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Using Overhearing and Rateless Coding in Disseminating Various Messages in Vehicular AdHoc Networks

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ABSTRACT Vehicular Ad hoc Networks (VANETs) are emerging technologies with the primary purpose of establishing Vehicular communications. Available protocols for data dissemination in VANETs are faced with issues like discontinuous connections, uncertainty about receiving messages, collisions, and latency. In this paper, a new method is presented for the dissemination of advertising and infotainment messages. The proposed method has used store carry and forward (SCF), rateless coding, and a new handshake mechanism to solve discontinuous connections, uncertainty about receiving messages, and collision problems, respectively. In this paper, changing the Road Side Unit (RSU) message over time and its impact on the network is proposed as a new step in evaluating data dissemination methods. Our results showed that if changing the RSU message happened very rapidly, the network performance will almost be eliminated; to address this problem and due to the advertising nature of messages, the use of overhearing has been suggested. To the best of our knowledge, this is the first time that message overhearing has been used in VANET. Extensive and accurate simulations results show that the proposed method for 2, 3, 5, and 10 messages: (i) reduces the overhead of handshake on average 70% 63%, 48%, and 3%, (ii) increases the number of delivered packets on average 5%, 22%, 75%, and 84%, and (iii) increases the range of data dissemination on average 47%, 187%, 661%, and 2962%, respectively. With the mentioned improvements, the proposed method can also significantly reduce the latency of disseminating messages between vehicles.

INDEX TERMS VANETs, data dissemination, rateless coding, overhearing.

I. INTRODUCTION

Vehicular Ad hoc Networks (VANETs) have various applications that can be divided into two general groups, including safety and non-safety applications [1]. For both safety and non-safety applications of VANETs, most traditional routing methods are inefficient due to the specific characteristics of these networks [2]. As a result, new routing protocols and other methods of information transmission are needed. One of the most important of these methods is data dissemination. Data dissemination refers to methods that distribute information without complex routing. There are three main models for disseminating data in VANETs: Pushing, pulling, and hybrid. In the push model, data is disseminated using intermittent broadcast, while in the pull model, data is disseminated on demand. Some applications of VANETs require that both push and pull models be combined. These models are called hybrid models. Safety applications require that data be sent quickly with minimum latency, so they often use the push method. While in non-safety applications, like advertising and infotainment, system pull or hybrid strategies are often used to prevent network overload, and bandwidth loss [1], [3]. Examples of the push method are presented in [4]–[7], while [8], [9] provide some examples of the pull method. The outline of the research in this paper is based on the dissemination of entertainment and advertising messages. Our scheme is a hybrid method because the Road Side Unit (RSU) uses the push method to transmit its information, while vehicles use the pull method.

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Due to specific features of VANETs, such as high mobility and low level of node cooperation, data dissemination has faced many challenges. Some of these challenges that are mentioned in [10]–[14] are:

- Nodes are not connected at all times in the sparse scenario.
- Storm problem and low level of packet delivery in the dense scenario.
- Uncertainty about channel conditions and complete and correct message delivery.
- The collision occurs due to the transmission of several transmitters in the radio range of one receiver.
- Delay in data dissemination and high speed of nodes.
- Handshakes cause excessive overhead to minimize collisions.

In this paper, a new data dissemination protocol is introduced, and its performance is evaluated by simulation. The proposed protocol tries to reduce the adverse effects of the challenges mentioned above and seeks to increase efficiency and provide a reliable approach. To create cooperation between nodes, both Vehicular to Vehicular (V2V) and Vehicular to Infrastructure (V2I) communications are considered. The proposed protocol uses Store-Carry-Forward (SCF) mechanism [15] to maintain its efficiency in different traffic conditions. Resolving the channel's uncertainty challenge is vital since the loss of only one packet will prevent the message from being decoded. Rateless codes have been applied to our proposed protocol to avoid uncertainty about receiving messages. These codes were provided for the first time by Luby [16]. With the use of rateless codes, the main message's content can be retrieved from a subset of encoded packets. As a result, the loss of one or a certain number of packets will not cause a severe problem in the message reconstruction process. In [17], The Handshake for Data Dissemination using Rateless Codes-2 (HDDRC-2) method is introduced. The HDDRC-2 method is used to make optimal use of bandwidth and solve the collision problem caused by sending several transmitters in one receiver's radio range. Another goal of this study is to investigate the effect of changing the RSU message on data dissemination and assess its impact on the messages' dissemination range. Changing the RSU messages will affect the decoding process, and if changing the messages happens rapidly, data dissemination protocol will encounter severe weakness. Given that the proposed method's sent messages are considered advertising, overhearing is suggested as an excellent way to reduce the adverse effect of changing the RSU message, the overhead of handshake, and the delay of data dissemination.

The paper is organized as follows. In section II, previous works are introduced. Outlines of the objectives of the proposed protocol are mentioned in section III. Using the HDDRC-2 scheme in the proposed method is explained in section III-A. Section III-B is dedicated to describing the rateless codes in the proposed scheme. In section III-C, first changing RSU message over time and its impact on the message decoding process is explained. Then, the way that the desired message is selected is described. Section III-D introduces the use of overhearing in the proposed scheme. In section IV, the simulation results are presented to compare the effect of using each method, in sections III-D, and III-C, with the situation of not using them. In the end, section V provides a conclusion. The major acronyms used in the paper are shown in Table 1.

TABLE 1. List of the major acronyms.

VANET	Vehicular Ad-hoc Network
RSU	ROAD Side Unit
SCF	Store-Carry-Forward
V2V	Vehicular To Vehicular
V2I	Vehicular To Infrastructure
DD	Decoding Distance
DP	Decoding Point
A_{oa}	Optimal Area for Overhearing
OH	Overhearing
NOH	Non-Overhearing
CTRI	Clear To Receive Idle
RTR	Request To Receive
CTRB	Clear To Receive Busy
CTRC	Clear To Receive Collision
D[j]	Desirable messages

II. RELATED WORK

In [18] a new method is considered for preventing storm problem due to blind flooding. This method's unique feature is that the rebroadcast probability is adaptively adjusted based on a vehicle's speed. Thus, different traffic densities in the transport network are taken into account.

In [19], different routing protocols that can be used for communications among autonomous vehicles have been investigated. In [20], a routing scheme in a drones-connected vehicle's network is proposed to reduce communication delay in a crowded environment. This paper aims to find the appropriate route with the minimum number of drones such that a given delay requirement is satisfied.

The assumption that all relay nodes are honest and cooperative can lead to catastrophic situations in the VANET. To deal with such misbehaving, trust establishment can be used [21]. In the Weighted truST-Aware Relay Selection Scheme for VANET (WeiSTARS) scheme choosing the reliable relay node in multi-hop communication is proposed [22]. By providing the weighted probabilistic trust-aware relay selection strategy, the authors of this paper reduced latency and enhanced the packet delivery ratio compared to previous methods. In order to provide: (i) fast and trusted event message dissemination, (ii) continuous estimations of both traffic density and dishonest nodes' distribution within the network, and (iii) efficient techniques to revoke dishonest nodes collaboratively, a trust establishment scheme is proposed in [23].

Data caching has been widely used to reduce data access costs. Authors of [24] introduced a data caching algorithm in wireless Ad hoc networks for static nodes to optimize cache placement and cache discovery by using overhearing in the intermediate nodes. By use of overhearing, they were able to reduce both message cost and data access delay. The emergency message dissemination with ACK-overhearing based re-transmission (EMDOR) is proposed to improve broadcast reliability in VANETs by utilizing an ACK overhearing method. In EMDOR, a selected relay node disseminates a received emergency message into the network and replies with an ACK message to the message's previous transmitter. Other nodes only overhear the ACK message and send a request message to the relay node if they become aware of the loss of its corresponding emergency message. They can recover the lost emergency message through additional broadcasting from the relay node [25]. Although this method provides reliability for receiving lost messages, it will increase the network overhead due to more rebroadcasting.

In the Basic Rateless Protocol (BRP) data dissemination method, the access point used rateless codes for disseminating its information. In this method, data dissemination is only V2I type and is done by using unicast method [26]. In [27] a V2I data dissemination protocol has been introduced to disseminate advertising messages. This article tries to place the RSU in the optimal place to improve the data dissemination protocol's performance. The Cooperative Rateless code Protocol (CORP) is a data dissemination method to send advertising messages. In this method, both V2I and V2V communications are considered. Rateless codes have been used to create reliability in the unreliable channel. The CORP method uses a complex handshaking mechanism consisting of eight steps for both V2V and V2I communications. I2V communications are only done by the unicast mechanism. In CORP, changing the RSU message over time does not consider. This method uses a very primitive motion model for vehicles, called Random Way Point (RWP) [26]. In RWP model [28], a series of road points are determined, and the speed between these road points is constant. Constant speed along the route rarely happens, so this model is often unsuitable for vehicular environments [29]. In the Data Dissemination in Vehicular Networks Using Rateless Codes (DDRC), considering several RSUs as primary data sources and the cooperation of vehicles in dissemination messages is the outline of the DDRC method. DDRC has used rateless codes to answer uncertainty about receiving messages and change channel conditions. In the DDRC protocol, when the vehicle carrying the message encounters a vehicle approaching from the opposite direction, the message is broadcast without handshakes. Therefore, in this method, no attention is paid to the vehicle's interest or lack of interest in the opposite direction to receive a message which is sent [30]. Although the absence of handshaking in this method may reduce the delay in simple scenarios, in general, not interacting with the receiving vehicle in sending the message leads to loss of bandwidth. Like the CORP method in the DDRC method, changing the RSU message over time and its impact on data dissemination is not considered. In [31], Handshake for Data Dissemination using Rateless Codes-1 (HDDRC-1) is introduced. In HDDRC-1, both V2V and V2I communications

TABLE 2. Prominent features of some protocols in related works.

Paper	Standard Mobility Model	Channel Reliability	Using Message Overhearing	V2V & V2I	Changing RSU message
CORP	RWP	YES	NO	YES	NO
DDRC	NO	YES	NO	YES	NO
HDDRC-1	Krauss	YES	NO	YES	NO
HDDRC-2	krauss	YES	NO	YES	NO

TABLE 3. Prominent features of some protocols in related works.

Paper	Handshake			
	Multi-Channel Operation	Vehicular Interaction	Collision Avoidance	
			Non Accelerated Motion	Accelerated Motion
CORP	NO	YES	NO	NO
DDRC	NO	NO	NO	NO
HDDRC-1	NO	YES	YES	NO
HHDRC-2	YES (2 channels)	YES	YES	YES

are assumed, and the challenge of uncertainty is addressed with the help of rateless codes. This method uses the Krauss mobility model, which is suitable for vehicular environments. The basis of this method's operation for channel reservation and collision avoidance is Network Allocation Vector (NAV) generation. The disadvantage of this method is that in accelerated movements, vehicles that are in the communication area after handshaking do not receive the message containing NAV, and it will lead to a collision. Another negative point of this method is that control and data messages are sent on the control channel. In the 802.11p standard, seven separated channels have been specified; one control channel and six service channels [32]. Regarding the standard, control and safety messages must be sent on the control channel, while data messages are transmitted through one of the service channels. The features of some protocols, which are more related to our proposed scheme, are prominent alongside the HDDRC-2 handshake mechanism, described in the section III-A, in tables 2 and 3.

III. PROPOSED PROTOCOL

From the above surveys and as far as we are aware, all available methods to improve data disseminating protocols have often solved one or only a few challenges and still have weaknesses. Our proposed method tries to take advantage of each method and eliminates its weaknesses. Furthermore, our protocol has used mechanisms to further improve the data dissemination protocol to achieve a more comprehensive and efficient protocol. The realization of the proposed protocol depends on achieving the following objectives:

- It can be implemented in a variety of dense and thin traffic, and with the reduction in the number of vehicles, the network performance is not eliminated.
- Use of HDDRC-2 handshake mechanism to provide efficiency in accelerated movements and to effectively eliminate collisions and create a little overhead.
- Use of rateless codes to answer the uncertainty challenge about receiving messages.
- The effect of changing and updating RSU messages on the network is considered.
- Use of overhearing in data dissemination.

- The dependence of the proposed protocol on the infrastructure unit should be reduced.

The proposed protocol integrates V2V and I2V communications to maximize the performance of the proposed protocol. For efficiency in different traffic conditions, the idea of SCF has been used. Therefore, the lack of network connection at certain times and places will not render the proposed protocol completely ineffective. Before we explain how to achieve the next goals in the later sections, we will define the carrier and collector vehicles in the proposed protocol as follows:

- **Collector:** Any vehicle that has not yet reached an RSU and has not collected RSU's messages is a collector for that RSU. Also, if a vehicle as A encounters a vehicle as B, which contains a message that A does not have in its buffer, vehicle A is a collector relative to vehicle B.
- **Carrier:** A vehicle is called a carrier if it has received several encoded packets. If that vehicle received a sufficient number of encoded packets, it could decode the message for itself and then re-encode it and send it to the requesting vehicle.

Therefore, a vehicle relative to some vehicles and RSUs is a collector and is a carrier compared to some other vehicles and RSUs. Figure 1 shows the carrier and collector vehicles in the proposed scenario. As it can be understood from the figure, vehicles can be carriers or collectors, regardless of their direction. Carriers have crossed the RSU and contain messages. In contrast, collector vehicles have not yet reached RSU and have not received message packets. The operation of the carrier and collector vehicles in the proposed protocol is shown in figure 2. In this example, vehicle "A" has passed the RSU and has the message. In contrast, vehicle "B" has not reached the RSU yet, and it has been assumed that it did not acquire the message from the V2V communication in advance. When vehicle "A" receives a data transmission request from vehicle "B," it acts as a carrier vehicle and starts handshaking with vehicle "B." During the handshake and message exchange between "A" and "B," other vehicles in the radio range of communication are silent under the HDDRC-2 handshake mechanism. It is worthwhile to mention that if the exchanged message between "A" and "B" is appropriate for other vehicles in the radio range of communication, they can obtain the message from overhearing.

A. USING HDDRC-2

The HDDRC-2 method uses two channels to perform handshake and data exchange. The HDDRC-2 method has been used for preventing collision and selecting the desired message. For the first step to start a handshake, the collector vehicle periodically sends a frequency tone as Clear to Receive Idle (CTRI) to the control channel, which shows the collector vehicle's situation is Idle. On the carrier side, in the beginning, the carrier vehicles put their message numbers on a list; the messages number show message types. Then, this list is divided into shorter lists. After that, in reply to CTRI, the carrier vehicle sends a short message named beacon on the control channel. The beacon message includes the carrier vehicle's ID and one of the shortlists of the message's number. In return, the collector vehicle sends a short message as Ready to Receive (RTR) on the control channel, including Ack and Message Number, and says which message is appropriate for it. By receiving RTR, the carrier produces encoded packets and sends them over the data channel. When the collector has received enough encoded packets to decode the message, or all existing encoded packets are received, the collector sends RTR to request another message or new list. During packet receiving or while waiting to receive packets, the collector vehicle periodically sends the Clear to Receive Busy (CTRB) frequency tone on the control channel to avoid the collision. Not receiving CTRB or RTR frequency tone on the control channel indicates the absence of the collector vehicle in the carrier's radio range, and the carrier vehicle will stop transmission. Also, when the back-off timer reached zero and no encoded packets were received on the data channel, the collector detects the absence of carrier and stops sending CTRB on the control channel. It is worth noting that after establishing a connection between carrier and collector, if a second transmitter sends packets with an upper time stamp and causes a collision in the collector's receiver, the collector vehicle will send Clear to Receive Collision (CTRC) to avoid the collision.

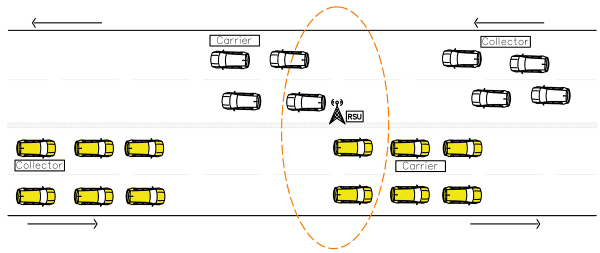

FIGURE 1. The carrier and collector vehicles in the proposed scenario.

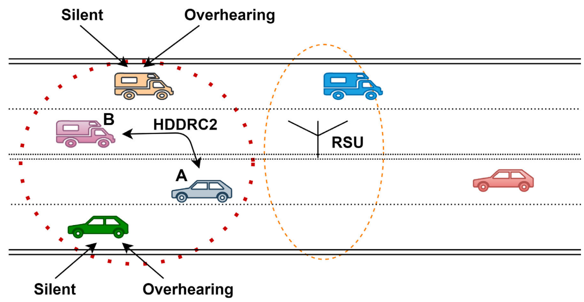

FIGURE 2. Operation of carrier and collector vehicles.

B. USING RATELESS CODES

Rateless coding refers to types of encoding that do not require a fixed rate for coding. In this method, encoded packets can be obtained in an arbitrary and unlimited number from original packets. These codes are proposed for binary erasure channels. Understanding the benefits of using rateless coding requires familiarity with erasure channels and traditional encoding methods for sending data. An erasure channel is a channel in which a packet is either received correctly or is completely lost. The traditional encoding requires two-way communication to send data over an erasure channel. In encoding with a rate, the sender encodes a packet with the length s bits, followed by a p-bit encoded message, which is acquired by $p > s$. The sender separates the p-bit encoded message into several packets if necessary and sends it to the recipient. The receiver needs all p-bits of encoded information in order to decode the message. If all packets are received correctly, the decoding operation will be successful, and a confirmation message will be sent to the sender. Otherwise, the receiver requests packets that have been lost in the channel. The problem with rate-coded methods is that the recipient must receive all the encoded packets to decode the message, and even if one packet is lost in the channel, the receiver cannot decode the message. Also, rate-based coding is based on two-way communication, while many protocols send data in full broadcast and use one-way communication. In the rateless coding method, encoded packets are generated with simple algebraic relations in arbitrary numbers. Simple algebraic relations impose a small overhead on the network, and the encoding and decoding process is simple. Using the rateless code is a response to the challenge of uncertainty about receiving messages in the VANETs. It means that if a sufficient number of encoded combinations from the original message are generated, a reliable connection will be established. In [16], it is shown that the receiver needs $K + \Gamma_k$ encoded packets to decode all the K data packets with the probability of $1-\delta$. Γ_k is the encoding overhead and is obtained from $\Gamma_k = O(\sqrt{k}ln^2(\frac{k}{\delta}))$. The encoding process is such that, first, the encoder generates a random number z, $1 \leq z \leq K$, based on the degree distribution function, where the characteristics of the degree distribution function depend on the network parameters and K. After that, the z packets randomly with a uniform distribution function are selected from the existing K packets. Finally, the encoded packet is obtained through the bit-wise, modulo two sums of the selected packets. The id of all packets that have been XOR is placed in the encoded packet's header. This operation can be repeated until the number of encoded packets is sufficient. Also, on the collector side, similar to the encoding process, the decoding process is performed through the bit-wise, modulo two sums of the encoded packets. For example in figure 3, the source message is divided to five distinct packets, $x_1, x_2, \ldots, x_5$. Six encoded packets $y_1, y_2, \ldots, y_6$ are obtained from bit-wise, modulo two sums of proper x_i, $i = 1, \ldots, 5$. The bit-wise, modulo two sums of packets, is done according to the number z. The relationship between x_i and y_i in the side of the encoder or carrier vehicle can be shown as:

$$y = Gx. \tag{1}$$

x and y are vectors representing x_i and y_i and G is the transformation matrix. For the figure 3, the equation 1 can be written as:

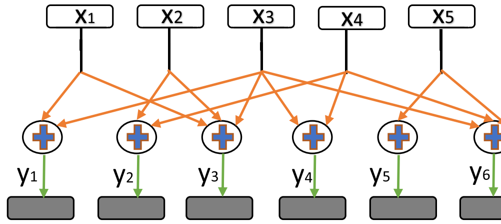

FIGURE 3. Using rateless codes in the proposed scheme: example.

$$\begin{pmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{pmatrix}. \tag{2}$$

The relationship between x_i and y_i in the side of decoder or collector vehicle can be shown as:

$$x = G^{-1}y. \tag{3}$$

In the figure 3, and according to equation 3, $x_1, x_2, \ldots, x_5$ can be retrieved as:

$$\begin{pmatrix} y_1 \oplus y_4 \oplus y_5 \\ y_1 \oplus y_3 \\ y_4 \oplus y_5 \\ y_5 \\ y_4 \oplus y_6 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{pmatrix}. \tag{4}$$

C. CHANGING RSU MESSAGES

As far as we are aware, none of the VANET data dissemination and performance evaluation methods have examined the effect of changing RSU messages. Since RSU, as the message generation's source, must send messages from different stores or businesses over time, changing RSU messages is necessary, and this will affect the message decoding process. For example, if RSU starts disseminating a message like M1 from moment zero to moment T1, there will be cooperation between RSU and vehicles for disseminating the M1 message until moment T1. Suppose RSU changes its message from M1 to M2 at T1. In this case, cooperation between RSU and vehicles for disseminating the M1 message will be stopped, and the network will be converted to V2V for disseminating the M1 message. In fact, since T1, only vehicles that already have a number of M1 packets in their buffer can participate in the M1 decoding process. Under these circumstances, vehicles spend more time receiving first messages, and new messages will be disseminated at lower speeds. So, changing the RSU message, or in other words, non-cooperation of RSU with vehicles for disseminating a message, can affect the decoding process and cause weakness in the data dissemination. The effect of message change on the data dissemination protocol will be evident in the simulations. We will also show how we can overcome the weaknesses caused by the RSU message change with the help

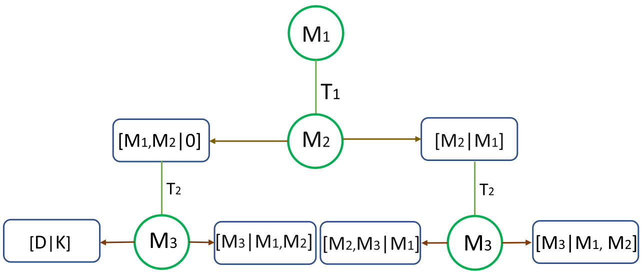

FIGURE 4. Changing RSU message over time.

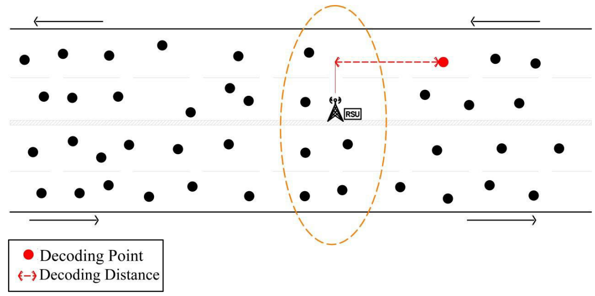

FIGURE 5. DD-DP.

of overhearing in the section III-D. In the following, we will explain how each vehicle selects the desired message in the proposed scheme.

To explain vehicles' operation in selecting the desired message, consider each message represents a set of advertisement and infotainment messages related to an industry. The time period when the RSU disseminates each message is called the state related to that message. In each state, it is possible to receive messages from previous states with the help of V2V communications. Since each state represents a time period, it is possible to receive multiple messages in each state. Messages with a lower state number are related to more substantial industries, and they have a higher priority to be received. Therefore, if a collector vehicle encounters a carrier vehicle containing several messages, it will first request messages with a lower state number. If X is a set that represents messages sent by the RSU, then the set X at the beginning of each state is equal to $X = \{M_1, M_2, \ldots, M_{state-1}\}$. If the set K represents the messages in the buffer of each vehicle, then $K \subseteq X$. For selecting the desire messages in each state, we have:

$$\text{Message Selector} = [D|K]. \quad (5)$$

Message Selector indicates that the desired message will be selected from the set D. Set D is equal to

$$D = \{M_1, M_2, \ldots, M_{state}\} - K. \quad (6)$$

Figure 4 shows the different modes of the message selector up to the beginning of the third state for a vehicle.

D. USING OVERHEARING

Given that the nature of the messages in this paper and all related works is an advertisement, one of this paper's suggestions for improving data transmission in VANETs is based on using overhearing in data dissemination. We use the word overhearing for vehicles that receive the transmitted message, though they are not the destination of the transmitted message. In general, vehicles that are not the destination of the message ignore the message, while in our proposed protocol, this message is used. Overhearing can have a significant impact on increasing delivery rates and reducing overhead, congestion, and delay of data dissemination. When a carrier vehicle begins a handshake with a collector vehicle, other vehicles in the communication area refuse to send packets during the handshake process; besides, they listen to messages that have been exchanged. If the message that is agreed upon in the handshake is proper for other vehicles in the communication area, they receive that message with the help of overhearing. Our scheme assumes that if a vehicle does not already have a message, this message is appropriate. If the message is not appropriate (already exists in the buffer) for a vehicle, the vehicle will only refuse to send packets until the handshake process is complete.

Since the messages' content is advertising, their dissemination up to far distances is regarded as an advantage. To check how far a message has been disseminated, we will define decoding point (DP) and decoding distance (DD). The DP is the point where a collector vehicle can decode the message for the first time. Also, the distance between each RSU and its corresponding DP is known as DD. In figure 5, each point is equivalent to the DP of a vehicle. The DD for a vehicle is also shown in this figure. Briefly, it could be concluded that overhearing can increase and expedite the delivery rate, which will lead to an increase in the dissemination range or mean DD during the time.

The proposed scheme is summarized in Algorithm 1 and 2. Algorithm 1 represents the operation of a collector and all other vehicles in the radio range of the collector during communication. In contrast, Algorithm 2 represents a carrier vehicle's operation in communicating with the collector. In these Algorithms, list[i] indicates i^{th} list of messages, D[j] indicates an array of desirable messages from the list[i], and the optimal area for overhearing is represented with A_{oa}.

IV. EXPERIMENTAL RESULTS

In this section, we use simulation to evaluate the proposed scheme. Simulations are performed using NS2 and SUMO. The NS2 simulates the network model. This simulator has different network protocols in different layers. The NS2 simulator supports the 802.11p standard for adapting to vehicular environments. Since NS2 is an open-source simulator, we made many changes and developed it to evaluate the proposed scheme. More information about NS2 can be found in [33], [34]. The SUMO simulator is used for creating a traffic model in which the vehicles' speed, acceleration, and path are determined randomly or definitively. This simulator is based on the microscopic mobility models, or more precisely,

Algorithm 1 Collector and Other Vehicles in Its Range

```
Input RTS, CTRB, encoded packets
Output CTRI, RTR, CTRB, CTRC, decoded packets
1. Repeat
2. Send beacon: CTRI
3. Until receiving CTRB or RTS
4. if received CTRB from another communication then
5.   Repeat
6.   Silent under process of handshaking
7.   if (vehicle ∃ A_oa) and (D[0] ∉ buffer) then
8.     Using overhearing to receive encoded packets
9.   end if
10.  until not receiving CTRB (back off timer= 0)
11. end if
12. if received RTS then
13.   if list[i] ⊆ buffer (K) then
14.     Send beacon: RTR (car id, list[i])
15.     Repeat
16.     Send periodically beacon: CTRB
17.     if received packet from another vehicle with upper
        time stamp then
18.       Send: beacon CTRC to that vehicle
19.     end if
20.     until back off timer= 0
21.   end if
22.   else
23.     D[j] = list[i] - (list[i] ∩ K)
24.     Send beacon: RTR (car id, D[0]) to the carrier
25.     Exec lines 15 to 20
26. end if
27. if received encoded data packets then
28.   while back off timer ! = 0 do
29.     Repeat
30.     Receiving encoded packets
31.     until message decoded or all packets is received
32.     update k and compute D[j] = list[i] - (list[i] ∩ K)
33.     if D[j] is empty then
34.       Send beacon: RTR (car id, list[i])
35.     else
36.       Send: beacon RTR (car id, D[0])
37.     end if
38.   end do
39. end if
```

Algorithm 2 Carrier

```
Input CTRI, RTR, CTRB, CTRC
Output RTS, encoded packets
1. if received CTRI then
2.   if the buffer (K) is not empty then
3.     Divided K into the "n" list
4.     Send beacon: RTS(car id, list[i = 1]) to the
         collector
5.   end if
6. end if
7. if received RTR then
8.   if RTR = RTR (list[i]) and "i" is less than "n" then
9.     i ← i + 1
10.    Send beacon: RTS(car id, list[i]) to the collector
11.  end if
12.  if RTR = RTR (D[0]) then
13.    produce encoded packets
14.    Repeat
15.    Send encoded packet of message D[0]
16.    until No receiving CTRB (back off timer= 0) or
       RTR received or CTRC with lower time stamp
       received
17.  end if
18. end if
```

is based on the Krauss mobility model. More information about Sumo can be found in [34], [35].

A. SIMULATION SCENARIO

To evaluate the proposed scheme with simulation, we consider a highway with a length of 20km. The road is bi-directional, and in each direction, there are two lanes for passing vehicles. An RSU is located at a distance of 10km from both ends of the road. The inter-arrival time of vehicles in each direction has Exponential distribution with parameter λ, and vehicles enter the road at an average interval of two seconds. Vehicles start moving at different speeds and accelerations from both ends of the road, and if they receive a message, they will disseminate it as a carrier of the message, on-demand. Since each vehicle's speed, acceleration, and location will affect the proposed protocol's performance, to examine the proposed scheme more precisely, its performance will be evaluated in distributed situation on all vehicles. Table 4 shows some of the parameters that are considered for simulation. Simulations are performed for states that RSU disseminates two, three, five, and ten messages, respectively. As the RSU message changes over time, the effects of changing the source message on the data dissemination process will be well understood. The desirable effects of overhearing are also evident in the simulation results.

In this paper, for disseminating two messages, the RSU disseminates the M1 message from 0 to 500 seconds and then disseminates the M2 message from 500 to 1000 seconds. In the case of three messages, the RSU disseminates M1, M2, and M3 messages, from 0 to 450, 450 to 700, and 700 to 950 seconds, respectively. For disseminating five messages, the RSU changes its message to M2 after 520 seconds, after which message change occurs every 120 seconds. In the case of ten messages, the RSU disseminates its messages in a time interval of 0 to 900 seconds; RSU changes its message to M2 after 450 seconds, after which, every 50 seconds, message change occurs.

B. SIMULATION RESULTS

Figure 6 shows the DD of RSU messages by collector vehicles according to time, in the mode of using overhearing, for

TABLE 4. Simulation parameters.

Parameter	Value
simulation time	1000 sec
Communication range (R)	250 meter
RSU location	10000 meter
Inter-arrival of vehicles (λ)	0.5 sec
Maximum vehicle speed	25m/s
Broadcast interval time	1s
Propagation model	Two Ray Ground
Maximum vehicle acceleration	4m/s^2
Simulation road length	20000 meter
Buffer size	5000 packets
Requested number of packets for decoding	400 packets
Message size	2Mb

two to ten messages. The order of the curves from top to bottom shows the states of two to ten messages, respectively. All of these sub-figures follow the same pattern of behavior. For example, in the topmost sub-figure, increasing the DD up to 500 seconds is related to the M1 message. After 500 seconds, the RSU changes its message from M1 to M2. Changing the message will result in a reduction of the DD up to the RSU location. After which, since the RSU message is not changed, the message's DD increases steadily. While in the second sub-figure, the RSU message change occurred after 450 and 700 seconds. Hence, two multi-second reductions of the DD up to the RSU location, at 450 and 700 seconds, are due to sudden RSU message change from M1 to M2 and then M2 to M3, respectively. For five and ten messages, similar to the states of two and three messages, DD has been regularly increased before each message change. Also, for each message change, reducing the DD up to the RSU location has happened.

Figure 7 shows the DD of RSU messages according to time, in the mode of not using overhearing, for two to ten messages. By intuitive comparison of this figure with the figure 6, it is clear that the DD in each sub-figure has decreased compared to the corresponding sub-figure in the previous figure. In non-overhearing mode, access to the channel and receiving the message is always done on-demand and by the unicast method. Therefore since vehicles generally spend more time decoding each message in non-overhearing mode, the DD will decrease relative to the RSU location. Reasons why spending more time reduces the DD is that first, when RSU frequently changes its message, most of the vehicles in this mode are still trying to decode previous RSU messages, and this is while the DD is calculated based on the state of the last message. Second, even if RSU does not change its message, spending more time causes vehicles to receive the message at a shorter distance from the RSU. For instance, not expanding the DD for ten messages is due to not using

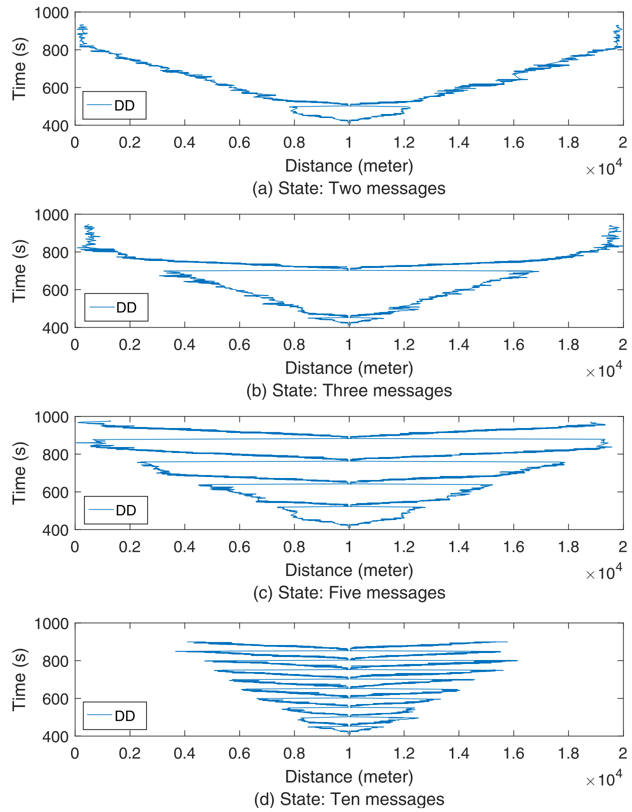

FIGURE 6. DD of RSU in overhearing mode.

overhearing and changing the RSU message every 50 seconds. The source message is replaced every 50 seconds, and the DD is calculated based on the new message. In other words, the transmission duration of each message by the RSU has a direct effect on DD. As each message's transmission duration decreases and the transitions between different messages increase, the DD will decrease. Therefore, the non-expansion of the last sub-figure is logical and was expected. The next important issue about these sub-figures is frequent increases and decreases of DD. In the non-overhearing mode, since vehicles in the communication area cannot do anything but are silenced under the handshake process, the DD is frequently increased and decreased.

To clarify the effect of using overhearing mode on improving the data dissemination protocol and increasing the DD, we compare the average DD in overhearing mode with non-overhearing mode for two to ten messages in figure 8. The order of the sub-figures from top to bottom shows the states of two to ten messages, respectively. Regarding this figure, overhearing has increased the DD relative to the RSU location. The mean DD for RSU until the moment the RSU message changes to M2 is the mean DD of the M1 message, and from that time until the moment the message changes to M3 is equal to the mean DD of M2. The same process repeats for the subsequent messages. According to the first two top sub-figures in figure 8, the DD in the non-overhearing mode will significantly decrease by increasing only the number of messages from two to three. In this mode, since

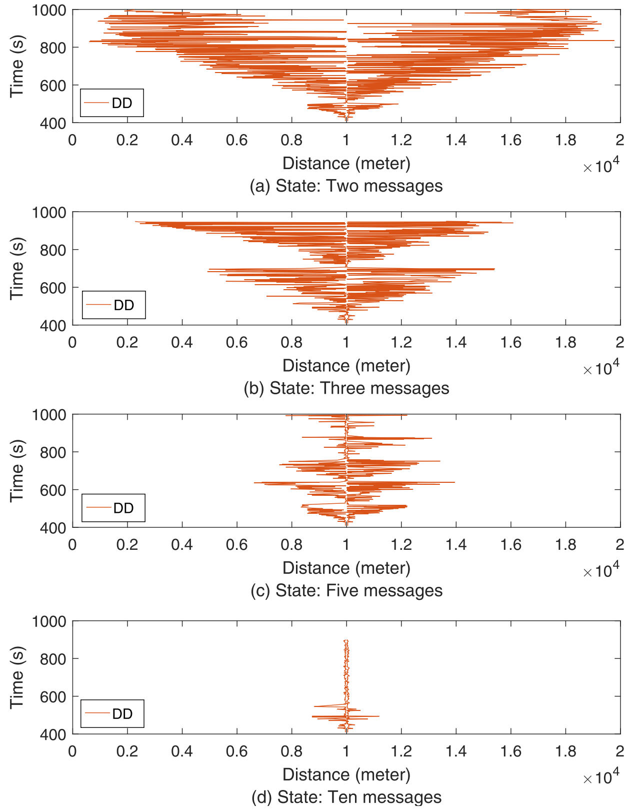

FIGURE 7. DD of RSU in non-overhearing mode.

vehicles spend much time sending and receiving previous RSU messages, and less time will remain for receiving subsequent messages, the mean DD will significantly decrease for the second sub-figure. However, in the overhearing mode, some vehicles achieve the messages without the handshake; by using overhearing, vehicles receive the previous RSU messages in a shorter time and thus have more time to receive new messages of RSU. Therefore, by increasing the number of messages to three in the overhearing mode, the mean DD will not significantly decrease compares to the state that RSU disseminates two messages. The last two sub-figures show the mean DD of RSU for states that RSU disseminates 5 and 10 messages. A sharp decrease in average DD in the non-overhearing mode in these states indicates that with more change of the RSU message, the network's efficiency is gradually eliminated. However, in overhearing mode, even for disseminating ten messages, although the DD has been significantly reduced, the network efficiency has been maintained to an acceptable level compared to the non-overhearing mode. According to figure 8, the mean DD in the overhearing mode compared to the non-overhearing mode is increased 47%, 187%, 661%, and 2962% for the state of disseminating 2, 3, 5, and 10 messages, respectively.

To get a deeper understanding of changing and increasing the RSU messages during the time and the effect of overhearing on it, we will show the DPs in the figures 9 and 10 for each message separately. Figure 9 indicates the DPs in the overhearing mode, while figure 10 shows the DPs in non-overhearing mode. To avoid repetition, we have considered only the state of disseminating five messages. In figures 9 and 10, the order of the sub-figures from top to bottom shows the DPs of M1 to M5 messages, respectively. In these figures, each point is equivalent to decoding a message by a vehicle. It can be understood from DPs location in figure 9 that DD in all sub-figures is almost continuously increased. While the expansion of the DD in the figure 10 has not occurred continuously. From M2, sub-figures represent dispersion at the DPs, and consequently decrements of the mean DD. Discontinuous expansion of the DD and the noticeable decrease in the number of DPs from M3 is due to the lack of overhearing. Lack of overhearing causes vehicles to spend more time receiving previous messages, leaving less time to decode subsequent messages.

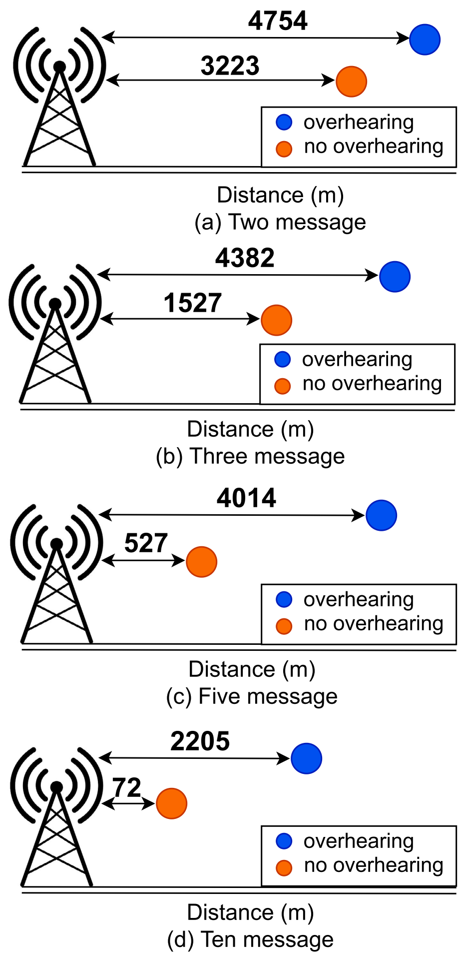

FIGURE 8. The average DD of RSU messages.

Regarding the figure 10, not using overhearing causes dispersion in DPs and reduces the mean DD. Figure 11 expresses the same issue by comparing the mean DD for the M1 to M5 in both modes of overhearing and non-overhearing. The mean DD for each message is calculated from the moment RSU sends that message to the end of the simulation time. As the message ID number increases, the difference in DD increases between overhearing and non-overhearing modes. The reason

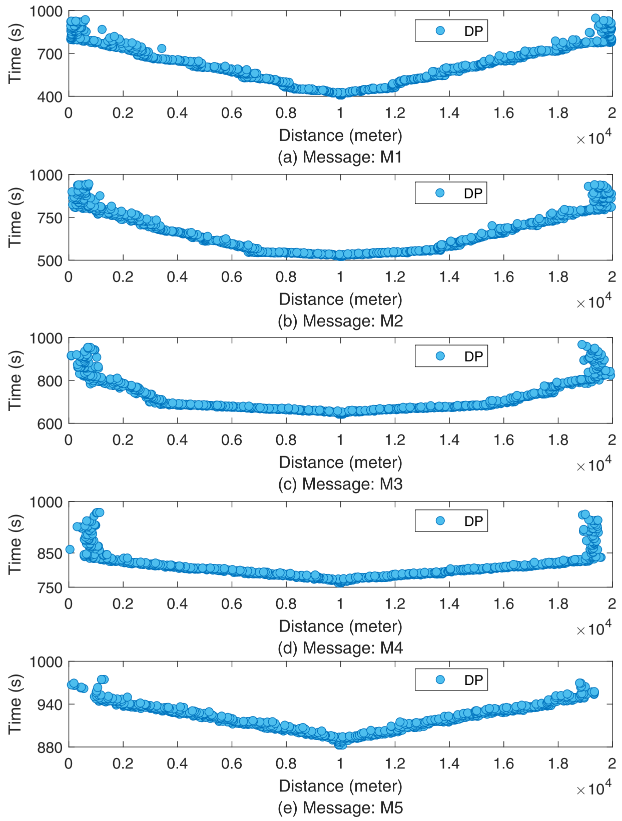

FIGURE 9. **DPs in overhearing mode: five messages.**

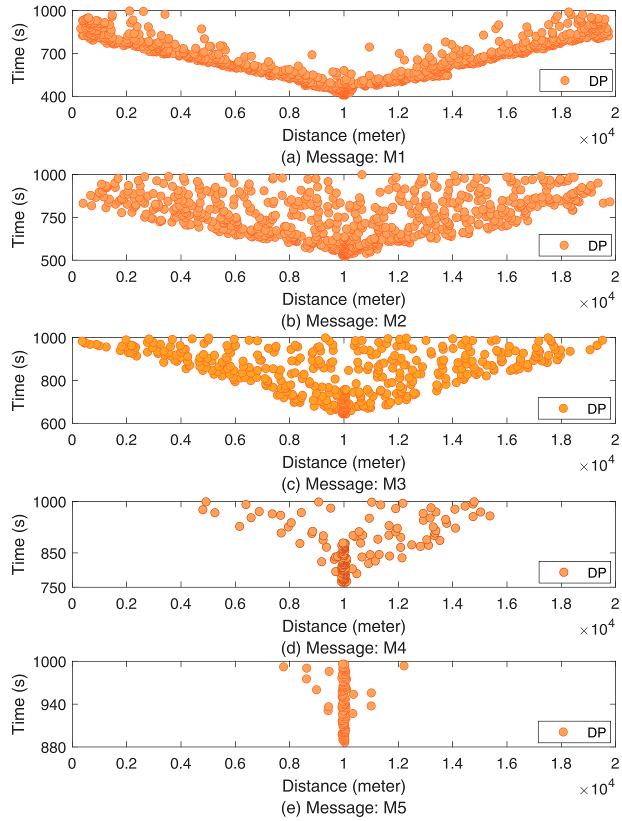

FIGURE 10. **DPs in non-overhearing mode: five messages.**

for this is that in non-overhearing mode, all vehicles except the collector and the carrier are silenced in the communication area under the handshake process. Therefore, each vehicle spends more time receiving each message, resulting in less time remaining to receive subsequent messages with V2V communications.

Using overhearing allows vehicles in the communication area to receive their favorite message without using a handshake. Receiving messages without handshakes will reduce the overhead caused by the handshake up to 70%, 63%, 48%, and 3% for the state of disseminating 2, 3, 5, and 10 messages, respectively. By intuitively comparing the number of handshakes in the figure 12 for disseminating two to ten messages between overhearing and non-overhearing modes, this reduction in the overhead of handshake becomes approximately apparent.

Figure 13 compares the number of vehicles that received each message between two modes of overhearing and non-overhearing for two to ten messages. Using overhearing allows vehicles in the communication area to receive messages without a handshake—indeed, overhearing increases the number of vehicles that receive messages in each communication. This is why we have a better delivery in overhearing mode. In the topmost sub-figure, since only two messages exist in the network and RSU collaboration time with vehicles for disseminating each message is long, most vehicles in non-overhearing modes have enough time to receive

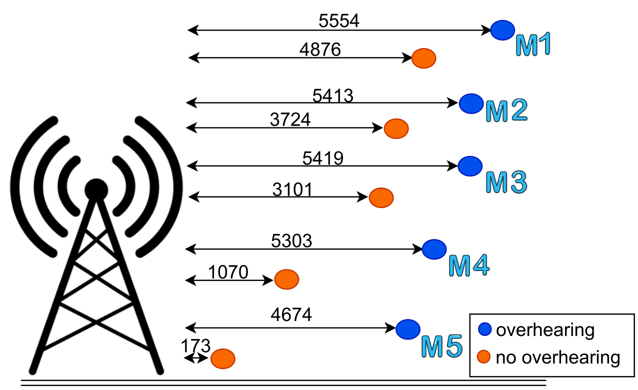

FIGURE 11. **The mean DD of M1 to M5.**

both messages. Hence, the number of recipient vehicles in overhearing and non-overhearing modes do not significantly differ. In other words, only a 5% improvement in message delivery in the overhearing mode can be achieved compared to the non-overhearing mode. As the number of messages increases and the RSU cooperation time with the vehicles to disseminate each message decreases, less time is left to receive subsequent RSU messages. Therefore, the number of deliveries for subsequent messages decreases. That is why in Figure 13 in the mode of non-overhearing, we see a noticeable decrease in the number of receipts from the M3 message on-wards for the state of disseminating three to ten messages. However, overhearing expedites decoding each message and

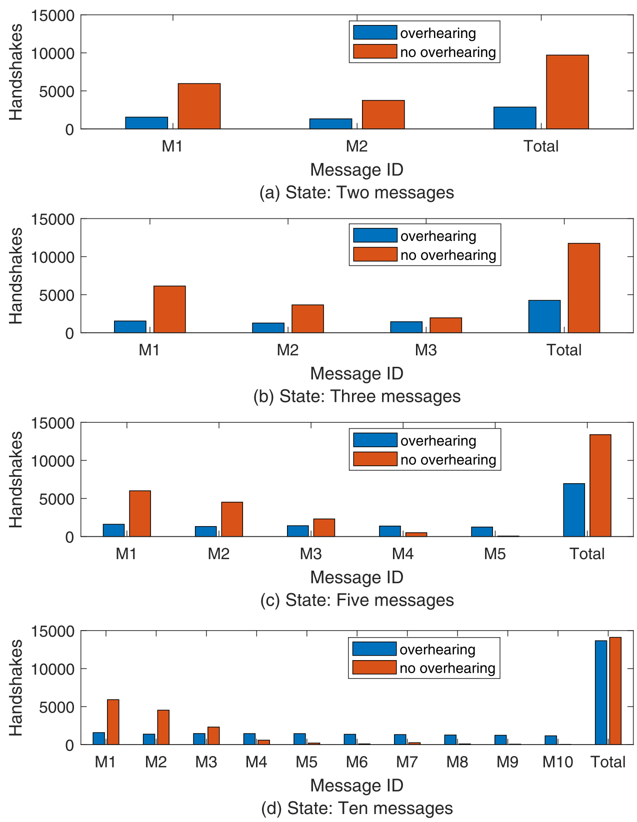

FIGURE 12. Comparison between number of handshakes.

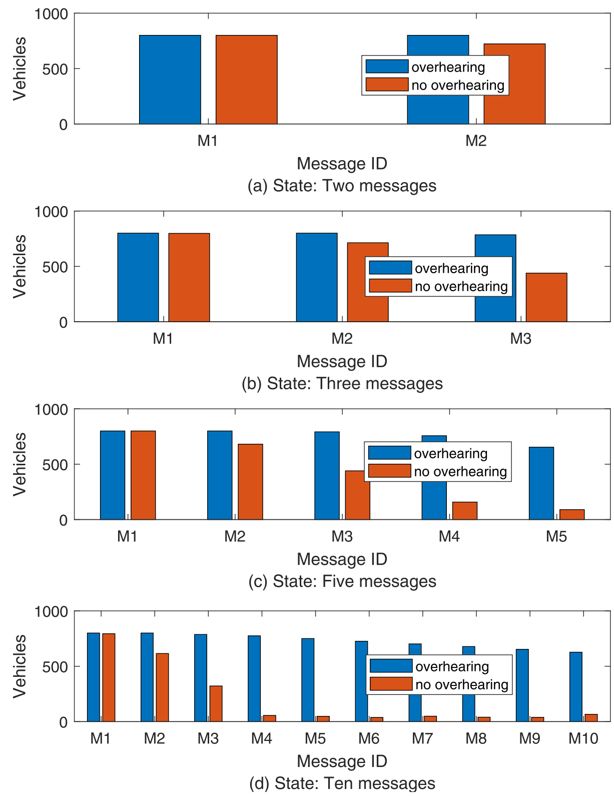

FIGURE 13. Comparison between number of vehicles.

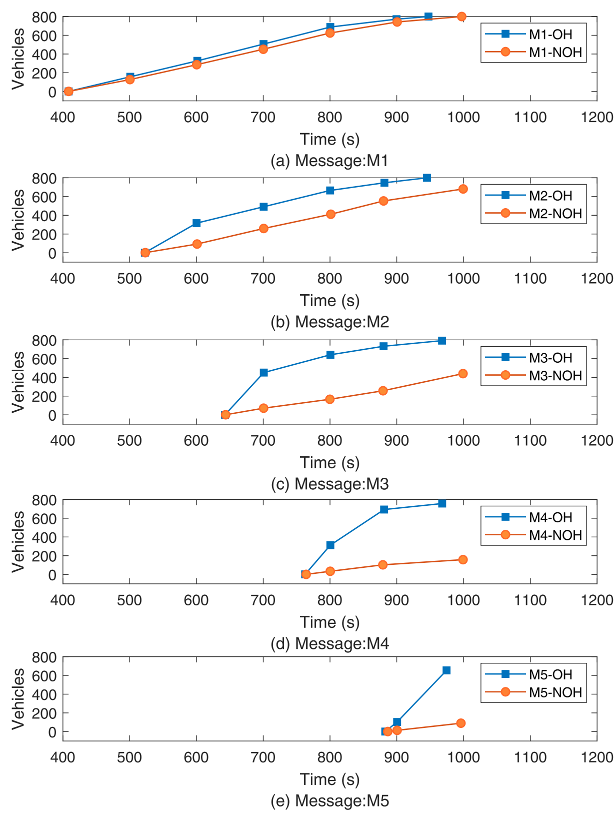

FIGURE 14. Comparison between the number of carrier vehicles over time.

giving vehicles more time to receive new messages. Consequently, the number of delivered messages in this mode does not significantly decrease from the M3 message on-wards and according to the figure 13, the number of decoded messages in the overhearing mode compared to the non-overhearing mode for the states of disseminating 3, 5, and 10 messages have increased by 22%, 75%, and 84%, respectively. Also, simultaneous observation of Figures 12 and 13 reveals that overhearing not only reduces the handshake overhead but also increases the number of messages received.

Figure 14 compares the number of vehicles that receive each message over time in overhearing and non-overheating modes for the state that RSU disseminates five messages. The order of the sub-figures from top to bottom is related to M1 to M5 messages, respectively. By comparing the two modes, it can be concluded that the time it takes to disseminate each message among vehicles in the mode of overhearing is less than the non-overhearing mode. According to the figure, the difference between the equivalent points in each sub-figure, between the overhearing and non-overhearing modes, will be more apparent by increasing the message ID number. That is because vehicles in the overhearing mode decode previous messages faster, and therefore the process of decoding new messages will start sooner. While in non-overhearing mode, vehicles will take more time to receive the first messages, and decoding subsequent messages will start with more delay. Therefore, with the help of overhearing, data dissemination delay will be reduced.

V. CONCLUSION

This paper introduced a novel data dissemination protocol that integrates V2V and V2I communications to maximize collaboration. The proposed scheme was efficient in various traffic conditions, such as thin and dense, and its performance was not related to a particular traffic situation. To avoid collisions, optimal bandwidth utilization, and desired message selection, the HDDRC2 handshake was used. Rateless codes were used to assure the complete and correct delivery of messages to the destination. The simulation was performed for states that RSU disseminates two to ten messages, respectively. The frequent RSU message change during time caused a lack of long-term cooperation of RSU with vehicles to disseminate each message. Therefore, when the number of messages in the network was increased, the network performance was significantly reduced. This was the reason for the inefficiency of the data dissemination protocol in the non-overhearing mode. Accordingly, due to the advertisement nature of the messages disseminated on the network, overhearing was proposed. The simulation results indicated that overhearing could significantly reduce handshake overhead and reception delay of messages and increase the message DD and the number of DPs. It is crucial to note that in overhearing mode, even at the time of non-cooperation of RSU with vehicles, the data dissemination protocol's efficiency is satisfactorily maintained. As a result, the proposed protocol's last goal, reducing the data dissemination dependence on the infrastructure units, was achieved.

REFERENCES

[1] 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.

[2] J. Wu, M. Fang, H. Li, and X. Li, "RSU-assisted traffic-aware routing based on reinforcement learning for urban vanets," *IEEE Access*, vol. 8, pp. 5733–5748, 2020.

[3] M. U. Ghazi, M. A. K. Khattak, B. Shabir, A. W. Malik, and M. S. Ramzan, "Emergency message dissemination in vehicular networks: A review," *IEEE Access*, vol. 8, pp. 38606–38621, 2020.

[4] D. R. Chowdhury and V. K. Jain, "VRDD: Vehicular relevance-based data dissemination in a vehicular ad hoc network," *IET Intell. Transp. Syst.*, vol. 13, no. 12, pp. 1792–1803, Dec. 2019.

[5] T. Nadeem, P. Shankar, and L. Iftode, "A comparative study of data dissemination models for VANETs," in *Proc. 3rd Annu. Int. Conf. Mobile Ubiquitous Syst. (Workshops)*, Jul. 2006, pp. 1–10.

[6] J. Bronsted and L. M. Kristensen, "Specification and performance evaluation of two zone dissemination protocols for vehicular ad-hoc networks," in *Proc. 39th Annu. Simul. Symp. (ANSS)*, Apr. 2006, p. 12.

[7] M. Saito, J. Tsukamoto, T. Umedu, and T. Higashino, "Evaluation of inter-vehicle ad-hoc communication," in *Proc. 19th Int. Conf. Adv. Inf. Netw. Appl. (AINA)* vol. 1, Mar. 2005, pp. 78–83.

[8] J. Zhao and G. Cao, "VADD: Vehicle-assisted data delivery in vehicular ad hoc networks," *IEEE Trans. Veh. Technol.*, vol. 57, no. 3, pp. 1910–1922, May 2008.

[9] B. K. Mohandas, A. Nayak, K. Naik, and N. Goel, "ABSRP—A service discovery approach for vehicular ad hoc networks," in *Proc. IEEE Asia–Pacific Services Comput. Conf.*, Dec. 2008, pp. 1590–1594.

[10] H. Yang, K. Zheng, K. Zhang, J. Mei, and Y. Qian, "Ultra-reliable and low-latency communications for connected vehicles: Challenges and solutions," *IEEE Netw.*, vol. 34, no. 3, pp. 92–100, May 2020.

[11] D. Li, T. Song, and Y. Yang, "Content retrieval based on prediction and network coding in vehicular named data networking," *IEEE Access*, vol. 8, pp. 125576–125591, 2020.

[12] B. Ji, X. Zhang, S. Mumtaz, C. Han, C. Li, H. Wen, and D. Wang, "Survey on the Internet of Vehicles: Network architectures and applications," *IEEE Commun. Standards Mag.*, vol. 4, no. 1, pp. 34–41, Mar. 2020.

[13] V. Nguyen, O. T. T. Kim, C. Pham, T. Z. Oo, N. H. Tran, C. S. Hong, and E.-N. Huh, "A survey on adaptive multi-channel MAC protocols in VANETs using Markov models," *IEEE Access*, vol. 6, pp. 16493–16514, 2018.

[14] V. Palma, E. Mammi, A. M. Vegni, and A. Neri, "A fountain codes-based data dissemination technique in vehicular ad-hoc networks," in *Proc. 11th Int. Conf. ITS Telecommun.*, Aug. 2011, pp. 750–755.

[15] J. Wu, S. Yang, and F. Dai, "Logarithmic store-carry-forward routing in mobile ad hoc networks," *IEEE Trans. Parallel Distrib. Syst.*, vol. 18, no. 6, pp. 735–748, May 2007.

[16] M. Luby, "LT codes," in *Proc. 43rd Annu. IEEE Symp. Found. Comput. Sci.*, Nov. 2002, pp. 271–280.

[17] N. H. Khiadani, "Analysis of data dissemination in vehicular ad hoc networks using rateless coding," Ph.D. dissertation, AmirKabir Univ. Technol., Tehran, Iran, 2015, pp. 1–114.

[18] Y. Mylonas, M. Lestas, A. Pitsillides, P. Ioannou, and V. Papadopoulou, "Speed adaptive probabilistic flooding for vehicular ad hoc networks," *IEEE Trans. Veh. Technol.*, vol. 64, no. 5, pp. 1973–1990, Jul. 2014.

[19] F. M. Malik, H. A. Khattak, A. Almogren, O. Bouachir, I. U. Din, and A. Altameem, "Performance evaluation of data dissemination protocols for connected autonomous vehicles," *IEEE Access*, vol. 8, pp. 126896–126906, 2020.

[20] O. Bouachir, M. Aloqaily, I. A. Ridhawi, O. Alfandi, and H. B. Salameh, "UAV-assisted vehicular communication for densely crowded environments," in *Proc. IEEE/IFIP Netw. Operations Manage. Symp.*, Apr. 2020, pp. 1–4.

[21] C. A. Kerrache, C. T. Calafate, N. Lagraa, J.-C. Cano, and P. Manzoni, "Trust-aware opportunistic dissemination scheme for VANET safety applications," in *Proc. Int. IEEE Conf. Ubiquitous Intell. Comput., Adv. Trusted Comput., Scalable Comput. Commun., Cloud Big Data Comput., Internet People, Smart World Congr. (UIC/ATC/ScalCom/CBDCom/IoP/SmartWorld)*, Jul. 2016, pp. 153–160.

[22] S. Dahmane, C. A. Kerrache, N. Lagraa, and P. Lorenz, "WeiSTARS: A weighted trust-aware relay selection scheme for VANET," in *Proc. IEEE Int. Conf. Commun. (ICC)*, May 2017, pp. 1–6.

[23] C. A. Kerrache, N. Lagraa, C. T. Calafate, J. C. Cano, and P. Manzoni, "T-VNets: A novel trust architecture for vehicular networks using the standardized messaging services of ETSI ITS," *Comput. Commun.*, vol. 93, pp. 68–83, Nov. 2016.

[24] W. Wu, J. Cao, and X. Fan, "Design and performance evaluation of overhearing-aided data caching in wireless ad hoc networks," *IEEE Trans. Parallel Distrib. Syst.*, vol. 24, no. 3, pp. 450–463, May 2012.

[25] D. Shin, H. Yoo, and D. Kim, "EMDOR: Emergency message dissemination with ACK-overhearing based retransmission," in *Proc. 1st Int. Conf. Ubiquitous Future Netw.*, Jun. 2009, pp. 230–234.

[26] P. Cataldi, A. Tomatis, G. Grilli, and M. Gerla, "CORP: Cooperative rateless code protocol for vehicular content dissemination," in *Proc. 8th IFIP Annu. Medit. Ad Hoc Netw. Workshop*, Jun. 2009, pp. 1–7.

[27] H. Zheng and J. Wu, "Placement optimization for advertisement dissemination in smart city," *IEEE Trans. Netw. Sci. Eng.*, vol. 7, no. 1, pp. 239–252, Jan. 2020.

[28] F. Delamare, F. L. Dotti, P. Fernandes, C. M. Nunes, and L. C. Ost, "Analytical modeling of random waypoint mobility patterns," in *Proc. 3rd ACM Int. Workshop Perform. Eval. Wireless ad hoc, Sensor Ubiquitous Netw. (PE-WASUN)*, 2006, pp. 106–113.

[29] H. Hartenstein and K. Laberteaux, *VANET: Vehicular Applications and Inter-Networking Technologies*. vol. 1. Hoboken, NJ, USA: Wiley, 2009.

[30] M. Sardari, F. Hendessi, and F. Fekri, "DDRC: Data dissemination in vehicular networks using rateless codes," *J. Inf. Sci. Eng.*, vol. 26, no. 3, pp. 867–881, 2010.

[31] N. H. Khiadani, S. M. S. Hemami, and F. Hendessi, "Introducing a handshake for data dissemination using rateless codes in vehicular ad hoc networks," *Trans. Emerg. Telecommun. Technol.*, vol. 28, no. 2, p. e2944, Feb. 2017.

[32] Y. Cao, H. Zhang, Y. Fang, and D. Yuan, "An adaptive high-throughput multichannel MAC protocol for VANETs," *IEEE Internet Things J.*, vol. 7, no. 9, pp. 8249–8262, Sep. 2020.

[33] T. Issariyakul and E. Hossain, "Introduction to network simulator 2 (NS2)," in *Introduction to Network Simulator NS2*. Boston, MA, USA: Springer, 2009, pp. 1–18.

[34] F. J. Martinez, C. K. Toh, J.-C. Cano, C. T. Calafate, and P. Manzoni, "A survey and comparative study of simulators for vehicular ad hoc networks (VANETs)," *Wireless Commun. Mobile Comput.*, vol. 11, no. 7, pp. 813–828, 2011.
[35] P. A. Lopez, M. Behrisch, L. Bieker-Walz, J. Erdmann, Y.-P. Flötteröd, R. Hilbrich, L. Lücken, J. Rummel, P. Wagner, and E. WieBner, "Microscopic traffic simulation using sumo," in *Proc. 21st Int. Conf. Intell. Transp. Syst. (ITSC)*, Nov. 2018, pp. 2575–2582.

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