar results since both solutions consider the farthest vehicle to forward the data dissemination message, however, DRIVE limits the possible vehicles to forward the message by using the angular region. EDDP presents a smaller road coverage area and this is due to the combination of distance and density in the forward delay mechanism.

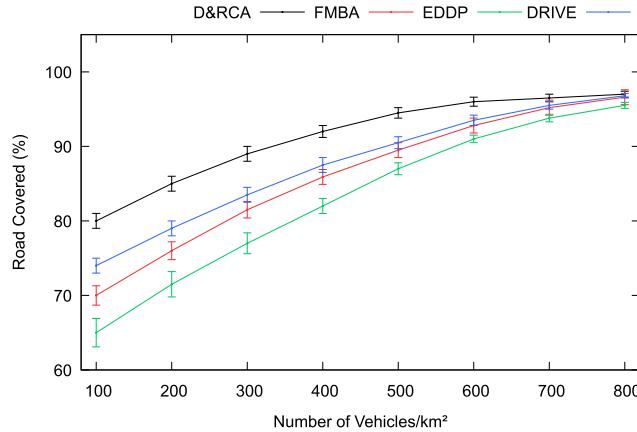


FIGURE 3. Total road covered after a data dissemination process considering different number of vehicles/km².

The total number of message collisions at the MAC layer during the data dissemination process is illustrated in Figure 4. When the network has 100 or 200 vehicles/km² all solutions present a low number of collisions, where D&RCA does not have collisions and FMBA, EDDP and DRIVE have 25, 20, and 20 collisions, respectively. As we increase the number of vehicles, the number of collisions also increases as expected. DRIVE, FMBA, and EDDP present similar results since they are based only on the distance from the sender. However, DRIVE solution presents better results than FMBA and EDDP. This is because the angular region limits the number of vehicles that are eligible to forward the message, therefore, a reduced number of vehicles compete for access to the wireless medium. When the number of vehicles/km² is 800, the number of collisions of the proposed D&RCA is 1.32, 1.43 and 1.64 times lower compared to DRIVE, EDDP, and FMBA solutions. Thus, it is possible to verify that the use of the distance and road covered area combination in the forwarding procedure can decrease the number of collisions

during the data dissemination process by distributing the re-transmissions alongside the available slots in the MAC layer.

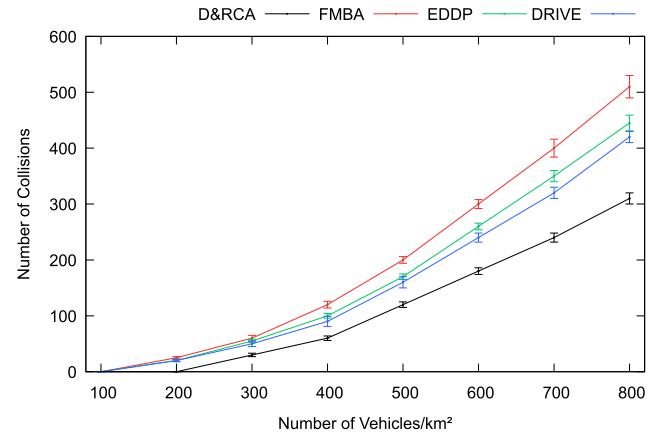


FIGURE 4. Number of message collisions at the MAC layer considering different number of vehicles/km².

Another important metric to evaluate the data dissemination solutions is the network coverage, where the goal is to cover the maximum number of vehicles. However, some vehicles may not receive the data dissemination message due to message collisions or the network partition problem. Considering Figure 5 it is possible to verify that for up to 300 vehicles/km², all solutions but the proposed one have a network coverage below 90% where D&RCA has a 94% of coverage. The better results of D&RCA compared to the other solutions are related to the road coverage area considered in the *DelayFactor* calculation, where vehicles with higher road coverage and distance from the sender forward the message first, improving the overall network coverage. However, as the number of vehicles in the network increases, all solutions present similar results due to the overlapping of vehicles in the same region, decreasing the impact of the road coverage area.

The latency during the data dissemination process, illustrated in Figure 6, is related to (i) the number of collisions that implies in a low coverage of vehicles, i.e., the number of vehicles that received a message correctly and (ii) the choice of a vehicle that will forward the message with a small additional delay. For 100 and 200 vehicles/km², i.e., a small density of vehicles in the network, the use of road coverage area introduces a greater latency in the forwarding procedure as illustrated in Figure 2. In this case, the use of only the distance presents better results compared to the proposed solution. However, as the number of vehicles increases, the D&RCA solution presents better results compared to the other solutions because of (i) for large number of vehicles in the network, there will be vehicles positioned for a higher road coverage and distant from the sender; (ii) the small number of collisions compared to the other solutions. For instance, when the network has 700 vehicles/km², the D&RCA latency

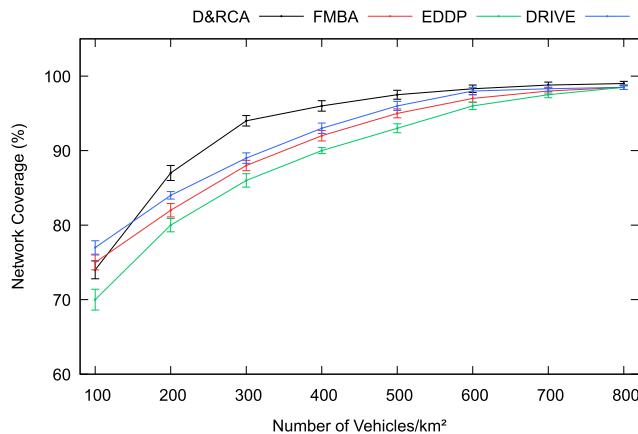


FIGURE 5. Network coverage considering different number of vehicles/km².

is, on average, 1.25 times smaller compared to the other solutions.

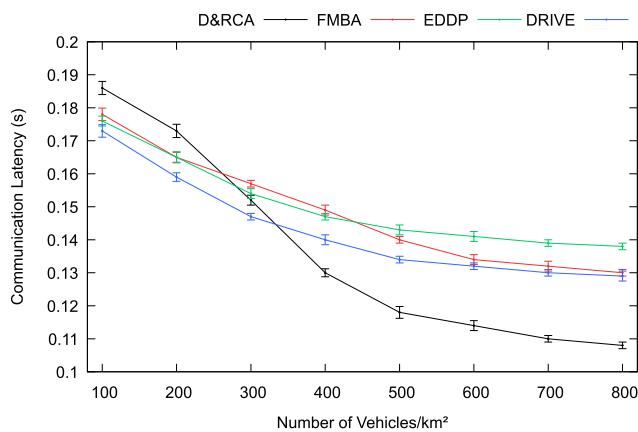


FIGURE 6. Communication latency considering different number of vehicles/km².

The previous performance evaluation considers one broadcast during the simulation in order to verify in detail the behavior of the data dissemination protocols considering different metrics. However, the data dissemination process may happen at the same time in different regions of the network in the execution of distributed applications. In this scenario, Figure 7 shows the data communication latency considering different numbers of broadcasts in the network, where all broadcasts start at the same time by different vehicles and these vehicles are chosen at random. This scenario can illustrate the performance of the solutions when the communication is stressed, for example, when a warning message is disseminated at the same time by different vehicles. It is possible to verify that when the number of broadcasts increases, the communication latency also increases and this is due to the fact of the wireless access channel contention and message collisions. Moreover, the solutions EDDP and FMBA have a greater increase compared to the DRIVE and

D&RCA solutions. EDDP combines a distance-based delay with road condition, where the roads with a higher number of vehicles are preferable. However, these roads face the wireless access channel issue, since the probability to have multiple transmissions at the same time increases with the number of neighboring vehicles. FMBA uses only the distance to estimate the delay to forward the message, and for a scenario with many broadcasts starting at different positions in the network, the use of only the distance is not appropriate to distribute the re-transmissions among the vehicles, since the most distance vehicle for different broadcasts could be located closely. On the other hand, DRIVE and D&RCA use different approaches to decrease the number of candidate nodes to forward the message. DRIVE uses the sweet spot, where the sender node defines the area of eligible vehicles to re-transmit the message, and the D&RCA uses the road covered area. For instance, when 15 broadcasts are executed at the same time by different vehicles, the communication latency of DRIVE, FMBA and EDDP are, respectively, 1.06, 1.28 and 1.45 greater compared to the D&RCA solution.

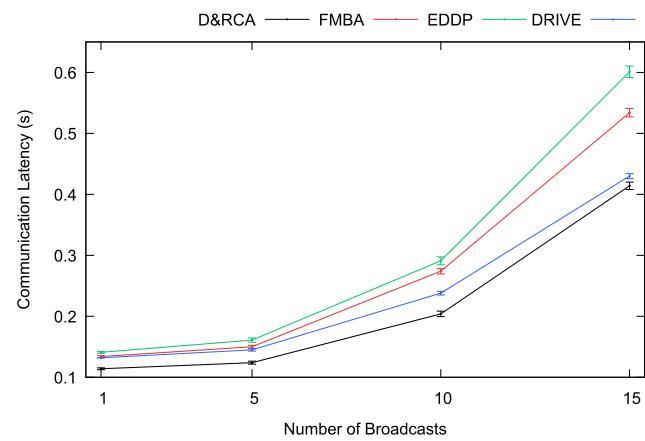


FIGURE 7. Communication latency considering different number of broadcasts.

V. CONCLUSION

This work presents an efficient data dissemination protocol for vehicular networks named Distance and Road Covered Area (D&RCA). Different from literature solutions, D&RCA considers the combination of distance and road covered area to estimate a delay before re-transmissions. This approach selects vehicles that will increase the network coverage and decrease the message collisions, thus decreasing the data dissemination latency. We described in detail how to calculate the road covered area, a topological network feature that showed to be important in data dissemination strategies.

For small number of vehicles' density, the proposed data dissemination protocol does not have messages collisions, whereas it occurs considering FMBA, EDDP and DRIVE. Considering a high density of vehicles, the number of message collisions of the proposed D&RCA is 1.32, 1.43 and 1.64 times lower compared to DRIVE, EDDP, and FMBA

solutions. For the network coverage metric, the D&RCA presents better results, however, for small density of vehicles, D&RCA presents a higher data dissemination latency. On the other hand, when the network has 800 vehicles/km², the D&RCA latency is, on average, 1.25 times smaller compared to the other solutions. D&RCA also showed the smallest data communication latency to perform the data dissemination considering different numbers of broadcasts at the same time. Thus, it is possible to verify the impact of the road covered area in the re-transmission process, since it is possible to decrease the messages collision, increase the network coverage and decrease the data dissemination latency. As future work, we plan to investigate a dynamic and weighted delay factor, where the distance factor has a more significant impact on the re-transmission delay in the case where the scenario has a small number of vehicles.

REFERENCES

- [1] G. P. R. Filho, R. I. Meneguette, J. R. T. Neto, A. Valejo, L. Weigang, J. Ueyama, G. Pessin, and L. A. Villas, "Enhancing intelligence in traffic management systems to aid in vehicle traffic congestion problems in smart cities," *Ad Hoc Netw.*, vol. 107, Oct. 2020, Art. no. 102265.
- [2] R. I. Meneguette, R. E. D. Grande, and A. A. F. Loureiro, *Applications and Services*. Cham, Switzerland: Springer, 2018, pp. 147–166.
- [3] M. S. Quesada, R. S. Pereira, W. Revejes, B. Sartori, E. N. Gottsfritz, D. D. Lieira, M. A. da Silva, G. P. R. Filho, and R. I. Meneguette, "ITSMEI: An intelligent transport system for monitoring traffic and event information," *Int. J. Distrib. Sensor Netw.*, vol. 16, no. 10, Oct. 2020, Art. no. 155014772096375.
- [4] M. Lourenco, F. S. H. Souza, C. M. Silva, R. I. Meneguette, and D. L. Guidoni, "A hybrid V2I and V2V approach for urban traffic management in vehicular networks," in *Proc. IEEE Latin-Amer. Conf. Commun. (LATINCOM)*, Nov. 2019, pp. 1–6.
- [5] R. I. Meneguette, A. Boukerche, G. Maia, A. A. F. Loureiro, and L. A. Villas, "A self-adaptive data dissemination solution for intelligent transportation systems," in *Proc. 11th ACM Symp. Perform. Eval. Wireless Ad Hoc, Sensor, Ubiquitous Netw. (PE-WASUN)*, 2014, pp. 69–76.
- [6] R. S. Pereira, D. D. Lieira, M. A. C. da Silva, A. H. M. Pimenta, J. B. D. da Costa, D. Rosario, and R. I. Meneguette, "A novel fog-based resource allocation policy for vehicular clouds in the highway environment," in *Proc. IEEE Latin-Amer. Conf. Commun. (LATINCOM)*, Nov. 2019, pp. 1–6.
- [7] F. Cunha, L. Villas, A. Boukerche, G. Maia, A. Viana, R. A. Mini, and A. A. Loureiro, "Data communication in VANETs: Protocols, applications and challenges," *Ad Hoc Netw.*, vol. 44, pp. 90–103, Jul. 2016.
- [8] M. Chaqfeh, A. Lakas, and I. Jawhar, "A survey on data dissemination in vehicular ad hoc networks," *Veh. Commun.*, vol. 1, no. 4, pp. 214–225, Oct. 2014.
- [9] E. Ahmed and H. Gharavi, "Cooperative vehicular networking: A survey," *IEEE Trans. Intell. Transp. Syst.*, vol. 19, no. 3, pp. 996–1014, Mar. 2018.
- [10] X. M. Zhang, L. Yan, K. H. Chen, and D. K. Sung, "Fast, efficient broadcast schemes based on the prediction of dynamics in vehicular ad hoc networks," *IEEE Trans. Intell. Transp. Syst.*, vol. 21, no. 2, pp. 531–542, Feb. 2020.
- [11] F. Mason, M. Giordani, F. Chiariotti, A. Zanella, and M. Zorzi, "An adaptive broadcasting strategy for efficient dynamic mapping in vehicular networks," *IEEE Trans. Wireless Commun.*, vol. 19, no. 8, pp. 5605–5620, Aug. 2020.
- [12] T. Yeferny and S. B. Yahia, "A Markov chain-based data dissemination protocol for vehicular ad hoc networks," *Comput. Commun.*, vol. 180, pp. 303–314, Dec. 2021.
- [13] A. Balamurugan, M. D. Priya, A. C. J. Malar, and S. Janakiraman, "Raccoon optimization algorithm-based accurate positioning scheme for reliable emergency data dissemination under NLOS situations in VANETs," *J. Ambient. Intell. Humanized Comput.*, vol. 12, pp. 10405–10424, Jan. 2021.
- [14] I. Achour, F. Alfayez, and A. Busson, "A robust and efficient adaptive data dissemination protocol based on smart relay selection in vehicular networks," *Wireless Netw.*, vol. 27, no. 7, pp. 4497–4511, Oct. 2021.
- [15] S. T. Hasson and A. T. Abbas, "A clustering approach to model the data dissemination in VANETs," in *Proc. 1st Babylon Int. Conf. Inf. Technol. Sci. (BICITS)*, Apr. 2021, pp. 337–342.
- [16] A. I. Tei, Z. Doukha, and Y. Zaoufe, "3DMAT: Data dissemination for disaster management using available technology in a smart city," *Ann. Telecommun.*, vol. 76, no. 9, pp. 633–645, 2021.
- [17] J. B. D. da Costa, A. M. de Souza, D. Rosário, E. Cerqueira, and L. A. Villas, "Efficient data dissemination protocol based on complex networks' metrics for urban vehicular networks," *J. Internet Services Appl.*, vol. 10, no. 1, pp. 1–13, Dec. 2019.
- [18] A. K. Sangaiah, J. S. Ramamoorthi, J. J. P. C. Rodrigues, M. A. Rahman, G. Muhammad, and M. Alrashoud, "LACCVoV: Linear adaptive congestion control with optimization of data dissemination model in vehicle-to-vehicle communication," *IEEE Trans. Intell. Transp. Syst.*, vol. 22, no. 8, pp. 5319–5328, Aug. 2021.
- [19] R. Lalitha, A. Lakshmi, H. Darisi, S. K. Nagireddi, and K. Kavitha, "An adaptive data dissemination in VANETs using dynamic routing," in *Computer Communication, Networking and IoT*. Cham, Switzerland: Springer, 2021, pp. 353–365.
- [20] X. Bao, H. Li, G. Zhao, L. Chang, J. Zhou, and Y. Li, "Efficient clustering V2 V routing based on PSO in VANETs," *Measurement*, vol. 152, Feb. 2020, Art. no. 107306.
- [21] F. D. Cunha, A. C. Vianna, R. A. F. Mini, and A. A. F. Loureiro, "Is it possible to find social properties in vehicular networks?" in *Proc. IEEE Symp. Comput. Commun. (ISCC)*, Jun. 2014, pp. 1–6.
- [22] B. M. Masini, C. M. Silva, and A. Balador, "The use of meta-surfaces in vehicular networks," *J. Sensor Actuator Netw.*, vol. 9, no. 1, p. 15, Mar. 2020.
- [23] L. H. S. Lopes, R. A. F. Mini, and F. Cunha, "A V2X approach for data dissemination in vehicular ad hoc networks," in *Proc. IEEE Symp. Comput. Commun. (ISCC)*, Jun. 2019, pp. 1–6.
- [24] S. A. Alghamdi, "Cellular V2X with D2D communications for emergency message dissemination and QoS assured routing in 5G environment," *IEEE Access*, vol. 9, pp. 56049–56065, 2021.
- [25] Z. H. Mir, N. Dreyer, T. Kürner, and F. Filali, "A top-down approach for building realistic reference scenarios and simulation framework for LTE C-V2X communications," *Ad Hoc Netw.*, vol. 138, Jan. 2023, Art. no. 103004.
- [26] A. Bazzi, A. O. Berthet, C. Campolo, B. M. Masini, A. Molinaro, and A. Zanella, "On the design of sidelink for cellular V2X: A literature review and outlook for future," *IEEE Access*, vol. 9, pp. 97953–97980, 2021.
- [27] A. Bujari, M. Conti, C. D. Francesco, and C. E. Palazzi, "Fast multi-hop broadcast of alert messages in VANETs: An analytical model," *Ad Hoc Netw.*, vol. 82, pp. 126–133, Jan. 2019.
- [28] C. D. Francesco, C. E. Palazzi, and D. Ronzani, "Fast message broadcasting in vehicular networks: Model analysis and performance evaluation," *IEEE Commun. Lett.*, vol. 24, no. 8, pp. 1669–1672, Aug. 2020.
- [29] M. Chaqfeh, H. El-Sayed, and A. Lakas, "Efficient data dissemination for urban vehicular environments," *IEEE Trans. Intell. Transp. Syst.*, vol. 20, no. 4, pp. 1226–1236, Apr. 2019.
- [30] L. A. Villas, A. Boukerche, G. Maia, R. W. Pazzi, and A. A. Loureiro, "DRIVE: An efficient and robust data dissemination protocol for highway and urban vehicular ad hoc networks," *Comput. Netw.*, vol. 75, pp. 381–394, Dec. 2014.
- [31] L. Liu, C. Chen, T. Qiu, M. Zhang, S. Li, and B. Zhou, "A data dissemination scheme based on clustering and probabilistic broadcasting in VANETs," *Veh. Commun.*, vol. 13, pp. 78–88, Jul. 2018.
- [32] S. Shafi and D. V. Ratnam, "A cross layer cluster based routing approach for efficient multimedia data dissemination with improved reliability in VANETs," *Wireless Pers. Commun.*, vol. 107, no. 4, pp. 2173–2190, Aug. 2019.
- [33] J. Sosipet, D. Wu, S. Hussain, and T. Tesfa, "An effective and efficient adaptive probability data dissemination protocol in VANET," *Data*, vol. 4, no. 1, p. 1, Dec. 2018.
- [34] L. A. Villas, A. Boukerche, R. B. Araujo, A. A. F. Loureiro, and J. Ueyama, "Network partition-aware geographical data dissemination," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Jun. 2013, pp. 1439–1443.
- [35] H. Shahwani, S. A. Shah, M. Ashraf, M. Akram, J. Jeong, and J. Shin, "A comprehensive survey on data dissemination in vehicular ad hoc networks," *Veh. Commun.*, vol. 34, Apr. 2022, Art. no. 100420.

- [36] H. Al-Omaisi, E. A. Sundararajan, R. Alsaqour, N. F. Abdullah, and M. Abdelhaq, "A survey of data dissemination schemes in vehicular named data networking," *Veh. Commun.*, vol. 30, Aug. 2021, Art. no. 100353.
- [37] E. Benalia, S. Bitam, and A. Mellouk, "Data dissemination for internet of vehicle based on 5G communications: A survey," *Trans. Emerg. Telecommun. Technol.*, vol. 31, no. 5, May 2020, Art. no. e3881.
- [38] *IEEE Guide for Wireless Access in Vehicular Environments (Wave) Architecture*, Standard IEEE 1609.0-2019, 2019. [Online]. Available: https://standards.ieee.org/standard/1609_0-2019.html
- [39] F. Bronner and C. Sommer, "Efficient multi-channel simulation of wireless communications," in *Proc. IEEE Veh. Netw. Conf. (VNC)*, Dec. 2018, pp. 1–8.
- [40] D. Eckhoff, C. Sommer, and F. Dressler, "On the necessity of accurate IEEE 802.11P models for IVC protocol simulation," in *Proc. IEEE 75th Veh. Technol. Conf. (VTC Spring)*, May 2012, pp. 1–5.
- [41] C. Sommer, S. Joerer, and F. Dressler, "On the applicability of two-ray path loss models for vehicular network simulation," in *Proc. IEEE Veh. Netw. Conf. (VNC)*, Nov. 2012, pp. 64–69.
- [42] M. Elazab, A. Noureldin, and H. S. Hassanein, "Integrated cooperative localization for vehicular networks with partial GPS access in urban canyons," *Veh. Commun.*, vol. 9, pp. 242–253, Jul. 2017.
- [43] J. M. Duarte, T. Braun, and L. A. Villas, "MobiVNDN: A distributed framework to support mobility in vehicular named-data networking," *Ad Hoc Netw.*, vol. 82, pp. 77–90, Jan. 2019.



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