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RBO-EM: Reduced Broadcast Overhead Scheme for Emergency Message Dissemination in VANETs

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ABSTRACT Effective information dissemination constitutes the cornerstone of communication in Vehicular Ad hoc Networks (VANETs). Avoiding broadcast storm is one of the considerable challenges in the development of an effective dissemination scheme for VANETs, which leads to extensive rebroadcasting. Reliable emergency messages delivery is another substantial measure of performance, especially in dense traffic and high mobility scenarios. A generic solution to deal with these problems is to cluster vehicles, so that emergency messages can be re-broadcasted to adjacent clusters only by a smaller number of vehicles. Thus, reliable selections of cluster head and relay nodes are important to reduce the number of retransmissions. In this regard, we propose a clustering technique for Reduced Broadcast Overhead Scheme for Emergency Message Dissemination (RBO-EM). RBO-EM is based on the mobility metrics to strengthen the cluster formation, avoid communication overhead and maintain the message reliability in a high mobility scenario. Moreover, we introduce relay nodes based on estimated link stability to limit the number of retransmissions. RBO-EM is evaluated against eminent schemes by varying traffic densities and speed. Simulation results indicate that RBO-EM enables a reasonable performance gain in terms of coverage, end-to-end delay and message reliability.

INDEX TERMS Cluster stability, congestion, emergency messages, flooding, reliability, safety applications, vehicular ad hoc networks.

I. INTRODUCTION

A. MOTIVATION

According to a report by the World Health Organization [1], every year the lives of nearly 1.3 million people are lost as a result of road accidents around the globe. To avoid such incidents, Vehicular Ad hoc Networks (VANETs) offer a promising solution. VANETs are a particular type of mobile ad hoc networks [2] that work in a variety of modes, including Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) as shown in Fig. 1. Advanced communication technologies, such as IEEE 1609 and IEEE 802.11p, are employed to exchange information between vehicles in the underlying VANET infrastructure. VANETs includes a wide range of applications that can be broken down into two classes, i.e., safety and comfort applications. Safety applications include cooperative collision avoidance and traffic information. Comfort applications, on the other hand, provide value added services, such as infotainment, road conditions and environmental protection [3].

In VANETs, safety applications rely mainly on broadcasting Emergency Messages (EMs). When a vehicle detects a hazardous event, it broadcasts EMs in the area of interest, so that the vehicles in vicinity can take adequate measures to prevent traffic accidents [4], [5]. However, excessive broadcasting leads to a number of critical issues, such as

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TABLE 1. Comparison of different EM dissemination schemes in VANETs.

Schemes	Network density considered	Vehicle speed considered	Evaluation metrics considered: Information coverage	PDR	End-to-end delay	Broadcast overhead considered?	Limitations
Little et al. [21]	High	Low	✓	✓	✓	✓	Hard to maintain an extended coverage area in a sparse network.
DV-CAST [28]	High	Low	✗	✓	✓	✓	High end-to-end delay and clustering overhead in intermittent network connectivity.
Flooding [16]	Low	Medium	✗	✓	✓	✗	A vehicle waits for a certain amount of time before sending EM, which increases end-to-end delay.
DMMAC [22]	High	High	✓	✓	✓	✓	The efficiency of secondary cluster head is reduced due to frequent switching caused by primary cluster head, which leads to unstable clusters.
Hassanabadi et al. [24]	Medium	High	✓	✓	✓	✓	Involves multiple iterative loops, which increase the cluster formation time and lead to high end-to-end delay.
Wistpongphan et al. [19]	Medium	Low	✗	✓	✓	✓	Congestion is triggered when more than one vehicles have p = 1.
Saeed et al. [17]	High	Medium	✓	✗	✓	✓	High end-to-end delay caused by the vehicle discovery process.
Velmurugan et al. [20]	Medium	Low	✗	✗	✓	✓	Simultaneous EM transmissions by multiple vehicles cause congestion.
Benkerdagh et al. [26]	High	High	✗	✓	✓	✓	End-to-end delay increases due to the post-event detection clustering process.
TBEM [27]	High	Medium	✓	✓	✓	✓	High number of retransmissions cause congestion and lower PDR.
MCA-V2I [25]	High	High	✗	✓	✓	✓	Clustering is based on BFS, which is time-consuming and, therefore, not suitable for large-scale networks.
P-DACCA [18]	Medium	High	✗	✗	✓	✓	Involves excessive cluster merging, which causes unstable clusters.
RBO-EM	High	High	✓	✓	✓	✓	Low communication range can reduce its coverage in sparse networks due to its pure V2V communication model.

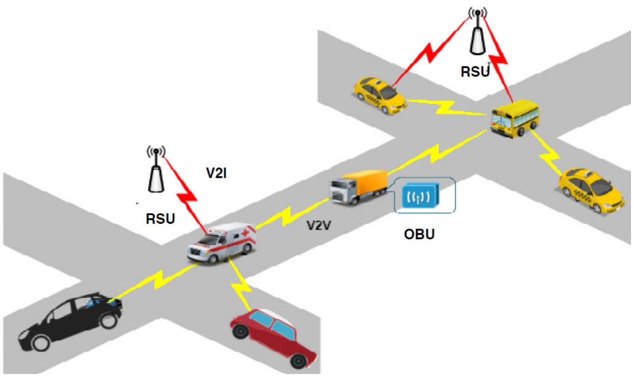

FIGURE 1. A generic representation of VANET architecture.

broadcast storms, communication network congestion and high latency [6].

Broadcast storms are triggered in VANETs due to high-traffic volumes, where each vehicle has the right to retransmit data packets simultaneously within the network. Such data dissemination techniques are based on flooding that results in redundant data transmissions. Transmission redundancy gives rise to packet loss rate and end-to-end delays [7]. For this purpose, several techniques, such as distance-based, counter-based and Store-Carry-Forward (SCF) based disseminations have been proposed in the literatures [8]–[10]. However, distance-based and counter-based techniques can only be used in well-connected networks and SCF incurs more end-to-end delay. Furthermore, without a central coordinator unit, the risk of redundant transmission will significantly increase. As a result, end-to-end delay and packet loss rate can also increase, particularly in dense networks. These limitations can be addressed by considering a cluster-based technique, which can create a hierarchical network structure by grouping vehicles based on certain predefined rules [11], [12]. Each cluster has a central coordinator, termed as a Cluster Head. Instead of transferring data to a more distant vehicle, the vehicle in a cluster delivers the data to its cluster head. This approach can significantly alleviate network congestion and broadcast storm problems [11]. Nevertheless, vehicular clustering has a number of open challenges, such as mobility and vehicle distribution, overhead in clustering process as well as the signal fading from neighboring vehicles and other obstacles [13], [14]. To address these challenges, this article presents a novel reduced broadcast overhead scheme, called RBO-EM, for emergency message dissemination in VANETs.

B. RELATED WORK

In recent years, EMs dissemination in VANETs has gained considerable attention. Drivers can prevent accidents by timely broadcasting EMs. Therefore, dissemination speed, particularly for time critical EMs, is a significant performance factor [15]. It is particularly challenging to design such systems for the highly dynamic vehicular networks. The timely EM forwarding and computationally efficient solutions are, therefore, required for EMs dissemination in VANETs. The schemes presented in this subsection seek to address specific problems in EMs dissemination, such as reducing the broadcast overhead and end-to-end delay, and increasing the information coverage and PDR. Table 1 presents a comparison of different schemes.

Broadcasting by flooding [16] is the easiest and most common way of disseminating information in VANETs. In flooding, every vehicle transmits a message to its neighbors. The receiving vehicles in turn transmit to their neighbors until the message propagates through the entire network. Since the network is infrastructure-less, therefore, it does not require any topological information. However, blind floods can lead to contention and collisions, which are commonly called broadcast storms that cause network breakdown, end-to-end delay and message collisions [17], [18]. To tackle these problems, researchers have proposed various schemes. For instance, the authors in [19] propose three schemes, namely, slotted 1-persistence, p-persistence and weighted p-persistence, where each vehicle retransmit the message with a probability $p \leq 1$. The proposed schemes are distributed and rely exclusively on data from Graphical Positioning System (GPS), which can effectively minimize the broadcast storm problem. However, these schemes depend solely on the distance among senders and receivers and, as such, are useful in solving the broadcast storm problem only in well-connected networks.

As aforementioned, minimizing collisions can increase Packet Delivery Ratio (PDR) and decrease delays in message transmissions in well-connected networks. The idea behind alleviating the broadcast storm problem and message collisions is to reduce retransmissions [20]. The existing techniques either allow a limited number of vehicles to retransmit messages, or completely restrain retransmissions. In [21], the network is partitioned into several clusters. Only the cluster head is responsible for rebroadcasting messages in each cluster. This approach can minimize the broadcast storm problem in a sparse traffic scenario, however, the approach is not easy to maintain an extended coverage area. In order to extend cluster coverage, the number of clusters must be minimized to enhance the cluster configuration and stability.

Recently, several clustering schemes [22]–[28] have been proposed for VANET. In [22], the authors propose a clustering scheme known as Distributed Multichannel and Mobility-Aware Cluster-based MAC Protocol for VANETs (DMMAC). DMMAC uses speed as the key factor for building the cluster, by employing a fuzzy framework for the processing of vehicle speeds to improve cluster stability. In addition, the DMMAC scheme employs a temporary cluster head concept which is used when the primary cluster head is not reachable. Similarly, in [23], a new clustering scheme is introduced for VANETs, where cluster heads are elected based on their neighborhood distances and relative velocity. The scheme selects a secondary cluster head for each cluster. These schemes [22], [23] are favorable to use in regions with high mobility, but primary cluster heads change very often with change in topology. Thus, the efficiency of secondary cluster head is reduced due to frequent switching caused by primary cluster head. Consequently, it leads to unstable clusters.

Moreover, the authors in [24] propose a new clustering scheme based on affinity propagation to deal with instability. Such a scheme does not require a fixed number of vehicles to form a cluster, it rather uses similarity measures among data points to exchange messages between data points during cluster formation. This method can help with cluster stability, however, the affinity algorithm involves multiple iterative loops, which increase the cluster formation time and, consequently, produce more delay. In [25], the authors propose a multi-hop clustering scheme based on breadth-first search algorithm (BFS) to improve network stability and efficiency. The key metric of this scheme is the relative velocity and distance to structure a stable cluster. In addition, the authors also consider Roadside Units (RSUs) to maximize coverage area, however, RSU-based communication incurs additional delays. Moreover, the multi-hop approach needs more control packet exchange, which causes communication overhead. In [26], an event-driven cluster-based scheme is introduced to achieve efficient bandwidth utilization and reduced message delivery time. However, clustering after event detection causes end-to-end delay, which is not favorable for time-critical information.

In [27], the authors propose a clustering scheme based on the time barrier technique, known as Time Barrier-Based Emergency Message Dissemination in Vehicular Ad-hoc Network (TBEM), to minimize unnecessary message dissemination. In their work, if an incident is observed, the farthest vehicle is used as a relay to cover more distance. There may be more vehicles at the same distance, so more than one vehicle can send the same message, which increases congestion. Moreover, after the time barrier has expired, vehicles are allowed to broadcast a message that results in a message redundancy and affects the overall network performance. Similarly, the authors in [28] propose Distributed Vehicular Broadcast (DV-CAST) protocol to adaptively increase the coverage area and reduce disconnected network problems. DV-CAST is the only approach we found in the literature, which specifically addresses different connectivity conditions in VANETs. DV-CAST employs SCF approach to increase coverage information. Moreover, to reduce the waiting time, the sending vehicles transmit EMs to the most distant vehicle with a high probability. However, the probability of a message being disseminated increases linearly as the distance increases. Consequently, the SCF approach leads to end-to-end delay. In such probabilistic approach, more than one vehicles can rebroadcast the same message and cause network congestion.

C. NOVELTY AND CONTRIBUTIONS

To address the challenges highlighted in the previous subsection, this article presents a cluster-based scheme, called, RBO-EM, which enables a vehicle to disseminate EMs in its area of interest (transmission range) so that other vehicles within its range can receive them. At the same time, it can decrease excessive broadcast by alleviating the right of each vehicle to broadcast data itself. The vehicles deliver data to their cluster head for further dissemination within a cluster and, to maximize the coverage area and reduce end-to-end delay, the farthest vehicle based on Estimated Link Stability ($\mathcal{L}_{\mathcal{ST}}$) can be used to rebroadcast the message. Compared to the existing schemes, i.e., conventional flooding [16], TBEM [27] and DV-CAST [28], our contributions are summarized as follows.

- We tend to build the clusters based on mobility metrics [25], [29], [30] together with our proposed $\mathcal{L}_{\mathcal{ST}}$ metric, which can maintain the cluster for a longer time, in order to reduce the communication overhead and achieve a high PDR in a highway scenario.
- To tackle the broadcast storm problem, we select a relay vehicle by considering $\mathcal{L}_{\mathcal{ST}}$, and thereby boost the

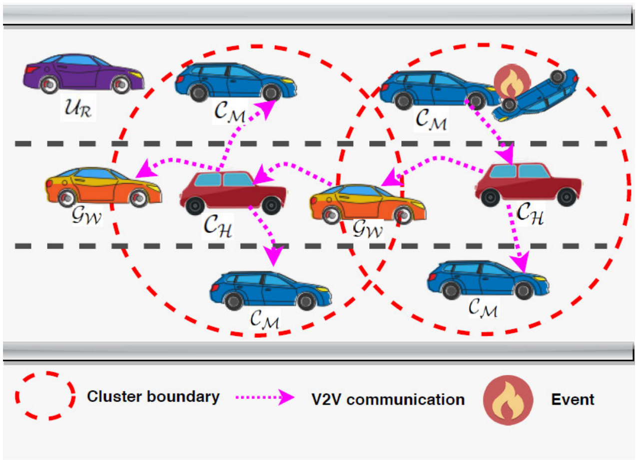

FIGURE 2. Network model.

PDR with acceptable end-to-end delay in high-density networks.

- We consider mobility and path loss factors for cluster head and gateway selection to use channel resources effectively.
- The results indicate that our proposed scheme outperforms TBEM, DV-CAST and flooding in terms of end-to-end delay, coverage information, network overhead, and message reliability.

The rest of the paper is structured as follows. Section II presents the system model. Section III presents the proposed scheme, while Section IV gives performance evaluation. The paper is concluded in Section V.

II. SYSTEM MODEL

This section presents network model, vehicle states, and mobility metrics used in the proposed scheme.

A. NETWORK MODEL

V2V communication is possible only when the vehicles are within the transmission range of each other. The considered scenario consists of different types of vehicles on a multi-lane highway, where vehicles can travel in different directions. To obtain the vehicle information, such as vehicle identifier, location and velocity, each vehicle is supposed to be equipped with Onboard Units (OBU) and GPS, as shown in Fig. 1. Moreover, OBU enabled vehicles periodically transmit *beacons* within their Transmission Range ($\mathcal{T_R}$), specified by Dedicated Short-Range Communication (DSRC) specification [31]. In the proposed RBO-EM scheme, the vehicles can be in one of the following states, as shown in Fig. 2.

- Un-registered ($\mathcal{U_R}$): The maiden state of a vehicle, which is not part of any cluster ($\mho$).
- Cluster Head ($\mathcal{C_H}$): The vehicle that makes coordination among the cluster members.
- Cluster Member ($\mathcal{C_M}$): The vehicle which is attached to an existing $\mathcal{C_H}$.
- Gateway ($\mathcal{G_W}$): The vehicle that can be part of multiple clusters. A $\mathcal{G_W}$ is used to deal with inter-cluster communication and is also called relay.

TABLE 2. List of notations.

Symbols	Description
$\mathcal{U_R}, \mathcal{C_M}$	Un-registered vehicle and cluster member, respectively
$\mathcal{C_H}, \mathcal{G_W}$	Cluster head and gateway vehicles, respectively
$\mathcal{C_{HA}}$	Cluster head advertisement
$\mathcal{T_R}$	Transmission range
$\mathcal{MM}$	Mobility metrics
$\mho$	Cluster
$\mathcal{C_{MA}}$	Cluster member advertisement
$\mathcal{C_{MT}}$	Cluster member table
$\mathcal{C_{HT}}$	Cluster head table
$\mathcal{C}\_id$	Cluster id
$\mathcal{C_H}\_id$	Cluster head id
$\mathcal{V}\_id$	Vehicles id
$\mathcal{N_C}_i$	Neighbor connectivity set of vehicle i
η_i	Neighborhood cardinality of $\mathcal{N_C}_i$
$\mathcal{C_{JR}}$	Request to join a cluster
$dist(i,j)$	Relative distance between vehicles i and j
$\mathcal{V_R}_i$	Relative normalized mean velocity of vehicle i
$\mathcal{D_R}_i$	Relative normalized mean distance of vehicle i
$\mathcal{L_T}_i$	Normalized longest remaining time of vehicle i
Γ	The remaining time of all the vehicles in the cluster
Ω_{ij}	Set of relative path loss of reference vehicles i and j
$\mathcal{P_L}_i$	Normalized average path loss of vehicle i
ψ_{ij}	Relative velocity set of vehicles i and j
$\mathcal{L_{ST}}$	Estimated link stability

B. MOBILITY METRICS

This section presents mobility information used in our proposed scheme (RBO-EM). Maintaining generality, the reference vehicles are represented as i and j. Other notations used in the scheme are shown in the Table 2. Considering a single parameter, such as distance or velocity to measure the quality of a vehicle as a cluster head, may result in degraded network efficiency [32]. Therefore, a vehicle's primacy to become a $\mathcal{C_H}$ relies on its Mobility Metrics ($\mathcal{MM}$), which is a combined weight determined according to the mobility parameters and neighborhood information of the vehicle listed below. Moreover, in order to minimize the possibility that one value cannot dominate the set of $\mathcal{MM}$ values, the values are normalized by dividing on the maximum (max) value in each set to be within the range [0,1].

- Neighborhood Connectivity ($\mathcal{N_C}$): $\mathcal{N_C}$ represents the set of neighborhood of a vehicle. Two vehicles are said to be neighbors if the distance between them is less than $\mathcal{T_R}$. Let $\mathcal{N}$ shows the set of vehicles in the network, then $\mathcal{N_C}$ of vehicle i can be calculated as

$$\mathcal{N_C}_i = \{j|dist(i,j) < \mathcal{T_R}\}, \tag{1}$$

where $i,j \in \mathcal{N}$. $dist(i,j)$ is the relative distance between vehicles i and j, which can be computed via Euclidean distance as [33]

$$dist(i,j) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}, \tag{2}$$

where (x_i, y_i) and (x_j, y_j) are the GPS coordinates of vehicle i and j, respectively.

- Neighborhood cardinality (η): η is the number of vehicles in $\mathcal{N_C}$. Thus, η of vehicle i can be expressed as

$$\eta_i = |\mathcal{N_C}_i|. \tag{3}$$

- Mobility direction: Vehicles on the road heading in the opposite direction to the cluster head will quickly lose contact with the cluster head. Contrarily, the vehicles traveling in the same direction will retain a relatively stable link with the cluster head. We, therefore, group vehicles according to their mobility direction. For simplicity, some existing works assume a direction, but it is not a practical approach. Among the other methods, magnetic vector field seems to be simple, but has low robustness and reliability, which may lead to unacceptable heading errors and reduced accuracy at higher latitudes [34]. Compared to the magnetometer, the proposed method, which is based on angle using the GPS coordinates, yields a more accurate heading direction. Two vehicles are considered to be in the same direction, if the angle (θ) between the velocity vectors is $\leq \pi/4$ [29]. Suppose the GPS coordinate positions (X, Y) of vehicles i and j at time steps t_1 and t_2 are (x_i, y_i), (x_j, y_j), and $(\bar{x}_i, \bar{y}_i)$, $(\bar{x}_j, \bar{y}_j)$, respectively, then θ between vehicles i and j can be computed as [35]

$$\theta_{ij} = \arccos\left(\frac{\Delta x_i \Delta x_j + \Delta y_i \Delta y_j}{\sqrt{\Delta x_i^2 + \Delta y_i^2}\sqrt{\Delta x_j^2 + \Delta y_j^2}}\right), \quad \begin{cases} \Delta x = \bar{x}_i - x_i, \\ \Delta y = \bar{y}_i - y_i. \end{cases} \tag{4}$$

Δx and Δy represents the change in x and y coordinates of the velocity vectors in an interval of t. Thus, the variation in x and y coordinates depends on the time duration and velocity of the vehicles, which cannot be a fixed value. However, the relative vehicles must be within the communication range of each other.

- Normalized Relative Mean Distance ($\mathcal{D}_{\mathcal{R}}$): Is the mean distance between vehicle i and its neighbors. A vehicle with the lower $\mathcal{D}_{\mathcal{R}}$ is close to the center of its neighborhood. Thus, the vehicle having lower $\mathcal{D}_{\mathcal{R}}$ will have more stable state, which will be a significant candidate for $\mathcal{C}_{\mathcal{H}}$. Based on (1), (2), and (3), the normalized relative mean distance $\mathcal{D}_{\mathcal{R}}$ of vehicle i with respect to its neighbors can be computed as

$$\mathcal{D}_{\mathcal{R}i} = \frac{1}{\eta_i}\frac{\sum_{j=1,j\neq i}^{\eta_i} dist(i,j)}{\max\{dist(i,j)\}}; \forall j \in \mathcal{N}_{\mathcal{C}i}. \tag{5}$$

- Normalized Relative Mean Velocity ($\mathcal{V}_{\mathcal{R}}$): Selection of $\mathcal{C}_{\mathcal{H}}$ is based on its velocity differences with the neighboring vehicles. A vehicle with lower relative mean velocity with respect to its one-hop neighbors shows that the vehicle has a more stable state. The stability ensures that the vehicle will remain in its own cluster area for a longer period of time as compared to other vehicles. Consequently, the $\mathcal{C}_{\mathcal{H}}$ switching may not occur frequently. Let v_i and v_j are the velocities of vehicles i and j, respectively, such that $\forall j \in \mathcal{N}_{\mathcal{C}i}$ and ψ_{ij} is the set of relative velocities, which can be computed as

$$\psi_{ij} = |v_i - v_j|. \tag{6}$$

Thus, the normalized relative mean velocity $\mathcal{V}_{\mathcal{R}}$ of vehicle i with respect to its neighbors can be calculated as

$$\mathcal{V}_{\mathcal{R}i} = \frac{1}{\eta_i}\frac{\sum_{j=1,j\neq i}^{\eta_i} \psi_{ij}}{\max\{\psi_{ij}\}}; \quad \forall j \in \mathcal{N}_{\mathcal{C}i}. \tag{7}$$

- Normalized Average Path Loss ($\mathcal{P}_{\mathcal{L}}$): Determines the average relative effects of fading on wireless signal in VANETs [30]. A vehicle with a lower average path loss value compared to other vehicles is more likely to become a $\mathcal{C}_{\mathcal{H}}$. As re-clustering and cluster merging are less likely to happen under the Log Normal Path Loss Model [36], therefore, considering cluster stability, the average path loss can be computed as [37]

$$\Omega_{ij}(d)(dB) = PL(d_0) + 10\alpha \log_{10}\left(\frac{d}{d_0}\right) + X_\sigma, \tag{8}$$

where Ω_{ij} is the path loss of vehicle i and its one-hop neighbor j, such that $\forall j \in \mathcal{N}_{\mathcal{C}i}$, $PL(d_0)$ is the path loss that can be calculated with the Friis equation at the reference distance d_0, d is the actual distance between vehicles i and j, and X_σ is a Gaussian random variable with zero mean and standard deviation 3.2 dB, as recommended by [38]. According to [39], α is path loss exponent with different environment parameters given in Table 3. Thus, d_0, α, and the standard deviation (σ) statistically describe $\Omega_{ij}(d)dB$ for an arbitrary location having a specific transmitter-receiver separation [40]. Finally, $\mathcal{P}_{\mathcal{L}}$ of vehicle i with respect to its neighbor j, such that $\forall j \in \mathcal{N}_{\mathcal{C}i}$, can be calculate as

TABLE 3. Path loss exponent values.

Environment	Path loss exponent, α
Free space	2 – 4.43
Urban region	2.7 – 3.5
Suburban region	3 – 5
Indoor	1.6 – 1.8

$$\mathcal{P}_{\mathcal{L}i}(dB) = \frac{1}{\eta_i}\frac{\sum_{j=1}^{\eta_i} \Omega_{ij}}{\max\{\Omega_{ij}\}}; \quad j \neq i. \tag{9}$$

- Normalized Longest Remaining Time ($\mathcal{L}_{\mathcal{T}}$): Each vehicle periodically computes the remaining time, $\mathcal{L}_{\mathcal{T}}$, for leaving the road based on its current position, which is determined by GPS. A vehicle with the longest $\mathcal{L}_{\mathcal{T}}$ to leave a road is, therefore, a favorable candidate for becoming a $\mathcal{C}_{\mathcal{H}}$ [41]. This metric, thus, extends the cluster longevity. In practice, each vehicle knows its destination and, thus, this metric can be easily applied [42]. Hence, $\mathcal{L}_{\mathcal{T}}$ of vehicle i can be calculated as

$$\mathcal{L}_{\mathcal{T}i} = \frac{L - D_i}{\max(\Gamma) D_i} t. \tag{10}$$

Here, L is the length of the road, D_i is the distance covered by the vehicle i in time t, and Γ is the time required for any vehicle to cover distance $L - D$, which is calculated as [41]

$$\Gamma = \frac{L - D}{D} t. \tag{11}$$

Hence, the mobility metrics $\mathcal{MM}$ of vehicle i based on (5), (7), (9) and (10), respectively, can be calculated as

$$\mathcal{MM}_i = \mathcal{D}_{\mathcal{R}i} + \mathcal{V}_{\mathcal{R}i} + \mathcal{P}_{\mathcal{L}i} - \mathcal{L}_{\mathcal{T}i}. \quad (12)$$

From (12), a vehicle having a minimum $\mathcal{MM}$ will be eligible to become a $\mathcal{C}_{\mathcal{H}}$.

III. THE PROPOSED SCHEME

This section presents our proposed EMs scheme, which is based on a single-hop directional clustering. The notion behind this scheme is to implement a clustering technique to guarantee an efficient EMs dissemination. In clustering, vehicles are managed into a number of clusters as shown in Fig. 2. Each cluster contains a $\mathcal{C}_{\mathcal{H}}$, which is responsible for managing information about the cluster members as well as EMs dissemination. The $\mathcal{MM}$ based on (12) are taken into consideration for $\mathcal{C}_{\mathcal{H}}$ selection and cluster stability. This would give the vehicles sufficient time to exchange information among themselves. The fading effect is also a significant factor in determining the transmission quality. Hence, we consider the fading effects and $\mathcal{MM}$, presented in the previous section, in our proposed RBO-EM scheme. RBO-EM mainly comprises of five phases, i.e., neighborhood discovery, cluster formation, gateway selection, cluster maintenance, and emergency message dissemination.

Every vehicle announces its existence in the network by broadcasting *beacon* messages. The receiving vehicle stores necessary information, such as address, velocity, location, and vehicle state from the information embedded in *beacon* message, to build a neighborhood connectivity. Afterwards, a vehicle can start cluster formation or enter an existing cluster depending on whether or not a $\mathcal{C}_{\mathcal{H}}$ is located nearby. The process to select gateways for inter-cluster communication will begin after cluster formation. Thus, following cluster formation and gateway selection, cluster maintenance is needed to check the validity of the cluster periodically. Meanwhile, when a vehicle observes a hazardous event, an EM will be disseminated so that all anticipated vehicles can take adequate precautionary measures. These phases are described in detail in the following subsections.

A. NEIGHBORHOOD DISCOVERY PHASE

To proclaim its presence in the network, each vehicle periodically broadcasts *beacon* messages to its immediate one-hop neighbors, containing information like, address ($\mathcal{V}$_*id*), position (x,y coordinates), speed, and vehicle state ($\mathcal{U}_{\mathcal{R}}, \mathcal{C}_{\mathcal{H}}, \mathcal{C}_{\mathcal{M}}, \mathcal{G}_{\mathcal{W}}$). The neighborhood discovery process is defined in Algorithm 1, where each vehicle updates its $\mathcal{N}_{\mathcal{C}}$ based on (2) and (4) after receiving *beacon* from its single-hop neighbors.

B. CLUSTER FORMATION PHASE

In order to select a suitable $\mathcal{C}_{\mathcal{H}}$, we consider various metrics and notations defined in the previous section. According to Section II-A, there are some un-registered vehicles ($\mathcal{U}_{\mathcal{R}}$) that want to join a new cluster. For this reason, these vehicles announce *beacon* message to their immediate neighbors,

Algorithm 1 Neighborhood Discovery

```
Require: N_Ci, state (C_H, C_M, U_R, G_W), vehicles
foreach vehicle do
    if (state == U_R || state == C_H || state == C_M ||
    state == G_W) then
        Broadcast beacon
    end
    foreach recieved beacon from a vehicle do
        Compute dist() & θ based on (2) and (4)
    end
    if dist() < T_R & θ ≤ π/4 then
        Add vehicle to N_Ci
    end
end
```

which includes the position, speed, and direction information. Similarly, there are cluster heads in the network, which also announce their basic mobility information, such as Cluster head id ($\mathcal{C}_{\mathcal{H}}$_*id*), location, velocity and direction, through $\mathcal{C}_{\mathcal{H}}$ Advertisement ($\mathcal{C}_{\mathcal{H}A}$).

Consequently, when vehicle i receives $\mathcal{C}_{\mathcal{H}A}$ or a *beacon* message, it records the corresponding sender's $\mathcal{C}_{\mathcal{H}}$_*id* or $\mathcal{V}$_*id* into its neighbor connectivity set, respectively. Then, it uses (4) to measure the angle (θ) between its direction relative to its one-hop neighbor's direction. If $\theta < \pi/4$, the corresponding neighbors are considered moving in the same direction. In all other cases, the record is deleted from $\mathcal{N}_{\mathcal{C}i}$. Upon checking θ and updating $\mathcal{N}_{\mathcal{C}i}$, vehicle i computes its $\mathcal{MM}_i$ value based on (12) and shares it with other vehicles in $\mathcal{N}_{\mathcal{C}i}$.

Whenever, there is only one $\mathcal{C}_{\mathcal{H}}$ in vehicle i's $\mathcal{N}_{\mathcal{C}i}$, it sends Request to Join a Cluster ($\mathcal{C}_{\mathcal{JR}}$) containing its $\mathcal{V}$_*id* to the $\mathcal{C}_{\mathcal{H}}$ and becomes a Cluster Member ($\mathcal{C}_{\mathcal{M}}$). When there are more than one cluster heads in vehicle i's $\mathcal{N}_{\mathcal{C}i}$, it selects a $\mathcal{C}_{\mathcal{H}}$ having the smallest $\mathcal{MM}$ value and sends a $\mathcal{C}_{\mathcal{JR}}$ to the $\mathcal{C}_{\mathcal{H}}$. Unless vehicle i's $\mathcal{N}_{\mathcal{C}i}$ does not include $\mathcal{C}_{\mathcal{H}}$, it compares its $\mathcal{MM}_i$ value with all the vehicles in the $\mathcal{N}_{\mathcal{C}i}$. If vehicle i observes that its $\mathcal{MM}_i$ value is lower than that of any other vehicle in its $\mathcal{N}_{\mathcal{C}i}$, it declares itself to be the $\mathcal{C}_{\mathcal{H}}$ and transforms its status from $\mathcal{U}_{\mathcal{R}}$ to $\mathcal{C}_{\mathcal{H}}$. Moreover, its $\mathcal{V}$_*id* is used as $\mathcal{C}_{\mathcal{H}}$_*id* as well as the Cluster id (C_*id*). Consequently, the newly selected $\mathcal{C}_{\mathcal{H}}$ will broadcast $\mathcal{C}_{\mathcal{H}A}$ packets to vehicles in $\mathcal{N}_{\mathcal{C}i}$, which contains the $\mathcal{C}$_*id* and its $\mathcal{MM}_i$ value. Upon receiving $\mathcal{C}_{\mathcal{H}A}$, other vehicles in $\mathcal{N}_{\mathcal{C}i}$ will respond by sending a $\mathcal{C}_{\mathcal{JR}}$ to vehicle i, if its $\mathcal{MM}_i$ value is lower than that of all $\mathcal{C}_{\mathcal{H}}$s. Upon receiving $\mathcal{C}_{\mathcal{JR}}$ from any vehicle j, such that $j \in \mathcal{N}_{\mathcal{C}i}$ and $\theta < \pi/4$ based on (4), a $\mathcal{C}_{\mathcal{H}i}$ will add vehicle j's $\mathcal{V}$_*id* in its Cluster Member Table ($\mathcal{C}_{\mathcal{MT}i}$). Thus, j will become member of the cluster. Conversely, vehicle j will add vehicle i's V_*id* in its Cluster Head Table ($\mathcal{C}_{\mathcal{HT}j}$).

Once a cluster is built, the $\mathcal{C}_{\mathcal{H}}$ periodically broadcasts $\mathcal{C}_{\mathcal{HA}}$ packets to show its existence in the network. Similarly, $\mathcal{C}_{\mathcal{M}}$ broadcasts Cluster Member Advertisement ($\mathcal{C}_{\mathcal{M}A}$) packets comprising the $\mathcal{C}_{\mathcal{M}}$'s id, location, speed, and direction. In this

Algorithm 2 Cluster Formation

```
Require: state, Ʊ, N_Ci
j, k ∈ N_Ci
foreach vehicle in N_Ci do
    Compute MM & θ
    if ∃ C_Hj ∈ N_Ci & MM_j < ∀ C_Hk & θ < π/4 then
        State_i ← C_M
        C_H_id_i ← V_id_j
        C_id_i ← C_H_id_i
        C_MT_j ← V_id_i
        Add i to Ʊ_j
        C_HT_i ← V_id_j
        Invoke Algorithm 3
    end
    else if (MM_i < ∀MM_j) then
        State_i ← C_H
        C_H_id_i ← V_id_i
        C_id_i ← C_H_id_i
        Broadcast C_HA
    end
    else if i receives C_JR from j & MM_i < ∀MM_j
    then
        C_MT_i ← V_id_j
        Add j to Ʊ_i
        C_HT_j ← V_id_i
        Invoke Algorithm 3
    end
    else
        Ignore cluster join request
    end
    Invoke Algorithm 4
end
```

way, both $\mathcal{C_H}$ and $\mathcal{C_M}$ identify each other's existence and maintain the cluster structure. Moreover, $\mathcal{N_C}$ should also be updated regularly. The details of the cluster formation procedure is illustrated in Algorithm 2.

C. GATEWAY SELECTION PHASE

RBO-EM aims to disseminate EMs on highways covering a large area. A gateway provides interaction between two clusters to increase the coverage area without the need to deploy RSUs. To achieve inter-cluster communication, $\mathcal{C_H}$ chooses two $\mathcal{C_M}$s, which travel on the boundary of the cluster to be the $\mathcal{G_W}$ vehicle. Sometimes, it may be the case that more than one vehicles have the same relative distance from their $\mathcal{C_H}$. In order to deal with this issue, $\mathcal{L_{ST}}$ is introduced between $\mathcal{C_H}$ and $\mathcal{C_M}$s. A lower $\mathcal{L_{ST}}$ value reflects a more sustainable link, which can be computed as

$$\mathcal{L_{ST}}_{ij} = \mathcal{T_R}(\frac{\mathcal{V_R}_{i,j}}{\mathcal{D_R}_{i,j}}), \quad (13)$$

where $\mathcal{V_R}_{i,j}$ and $\mathcal{D_R}_{i,j}$ are the relative velocity and relative distance between reference vehicles i and j based on (7) and (5), respectively. As shown in Algorithm 3, a vehicle

Algorithm 3 Gateway Selection

```
Require: state (C_H, C_M), Ʊ
 vehicles i, j, k ∈ Ʊ
for ∀ C_Ms of C_Hi do
    Compute dist()
    if (dist(i, j) > dist(i, k)) then
        Select j as a G_W
    end
    else
        Select k as a G_W
    end
    if dist(i, j) == dist(i, k) then
        Compute L_ST based on (13)
        if L_STij < L_STik then
            Select j as G_W
        end
        else
            Select k as a G_W
        end
    end
end
```

having lower $\mathcal{L_{ST}}$ will be selected as a $\mathcal{G_W}$. The overall clustering process is represented in Fig. 3 and illustrated in Algorithm 1 to Algorithm 4.

Once a cluster is formed, $\mathcal{C_H}$ and $\mathcal{C_M}$s periodically broadcast $\mathcal{C_{HA}}$ and $\mathcal{C_{MA}}$ messages to determine and maintain the link connectivity status. There are frequent topological changes in clusters due to high mobility in VANETs. Therefore, the cluster should be maintained on a regular basis as described in the next subsection.

D. CLUSTER MAINTENANCE PHASE

VANETs are usually unstable due to their dynamic nature. Vehicles frequently join and leave clusters, thereby triggering extra overhead that needs to be managed. The events that need to be addressed are outlined below.

- Joining a cluster: when a $\mathcal{U_R}$ vehicle arrives in the vicinity of a $\mathcal{C_H}$ and sends a $\mathcal{C_{JR}}$ message, its eligibility will be checked according to Algorithm 2. The eligible vehicle's request will be entertained by adding it to the cluster head's $\mathcal{C_{MT}}$. In a similar way, all cluster members add their cluster head's $\mathcal{V}\_id$ in their $\mathcal{C_{HT}}$.
- Leaving a cluster: when a $\mathcal{C_M}$ moves out of the $\mathcal{C_H}$ transmission range and loses contact with its respective $\mathcal{C_H}$, both $\mathcal{C_H}$ and $\mathcal{C_M}$ remove each other's record from their respective tables ($\mathcal{C_{MT}}$, $\mathcal{C_{HT}}$) according to Algorithm 4. $\mathcal{C_H}$ checks its $\mathcal{C_{MT}}$, if no more cluster members exist, $\mathcal{C_H}$ resigns from the position of the cluster head and transfers its status to $\mathcal{U_R}$.

We borrow the concept of *soft handoff* [43] in cluster maintenance to minimize packet loss rate due to link disconnection between cluster members and $\mathcal{C_H}$. As illustrated in Algorithm 4, when a $\mathcal{C_M}$ listens to *beacon* from more than

Algorithm 4 Cluster Maintenance

```
Require: state (C_H, C_M, U_R), Ʊ
foreach C_H and C_Ms in Ʊ do
    if C_H cannot reach a C_M then
        Drop V_id of C_M from C_MT
        if no more C_Ms exist in C_MT then
            C_H resigns from the C_H role
            State ← U_R
            Invoke Algorithm 2
        end
    end
    else if a C_M cannot reach C_H then
        Drop C_H_id from C_HT
        State ← U_R
        Invoke Algorithm 2
    end
    else if a C_M recieves signals from more than one C_Hs then
        C_M joins a C_H with minimum MM value
        Update C_HT
    end
    else
        The C_H continues its role as C_H
    end
end
```

Algorithm 5 Emergency Message Dissemination

```
Require: state (C_H, C_M, U_R, G_W), Ʊ
foreach EM in Ʊ do
    Step1:
    if a C_H having EM then
        if G_W ≠ Ø then
            C_H broadcast EM and authorize G_W to send
            EM to the C_H in neighbouring clusters
        end
        else
            C_H broadcast EM and select farthest vehicle
            based on L_ST to disseminate EM to the
            neighbouring clusters
        end
    end
    Step 2:
    else if a C_H recieved EM from a C_M then
        if the same EM already recieved by the C_H then
            Ignore the EM
        end
        else
            Invoke Step 1
        end
    end
    else
        Invoke Algorithm 2
    end
end
```

one cluster heads, the $\mathcal{C}_\mathcal{M}$ joins a $\mathcal{C}_\mathcal{H}$ with minimum $\mathcal{MM}$ value before disconnecting from its respective $\mathcal{C}_\mathcal{H}$.

E. EMERGENCY MESSAGE DISSEMINATION PHASE

The goal of RBO-EM is to improve the efficiency of EMs dissemination in terms of end-to-end delay, information coverage and message reliability in V2V communication. In traditional approaches, the information is disseminated as a broadcast, which causes network congestion and increases the chances of end-to-end delay and packet drop rate. On detection or reception of any EM, dissemination can take place on the basis of the following criteria.

- If the receiver/detector is a $\mathcal{C}_\mathcal{H}$, the message will be disseminated to all the cluster members.
- If the receiver/detector is a $\mathcal{C}_\mathcal{M}$, the EM will only be sent to the corresponding $\mathcal{C}_\mathcal{H}$ for further dissemination. Thus, uni-casting will stop the broadcast storm from overwhelming the network.

Inter-cluster communication can be used to achieve maximum coverage. The proposed RBO-EM scheme will check the following situations in order to achieve inter-cluster communication.

- The message will be disseminated to the nearby clusters via $\mathcal{G}_\mathcal{W}$.
- If a neighboring cluster does not exist, $\mathcal{C}_\mathcal{H}$ would enable the farthest vehicle in the cluster to disseminate EM within its broadcast range to maximize coverage. However, if multiple vehicles have the same distance from $\mathcal{C}_\mathcal{H}$, then more than one vehicles can broadcast EMs simultaneously, which may cause congestion. In order to deal with this problem, the farthest vehicle based on (13) with minimum $\mathcal{L}_{\mathcal{ST}}$ will be selected to disseminate EMs as illustrated in Algorithm 5.

The above mentioned procedure in the subsequent clusters will be followed to gain maximum coverage. The overall procedure of the proposed RBO-EM scheme is shown in Fig. 3.

IV. PERFORMANCE EVALUATION

In this section, we evaluate the performances of the proposed RBO-EM scheme using multiple vehicular traffic simulators, namely, Simulation of Urban Mobility (SUMO), Mobility Model Generator for Vehicular Networks (MOVE), and ns-2 (version 2.35). SUMO and MOVE allow users to create VANET simulations with real world mobility models. MOVE is built on top of SUMO, which is open source micro-traffic simulator. The output from MOVE is used by ns-2, which is widely used for analyzing VANETs performance [44]. Mobility is simulated on a 6 km long highway with 3-lanes per direction, according to the Krauss car-following model [45]. Vehicle speeds vary uniformly between 40 km/hr and 125 km/hr. The vehicle density varies between 25/km to 125/km and transmission range is 300 m. A complete list of simulation parameters is given in Table 4.

The proposed RBO-EM scheme is compared and analyzed against conventional flooding [16] and two eminent schemes, namely, TBEM [27] and DV-CAST [28]. Performance is analyzed based on the following metrics.

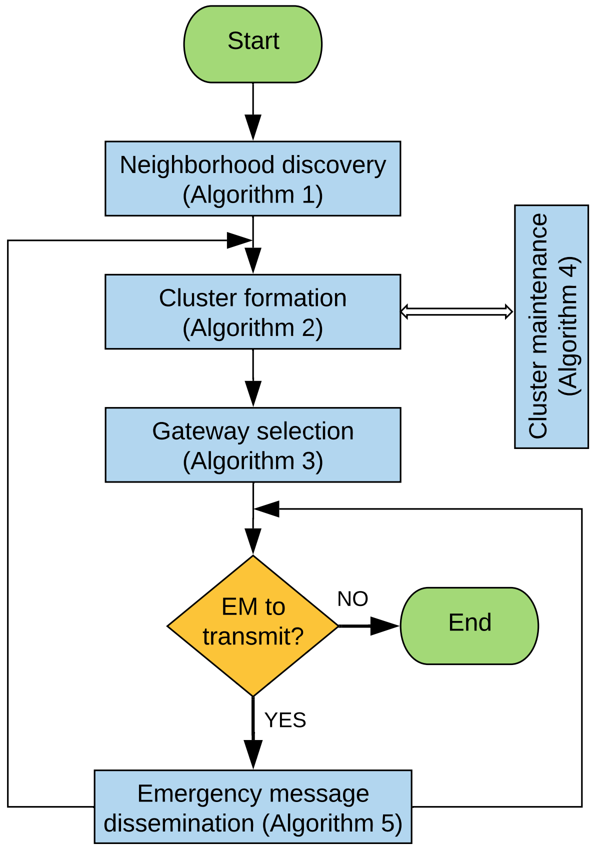

FIGURE 3. Procedural flowchart of RBO-EM.

TABLE 4. Simulation parameters.

Parameters	Configuration
Wireless access	IEEE 802.11p / IEEE I609
Frequency	5.9 GHz
Propagation model	Shadowing
Transmission power	20 mW
Mobility model	Krauss
Maximum number of lanes	3
Simulation time	500 s
Simulation area	6000 m x 600 m
Transmission range	300 m
Vehicle density	25–125 /km
Vehicle velocities	40–125 km/hr
beacon interval	60 ms
Accident interval	20 s
Number of RSUs	None
Bit rate	6 Mbps
beacon pcket size	200 Bytes
EM packet size	170 Bytes

- Information coverage: The number of vehicles that received EM successfully from all the anticipated vehicles in a particular area.
- End-to-end delay: The latency experienced by a packet from source to destination.
- PDR: The ratio of successfully received packets at the destination to the total packets sent by the source vehicle.
- Normalized network overhead: The ratio of the total generated packets to the data packets successfully received by the destinations.
- Cluster formation overhead: The average number of packets sent per vehicle during the $\mathcal{C}_{\mathcal{H}}$ selection phase.

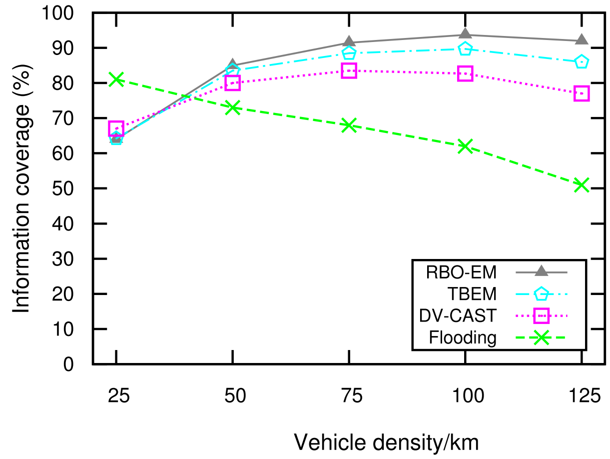

FIGURE 4. Information coverage vs. vehicle density.

A. INFORMATION COVERAGE

Information coverage among the compared schemes is assessed with different vehicle densities as shown in Fig. 4. The figure shows that the information coverage is low at the beginning. This is due to the lack of guarantee that a full end-to-end route exists between the vehicles in a sparse environment. In this case, the information coverage increases with the increase in network density. However, information coverage begins to decline when the size of network exceeds a certain threshold, e.g., 100/km. The reason is that the broadcast storm problem becomes more rigorous in a dense network, thus, reducing the information coverage. In the flooding scheme, each vehicle broadcasts a message without a proper coordination, which leads to a broadcast storm. The farthest vehicle in both DV-CAST and TBEM has the highest priority to forward EMs. Since only distance is considered by DV-CAST and TBEM, multiple vehicles may have the same distance, which simultaneously send messages causing congestion and lower network performance. Conversely, RBO-EM uses the farthest vehicle based on $\mathcal{L}_{\mathcal{ST}}$, which reasonably prevents multiple vehicles from simultaneously transmitting EMs, thereby minimizing congestion and improve network performance. As an example, for 100 vehicles/km, we observe that RBO-EM has 13.3%, 4.5% and 51.12% more coverage area compared to DV-CAST, TBEM and flooding, respectively.

B. END-TO-END DELAY

Fig. 5 illustrates the average end-to-end delay relative to vehicle density. The flooding technique outperforms DV-CAST, TBEM and RBO-EM schemes in a low density environment. However, flooding generates a significantly large network traffic in high density, which causes a broadcast storm and incurs end-to-end delay. DV-CAST uses SCF approach in low density while a probabilistic approach in high-density environments. Because message can travel faster than vehicles, and the probabilistic approach increases the probability of more vehicles to retransmit EMs, which causes packet congestion. Consequently, DV-CAST faces an extra delay due to its SCF and distance based probabilistic

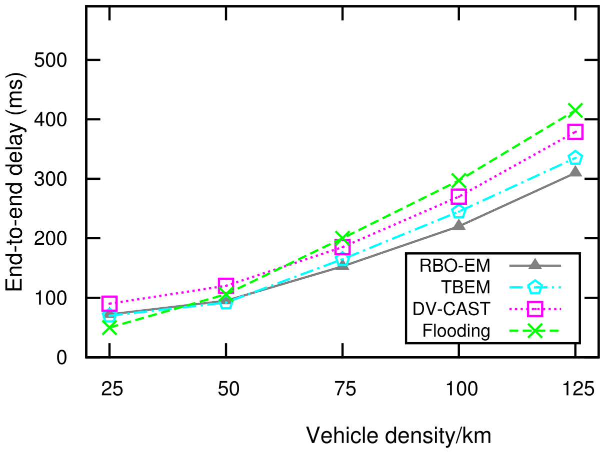

FIGURE 5. End-to-end delay vs. vehicle density.

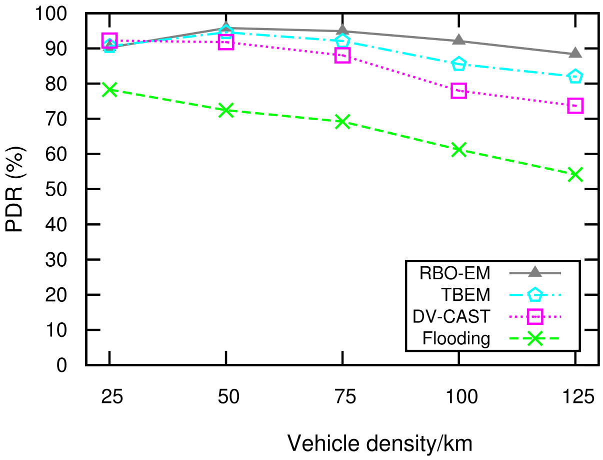

FIGURE 6. PDR vs. vehicle density.

approach. In TBEM, every vehicle has the right to rebroadcast EMs once its time barrier has expired. These retransmissions increase communication network congestion and result in increased end-to-end delays. Conversely, RBO-EM suppresses the broadcast storm and reduces the average end-to-end delay by 8.22%, 18.97% and 3.8% as compared to flooding, DV-CAST and TBEM, respectively.

C. PACKET DELIVERY RATIO

Fig. 6 illustrates PDRs of RBO-EM, DV-CAST, TBEM and flooding as functions of network density. It can be observed that PDR increases rapidly with an increase in vehicle density. This is because the increase in vehicle density increases network connectivity and, thus, offers more chances of delivering the messages successfully. Once the network becomes more crowded, increased packet exchange will result in more congestion that causes a high packets failure. Fig. 6 shows that DV-CAST performs well at low density due to its SCF approach. However, this approach is inefficient for time-critical data due to end-to-end delay. The most distant vehicle in both the DV-CAST and TBEM schemes has the highest priority EM. Thus, multiple vehicles may concurrently broadcast EM, which causes congestion in a dense

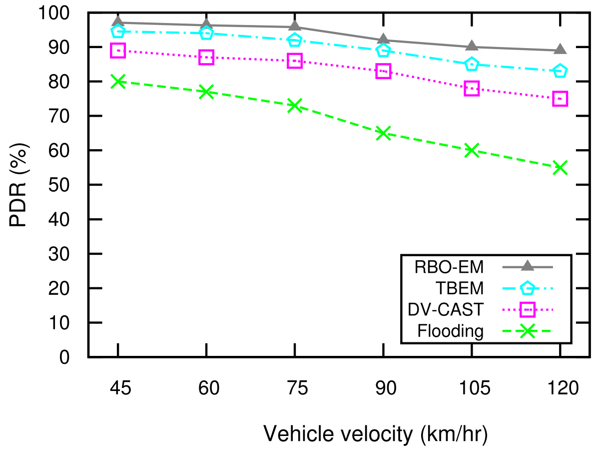

FIGURE 7. PDR vs. vehicle velocity.

network, resulting in lower PDR. Moreover, in TBEM, every vehicle has the right to rebroadcast EMs once its time barrier has expired. These retransmissions increase network congestion in high density case and result in lower PDR. Contrarily, RBO-EM minimizes excessive broadcasting and yields an average increase of 9.5%, 3.79% 39.73% in PDR relative to DV-CAST, TBEM and flooding, respectively.

Fig. 7 shows the impact of velocity on the PDR. The ratio is high at lower speeds but decreases with increasing vehicle velocity. High mobility decreases network lifetime, which may reduce PDR, so the cluster stability plays a significant part. Network instability can cause more control packets (*beacons*) to be exchanged for clustering and relaying node selection, which leads to extra communication overhead and congestion. Generally, with high mobility, the distance between the vehicles increases. For DV-CAST and TBEM, vehicles are more likely to forward EMs to vehicles farther apart. Both DV-CAST and TBEM determine the farthest vehicle based on the distance without considering other parameters, which increases the probability of more vehicles to disseminate EMs. Moreover, in TBEM, a vehicle can rebroadcast EMs after time barrier has expired, which causes congestion and decreases PDR. To sum up, RBO-EM shows improved average PDR with respect to velocity by 38.49%, 12.67% and 4.29% compared to flooding, DV-CAST and TBEM, respectively.

D. NORMALIZED NETWORK OVERHEAD

Fig. 8 shows normalized network overhead for varying vehicular velocities. From the figure, it can be observed that the network overhead has increased with increasing velocities for DV-CAST, TBEM and RBO-EM. This is because mobility in VANETs causes high topological changes and, in turn, leads to frequent communication link failures that require excessive control packets. The proposed RBO-EM scheme outperforms the rest of the schemes at high velocities due to its stable structure. Stability, therefore, plays a key role in reducing network overhead. However, periodic *beacon* messages among $\mathcal{C}_{\mathcal{M}}$s and $\mathcal{C}_{\mathcal{H}}$s cause a network overhead. In order to address this issue, the *beacon* interval

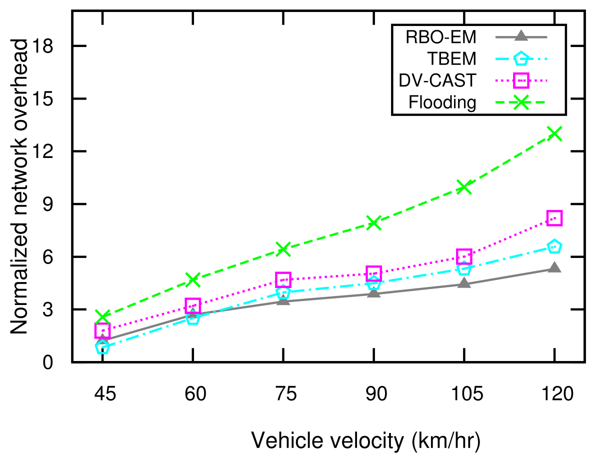

FIGURE 8. Normalized network overhead vs. vehicle velocity.

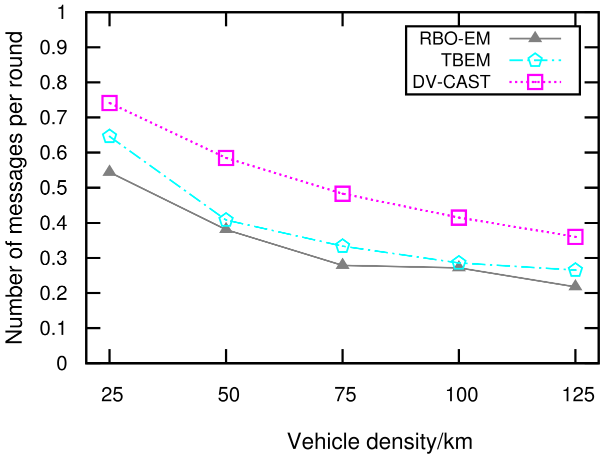

FIGURE 9. Number of messages per round vs. vehicle density.

should be properly tuned, which is described in the next subsection.

E. CLUSTER FORMATION OVERHEAD

Fig. 9 illustrates the cluster formation overhead in terms of average number of messages sent per vehicle during the $\mathcal{C}_{\mathcal{H}}$ selection phase. It can be observed that the number of messages decreases with an increase in vehicle density. This is because, every vehicle does not send $\mathcal{C}_{\mathcal{HA}}$ or $\mathcal{C}_{\mathcal{JR}}$ message in response to each announcement. In RBO-EM, when a vehicle receives a $\mathcal{C}_{\mathcal{HA}}$ from any other vehicle that has $\mathcal{MM}$ value greater than the receiver, then for that specific round the receiving vehicle will not send its announcement. By using this procedure, RBO-EM sends least average number of messages during the $\mathcal{C}_{\mathcal{H}}$ selection phase, which reduces the cluster formation overhead as compared to DV-CAST and TBEM. Thus, our proposed scheme contributes to controlling the congestion in the network with a low clustering overhead and an acceptable end-to-end delay.

F. EFFECTS OF *beacon* INTERVALS ON RBO-EM

The *beacon* interval is known as the time when the vehicle generates *beacon* messages to show its presence. High *beacon* rate leads to network congestion in high traffic density, which, in turn, leads to more end-to-end delays and lower PDR. Fig. 10 (a) illustrates end-to-end delays at different *beacon* intervals for varying vehicle density. More packets are generated in the network with shorter *beacon* intervals, which aggravates the network load and adversely impacts the end-to-end delay. A similar effect has been observed in the PDR with varying density and velocity, as shown in Fig. 10 (b) and Fig. 10 (c), respectively.

G. EFFECTS OF ACCIDENT INTERVAL ON RBO-EM

Accident interval is the time between two back-to-back EMs generated by a vehicle. Usually, low accident intervals lead to low PDR and higher network congestion and end-to-end delays. Since RBO-EM is able to effectively suppress congestion and broadcast storm, it remains unaffected by low accident intervals. Fig. 11 (a) reveals the effects of accident intervals on PDR for varying vehicular density in RBO-EM. As evident from the results, no adverse effects have been observed for PDR with varying density and accident intervals in RBO-EM. This is because RBO-EM effectively suppresses broadcast storms even for low accident intervals. A similar effect has been observed in end-to-end delay with varying density and accident intervals, as shown in Fig. 11 (b).

H. EFFECTS OF TRANSMISSION RANGE ON RBO-EM

Fig. 12 depicts the performance of RBO-EM with varying vehicle densities and transmission ranges. As can be seen from the figure, the increasing transmission range shows a positive impact on the performance of RBO-EM. Fig. 12 (a) shows that the information coverage increases with increasing transmission range. This is because the increasing transmission range provides sufficient connectivity by covering a wide area with higher signal power and, thus, ensures that nearly every vehicle receives EMs. A similar effect has been observed in PDR with varying vehicular density and transmission range, as shown in Fig. 12 (b). This is due to the reduction in number of hops and high connectivity in a sparse network for high transmission range. Similarly, Fig. 12 (c) shows that the delay is high when the transmission range is 100 m. This is due to a higher number of hops between source and destination, which incurs end-to-end delay. Contrarily, with the increase in transmission range, end-to-end delay decreases. The reason is that when the transmission range is high, the number of retransmitting nodes become lower in dense networks, which limits the network congestion and produces lower end-to-end delay. However, according to DSRC standard specification, typical transmission range varies between 100-300 m.

I. CRITICAL DISCUSSION

Accident detection and avoidance via safety message dissemination is considered to be one of the most valuable services of VANETs. Because of high mobility and restricted mobility patterns, it is difficult to develop an EM dissemination scheme with low end-to-end delays and high reliability. In order to minimize the end-to-end delay

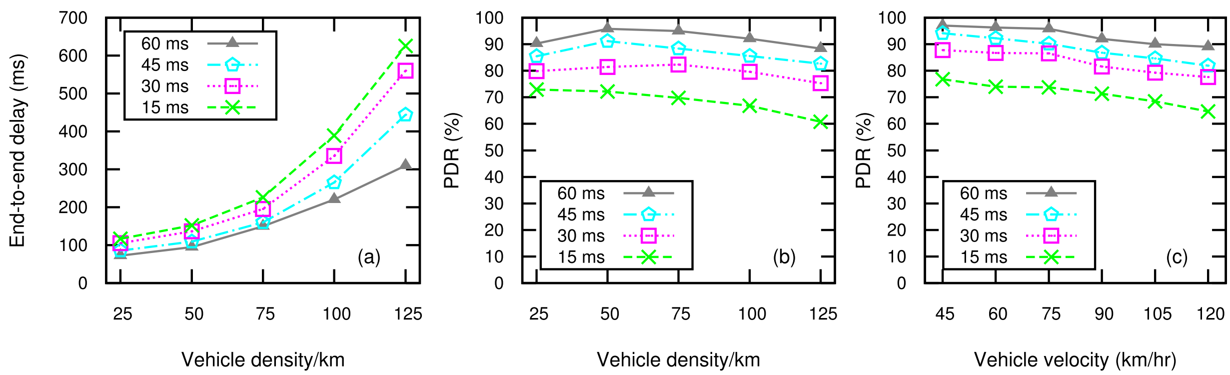

FIGURE 10. Effects of *beacon* intervals on (a) end-to-end delay vs. density, (b) PDR vs. density, and (c) PDR vs. velocity.

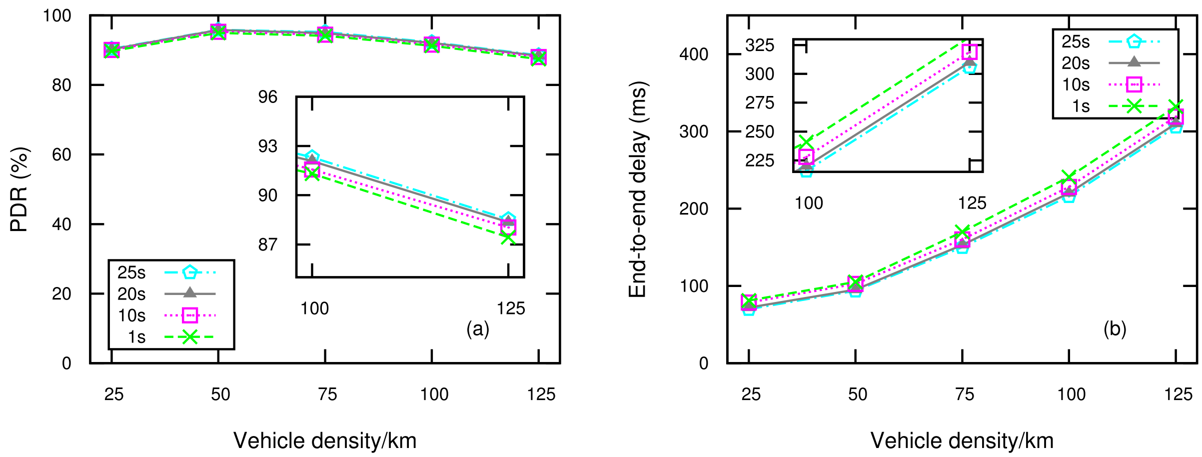

FIGURE 11. Effects of accident intervals on (a) PDR vs. vehicle density and (b) end-to-end delay vs. vehicle density.

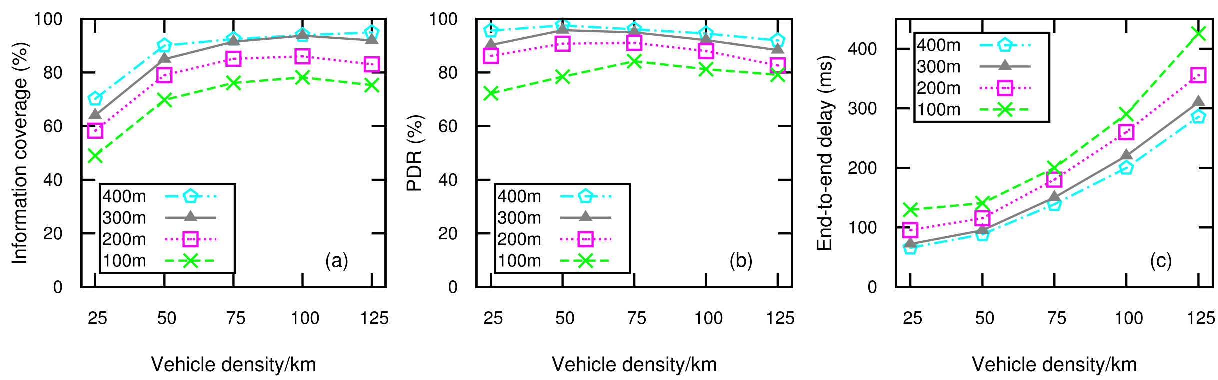

FIGURE 12. Effects of transmission range on (a) information coverage vs. density, (b) PDR vs. density, and (c) end-to-end delay vs. density.

in transmission, several researchers prefer broadcasting by flooding. However, flooding leads to a broadcast storm, which degrades network efficiency and reliability. To resolve this issue, a number of schemes in literature use the farthest vehicle to retransmit EMs. Nevertheless, considering the farthest vehicle based on distance without considering other parameters would increase the probability of multiple vehicles to transmits EMs simultaneously. This simultaneous transmission raises congestion.

We have proposed a cluster-based emergency messages dissemination scheme, called RBO-EM, to address the aforementioned issues. RBO-EM is based on mobility metrics. These metrics enable RBO-EM to form a stable cluster and select a cluster head. A stable cluster can minimize communication overhead and increase message reliability. RBO-EM uses gateways for inter-cluster communication to achieve an extended information coverage. Moreover, to ensure uni-casting and minimize communication overhead and congestion, a link-state stability metric is used to prevent multiple vehicles from disseminating EMs simultaneously.

In contrast to eminent EM dissemination schemes, such as TBEM, DV-CAST and flooding, the proposed

RBO-EM scheme performs reasonably well for all considered performance metrics, including information coverage, end-to-end delay, PDR, and network overhead. RBO-EM reasonably reduces the delay compared to the benchmark schemes. Since the timely delivery of EMs is highly critical, reducing end-to-end delay is, therefore, extremely beneficial. Moreover, RBO-EM has also demonstrated to reasonably increase PDR and information coverage. This is because RBO-EM is based on link state stability, which suppresses excessive retransmissions in dense networks and prevents multiple vehicles from broadcasting the same EM simultaneously. Conversely, the benchmark schemes suffer excessive retransmissions, which cause broadcast overhead and result in lower network performance in dense environments. The major hurdle in EMs dissemination in VANETs is the rapid change in topology due to high mobility and frequent link failure, which result in reduced packet delivery rates and increased network overheads. However, due to its stable structure, RBO-EM outperforms DV-CAST, TBEM and flooding in high mobility environments by minimizing network overhead and increases PDR.

Simulation results described earlier reveal the robust nature of RBO-EM. The results demonstrate reduced average end-to-end delay for RBO-EM by 8.22%, 18.97%, 3.8%; and network overhead by 52%, 26.5% and 1.5%, as compared to flooding, DV-CAST and TBEM, respectively. Considering average information coverage and PDR in varying vehicle density, RBO-EM has shown to enhance information coverage by 8.9%, 3.3%, 32.3%; and PDR by 9.5%, 3.79% and 39.73%; as compared with DV-CAST, TBEM and flooding, respectively. Moreover, considering varying vehicles velocity, RBO-EM has demonstrated an average increase in PDR by 38.49%, 12.67% and 4.29%, as compared to flooding, DV-CAST and TBEM, respectively.

The proposed RBO-EM scheme can be integrated into intelligent transportation systems to enable a safe driving environment through in-time and reliable EM dissemination. This will provide ample time for vehicles to adopt proactive measures to avoid road accidents. Although RBO-EM has shown to improve network performance in dense traffic scenarios, the communication range can reduce its coverage in sparse networks due to its pure V2V communication model. Our future work will seek to address this limitation.

V. CONCLUSION

We have proposed an EM dissemination scheme, called RBO-EM, to reduce excessive communication overhead due to message congestion in vehicular ad hoc networks. We have developed a clustering scheme based on mobility metrics to form stable clusters and select cluster heads. In addition, link state stability has been used to select a reliable gateway for inter-cluster communication and to limit the number of vehicles to rebroadcast EMs. The stable cluster structure and link stability metric in RBO-EM enable us to to disseminate EMs with minimum possible end-to-end delay to a large number of vehicles on the same route. Simulation results show that RBO-EM scheme outperforms eminent schemes with respect to end-to-end delay, information coverage, PDR, and network overhead. Our future work will study the effects of fading under different propagation models in V2V scenarios and routing with increased coverage and minimal delay to effectively disseminate EMs. In addition, RBO-EM can be extended to urban environments to tackle the challenges associated with road intersections. Furthermore, rogue node identification can also be taken into account to mitigate unnecessary messages.

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