DABFS: A Robust Routing Protocol for Warning Messages Dissemination in VANETs

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***Abstract*—Vehicular ad hoc networks play a pivotal role in the enrichment of transportation systems by making them intelligent and capable of avoiding road accidents. For transmission of warning messages, direction-based greedy protocols select the next hop based on the current location of relay nodes towards the destination node, which is an efficient approach for uni-directional traffic. However, such protocols experience performance degradation by neglecting the movement directions of nodes in bi-directional traffic where topological changes occur dynamically. This paper pioneers the use of movement direction and relative positions of source and destination nodes to cater to the dynamic nature of bi-directional highway environments for efficient and robust routing of warning messages. A novel routing protocol, namely, Direction Aware Best Forwarder Selection (DABFS), is presented in this paper. DABFS takes into account directions and relative positions of nodes, besides the distance parameter, to determine a node's movement direction using Hamming distance and forwards warning messages through neighbor and best route discovery. Analytical and simulation results demonstrate that DABFS offers improved throughput and reduced packet loss rate and end-to-end delay, as compared with eminent routing protocols.**

***Keywords* – Vehicular ad hoc networks, Routing protocols, Direction-based greedy forwarding, Bi-directional traffic, Warning message dissemination.**

I. Introduction

Recent technological developments in the field of wireless networks have given rise to Vehicular Ad hoc Networks (VANETs) [1] that enable communication between high-speed vehicles (hereinafter nodes). Major applications of VANETs include smart cities, infotainment, travel route identification, travel time prediction and avoidance of road accidents [2]. Among these applications, avoidance of road accidents takes the highest priority, as approximately 1.25 million people die each year in road accidents, whereas about 20 to 50 million people get injured or become disabled [3-4].

To avoid such unpleasant situations, Cooperative Collision Avoidance (CCA) schemes compute collision probability among nodes at regular intervals. When the collision probability exceeds a predefined threshold, a safe speed for a target node along with the probability of collision are computed and encapsulated in a warning message, which is transmitted to intimate other nodes about a possible collision. The destination node adopts this safe speed to avoid an expected collision. A CCA may either be based on a Vehicle-to-Vehicle (V2V) model or a Vehicle-to-Infrastructure (V2I) model. However, V2I models have increased capital and operational overhead because of the cost involved in deploying and maintaining Road Side Units (RSUs). Besides the efficient collision probability computation, fast and reliable routing of warning messages becomes equally important, as delays and packet losses during transmission of warning messages may cause collisions among nodes at a large scale [2].

When a source node is ready to transmit a warning message, it may encounter two kinds of situations. Firstly, if there is only one route to reach the destination node, then using this particular route becomes inevitable. Secondly, if there are more than one routes available to reach the destination node, the selection of the best route with minimal latency and minimal packet loss becomes important. This makes the selection of the next hop, called the Best forwarder (B_f), a crucial decision during the transmission of warning messages.

In this regard, greedy routing protocols [5] consider parameters such as current positions of the intermediary relay nodes and their distances from the destination node. Such parameters prove to be useful only when the nodes are static. In mobile networks like VANETs, "direction-based" greedy routing protocols [5] select the next hop in the direction towards a destination node, which is an efficient approach in uni-directional traffic scenarios. However, the performance of direction-based greedy protocols declines in bi-directional scenarios, where a next hop selected based on its current location in the direction of the destination node may produce problems. Since a bi-directional highway scenario allows high-speed mobility of nodes in different directions, the distance between nodes keeps changing. Hence, causing continuous topological changes, as these nodes enter and leave communication ranges of each other frequently. Therefore, a route, chosen at a certain time step, does not remain fixed all the time. Rather, it may change on the later time steps for the transmission of even a single message. This change may occur in terms of increased or decreased number of hops, which affects the latency accordingly. Moreover, routes are broken and new routes are defined at regular intervals, which may cause network partitions [5]. As a result, all messages forwarded on the broken routes are dropped. All these factors lead to increased packets losses and latency in transmission of warning messages, and reduced network throughput.

A. Novelty and Contributions

Keeping in view all the aforementioned issues, we propose a novel protocol, namely, Direction Aware Best Forwarder Selection (DABFS), which makes the following contributions:

- DABFS follows a novel direction-based greedy approach to find the best route for dissemination of warning messages in a bi-directional V2V highway scenario. Since, movement direction remains a major factor for all the topological changes and link breakages on the routes, DABFS takes into account nodes' movement direction, in addition to the distance parameter, to ensure fast and reliable delivery of warning messages. To that end, we introduce a Hamming distance function.
- Moreover, as the relative positions of the source and destination nodes also remain important during routing, DABFS proposes the use of these relative positions as an additional parameter to the aforementioned parameters in order to find the most appropriate route among the available set of routes.
- There are two major findings of this work. We find that the use of direction component along with the relative positions of source and destination nodes (i) increases network throughput and reduces packet delays and losses; and (ii) enables a VANET routing protocol to cater for topological changes during the transmission of warning messages.

Simulation results for packet loss rate demonstrate an average improvement of DABFS by 5% over Improved Directional Location Added Routing (ID-LAR) [5], 14% over Path Aware-Greedy Perimeter Stateless Routing (PA-GPSR) [6], 17% over Connectivity-Aware Data Dissemination (CADD) [53], and 19% over GPSR [7]. Furthermore, on average, DABFS minimizes end-to-end delay by 4.4 ms, 6.3 ms, 7 ms, and 8 ms compared with ID-LAR, PA-GPSR, CADD, and GPSR, respectively. Moreover, DABFS enhances average network throughput by 4%, 13%, 16%, and 18% compared with ID-LAR, PA-GPSR, CADD, and GPSR, respectively. This makes our protocol more efficient and robust as compared to eminent VANET routing protocols.

B. Paper Organization

The rest of the paper is organized as follows. Section II presents related work. Section III details the proposed protocol and Section IV evaluates its performance. Finally, Section V concludes the paper with future research directions.

II. Related Work

Fast and reliable transmission of warning messages in VANETs remains as important as efficient collision detection. VANET routing protocols can be classified into three categories, namely, position based routing, greedy forwarding and direction-based greedy forwarding. The following subsections review state-of-the-art in each of these categories.

A. Position-based Routing

The work in [8] proposes a routing protocol that uses Combined Location and Velocity (CLV) tree to keep track of neighbor nodes for the selection of next hop. The work in [9] proposes Connectivity Aware Routing (CAR) protocol, which employs the connectivity interval of an intermediary node to find the best path. However, the extra communication overhead restricts its functionality. The authors in [10] propose an extension to CAR, which is referred to as Adaptive CAR (ACAR). This protocol is capable of identifying the traffic density level on roads. However, the computational overhead in the density assessment process is a weakness of ACAR. The protocol also has high storage requirements, which adversely affects its performance during the search process. Another extension to CAR, namely, Intersection-based CAR (iCAR) [11] is capable of predicting life-time for a certain route. Since the dynamic nature of VANETs decreases the life-time of routes, such an approach adds reliability during transmission. The prediction process, however, may increase the processing overhead, which may result in a degraded performance in highly dense networks. The work in [12] proposes Position-based Adaptive Routing (PAR) that takes into account the current position of intermediary relay nodes to identify routes. However, the neighbor table construction process remains a tedious job in this protocol.

Probabilistic approaches add reliability to the routing process. A probabilistic route identifier, namely, Acute Position-based Routing (APR), is proposed in [13]. However, the extra computation overhead in probability calculations increases the computational cost of APR. In [14], the authors propose another probabilistic routing protocol to enable fast transmission of warning messages.

The work in [15] proposes an Adaptive Beacon Broadcast Opportunistic Routing (ABOR) strategy that considers link life-time and predicts the link expiry time to route packets in an efficient way. The authors in [16-19] suggest the use of ant colony method for route discovery. The proposed algorithms take into account the position of nodes to identify a suitable route. Another protocol in [20] adopts local search with multi-objective optimization for route discovery in a uni-directional traffic scenario. Among the multiple routes to a destination, optimal route discovery is a challenging task, for which the protocol proposed in [21] provides a decent solution. Moreover, the authors in [53] propose a novel Connectivity-Aware Data Dissemination (CADD) protocol that uses wavelet neural network to predict the forwarding capability of a certain node. This is one of the most recent position-based routing protocols that outperforms well-established routing protocols in this category.

B. Greedy Forwarding

One of the most eminent greedy forwarding protocols, which is used as a benchmark in a variety of studies [54], is Greedy Perimeter Stateless Routing (GPSR) [7]. For packet forwarding, it identifies an intermediary relay node, which bears the smallest distance with the destination node. The algorithm enters a recovery mode, where it performs perimeter-based forwarding where all intermediary nodes are located at longer distances from the destination than the source node. The authors in [22] propose an extension to GPSR, namely, Greedy Perimeter Coordinator Routing (GPCR), which takes into account road conditions for a better path selection towards a destination. However, this protocol remains less effective in sparse networks. Maxduration-Minangle-GPSR (MM-GPSR) [23] also extends GPSR by considering next hops based on the maximum communication time. Another recent variant of GPSR, namely, Path Aware-GPSR (PA-GPSR) [6], uses left-hand rule besides the right-hand rule adopted by the traditional GPSR in the recovery mode to enhance the routing process. PA-GPSR has been shown to outperform GPSR.

Furthermore, the work in [24] proposes Back-Bone-Assisted Hop Greedy Routing (BAHG). It employs number of hops and connectivity among nodes as parameters to define the shortest path to a destination. Here, a path bearing minimum hop counts and strongest connectivity is preferred over the rest for transmission of the messages. Similarly, the Connected Junction-Based Routing (CJBR) [55] aims to enhance connectivity among nodes for routing performance improvement. The authors in [25] propose Vehicle-Assisted Data Delivery (VADD) protocol, which uses the carry and forward mechanism to identify the best path. Here, intersection points are taken into account for path tracking towards a certain destination node. The delay that results due to frequent path discovery operations remains a disadvantage of this protocol. Similarly, Geographic Source Routing (GSR) [26] also uses a greedy forwarding approach. However, it has a high routing overhead and is not considered to be suitable for sparse networks. Geographical Opportunistic routing (GeOpps) [27] proposes a navigation-based route selection method. However, the navigation systems may breach privacy of nodes, which is a critical problem. The Anchor-based Street and Traffic Aware Routing (A-STAR) protocol proposed in [28] uses the well-known Dijkstra's algorithm for shortest path identification with a drawback of performance degradation in dense environments. Another routing protocol, referred to as Improved Greedy Traffic Aware Routing (GyTAR) [29], helps to route messages between nodes on intersections. This protocol remains costly due to its high control messages overhead.

C. Direction-based Greedy Forwarding

The work in [30] proposes a direction-based protocol that takes into account the link quality to identify the best route. Since the nodes move at high speeds in different directions on the road, the distances among nodes keep changing. An increase in distance degrades the connectivity among nodes. This results in frequent link breakages, which adversely affect the packet delivery process. Such problems even become more severe in sparse networks where nodes are at a larger distance from each other. A recent work [5] proposes Improved Directional Location Added Routing (ID-LAR) that outperforms other renowned direction-based greedy protocols. This protocol considers the angle between nodes for the selection of next hop. It identifies relay nodes that are closer to the transmission range boundary of the source node towards the destination node, which results in improved routing performance. Similarly, the authors in [31] and [32] use the angular direction of the intermediary relay nodes for routing.

In [33] and [34], the authors propose predictive protocols, namely Prediction-based Greedy Perimeter Stateless Routing (PGPSR) and Predictive Directional Greedy Routing (PDGR) protocol, respectively. These protocols use a probabilistic approach to estimate the sustainability of all routes. Here, the routes with higher probability scores remain comparatively more reliable. Another protocol, i.e., Improved Geographic Routing (IGR) [35], considers the link error rate and density of nodes on a particular road as parameters for selection of the best route. Similarly, the work in [36] considers the prediction of possible disruptions or breakages on the route prior to the start of message transmission process. Furthermore, the work in [56] includes an opportunistic routing protocol that performs predictive analysis to prioritize intermediary relay nodes by using a weight-based algorithm. Such probabilistic protocols improve packet delivery rate. However, computational overhead, created due to probability calculations, remains a disadvantage of probabilistic protocols. The authors in [37] propose GreeDi protocol, which chooses the best path to cloud servers based on energy efficiency. A similar protocol proposed in [38] employs linear programming for the selection of the most appropriate path. Moreover, the work in [39] proposes a reactive GreeAODV protocol that also considers energy consumption among nodes to find the best path.

An extension of the aforementioned GyTAR protocol [29] with direction awareness, namely, Enhanced GyTAR-Directional, prioritizes nodes that lie in the direction toward the destination node [40]. Furthermore, a similar uni-directional scenario-based protocol is proposed in [41] to enhance the packet routing process. The authors in [42] analyze the impact of MAC layer upon the routing efficiency. They present a comparative analysis of IEEE 802.11 and dynamic Time Division Multiple Access (TDMA) to show that IEEE 802.11 based routing produces higher network traffic overhead, which degrades its performance in terms of reduced packet delivery rates. The authors in [43] propose Predictive Geographic Routing Protocol (PGRP) that includes assignment of weights to different routes to reach the destination node. These weights are assigned with respect to accelerations or decelerations attained by nodes. The authors in [44] propose GPSR with Movement Awareness (GPSR-MA), which takes the direction of nodes for route identification in a uni-directional traffic scenario. In this protocol, the intermediary node at 0^o is selected as next hop during transmission of messages. However, the protocol may fail in the scenario where the destination lies on the rear side of a source node.

From the literature study, it is found that the high-speed

TABLE I: List of notations

Notation	Description
$>>$	Packet forwarded from left to right node
Ack	Acknowledgment received in response to a $Hello$ packet
B_f	Best forwarder intermediary relay node
χ	Set of speeds for nodes
CNP	Current position of a node
D	Destination node
δ	Final distance between NG_i and D
Δ	L1-norm distance between NG_i and D
E_d	End-to-end delay for packets
E_r	End-to-end delay ratio
$H(.)$	Hamming distance function
n	A member node
N	Set of all nodes
NG	Neighboring table for a node
NID	Node identity
P_l	Packets dropped
P_r	Packet loss rate
P_t	Total packets transmitted across the network
R_p	Total received packets
S	Source node
τ	Time stamp of the last received Ack
T_r	Network throughput
x	Total number of nodes

mobility of nodes in VANETs causes frequent topological changes that limit the performance of position-based and greedy routing protocols [57]. The existing direction-based greedy protocols bridge this gap to certain extent, however, these protocols also experience performance degradation in bi-directional traffic where topological changes are intense and path variations are experienced even during the transmission of a single packet. To this end, we propose a novel direction-based greedy routing protocol, which is detailed in the following section.

III. Direction Aware Best Forwarder Selection Protocol (DABFS)

This section presents our proposed DABFS protocol for V2V communication among nodes moving in a real-time bi-directional highway scenario. Fig. 1 shows a complete overview of the proposed protocol, which performs direction-based priority assignment among multiple routes to a destination. Moreover, Table I includes a list of notations used in this paper.

An inefficient routing protocol for vehicular collision avoidance may cause collisions between nodes at a large scale. Therefore, besides the significance of collision identification between nodes, routing performance gains equal importance. This is because fast and reliable warning message delivery remains critical in order to apply the preventive measures for collision prevention. In this regard, when the source node is ready to transmit a warning message and there is only one route to the destination, it becomes inevitable to follow that route. However, if there are multiple routes available towards the destination, then selection of the best route with minimal latency, fewer packet losses, and maximum throughput becomes important. In this regard, the greedy protocols employ distance as a parameter to identify the best route, whereas the direction-based greedy protocols determine the availability of relay nodes in the direction toward the destination node. On a specific time step, e.g., τ_0, all routes to the destination are analyzed. Both greedy and direction-based greedy protocols select the next best possible hop according to their corresponding parameters, as mentioned above, for the transmission of messages. However, since the nodes move at high speeds, they enter and leave the communication ranges of each other frequently, due to which continuous topological changes occur in bi-directional scenarios. Such a dynamic nature may cause two cases during the transmission of messages. Firstly, routes to the destination may experience breakages that drop all the messages forwarded on these routes. Secondly, since the initially defined route at τ_0 does not remain intact all the time, it may undergo a route reconstruction process at τ_1, τ_2, ..., τ_n till the message is successfully delivered. This may increase or decrease the length of a route. Consequently, packet drop rate and latency also increase, which adversely affect throughput of the greedy and direction-based greedy protocols. To that end, we propose the use of the following parameters, in addition to the distance parameter, for the best route selection:

- The movement direction of nodes: Here, we introduce a simple logical Exclusive-OR (XOR) operation-based Hamming distance function.
- Relative position of source and the destination nodes.

The proposed DABFS protocol is composed of three algorithms, namely, Warning Message Transmission, Neighbor Discovery, and Best Route Discovery, which are detailed in the following subsections.

Algorithm 1 Warning Message Transmission

Input: S, D, and τ
Output: Success or Failure in transmission of a warning message
Begin:
    Bulid NG_S for S
        Loop
            If $D \in NG_S$ **Then**
                $S >> D$
                Exit
            Else
                Identify B_f
                $S >> B_f$
                $S \longleftarrow B_f$
                Build NG for newly deputed S at τ_i
            End If
        End Loop
End

A. Warning Message Transmission

We propose Algorithm 1 that includes the steps for warning message transmission. The algorithm takes S, D, and τ as inputs, where S represents the source node, D represents the destination node, and τ represents the time step. When S intends to transmit a warning message to D, there are two

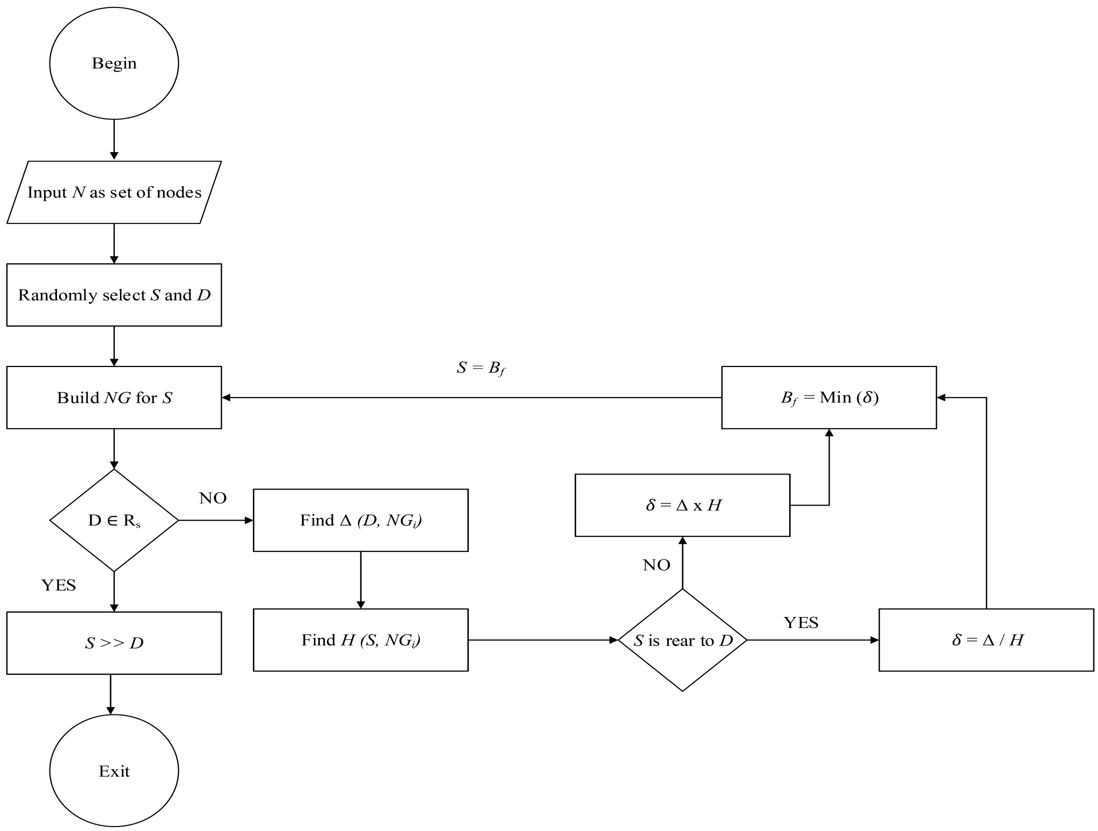

Fig. 1: Overview of DABFS protocol.

Algorithm 2 Neighbor Discovery

Input: N, Ack
Output: NG
Begin:
  Flush NG_S
  $i \longleftarrow 0$
  S broadcasts $Hello$ packets
    Repeat
      For Ack received from Node n_i
      S updates the NG_S:
        NG_S (i, 1) $\longleftarrow NID_{n_i}$
        NG_S (i, 2) $\longleftarrow CNP_{n_i}$
        NG_S (i, 3) $\longleftarrow \tau_{n_i}$
      Increment i
    Until All the received Acks are processed
  Return NG
End

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possibilities, i.e., either D is at one hop distance or it is at more than one hops distance from S. In the first case, the message is transmitted straight away. However, if D is at multi-hop distance, S employs the services of intermediary relay nodes to reach D. The output of Algorithm 1 is the success or failure in transmission of a warning message.

B. Neighbor Discovery

For neighbor discovery, we present Algorithm 2 that takes N and Ack as inputs, where N = n_1, n_2, ..., n_x represents a set of all nodes, and Ack represents an acknowledgement received in response to a transmitted *Hello* packet. Here, x is the total number of nodes on the road and n represents an individual member node. The algorithm performs discovery of neighbor nodes and builds a Neighboring Table (*NG*), which is a set of all neighbors of a particular node. We call neighbors as the nodes that are directly connected or are at one hop distance from a certain node. For neighbor discovery, each node broadcasts *Hello* packets at regular intervals. For example, when S receives an Ack from the other node in response to its broadcasted *Hello* packet, it creates an entry in its NG for this node. The information stored regarding neighboring nodes in NG includes Node Identity (NID), Current Node Position (CNP) and time stamp (τ) of the last successfully received Ack. Here, τ is used to identify freshness of the received Ack packet and to discard any older information. We assume that each node is equipped with Global Positioning System (GPS) for node localization. The output of Algorithm 2 includes NG.

C. Best Route Discovery

In bi-directional traffic, due to frequent topological changes, routes to disseminate warning messages undergo changes at each time step. A direction-based protocol, which takes relative positions of the source and destination nodes, may provide better efficiency. To this end, we propose Algorithm 3 that takes as inputs S, D, and NG. The algorithm makes use of relative positions of S and D along with their movement

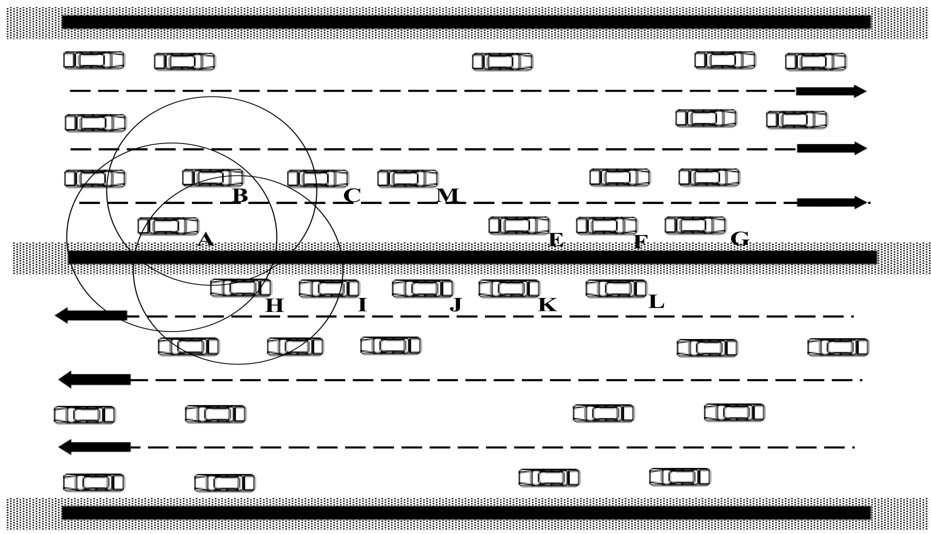


Fig. 2: Greedy mode forwarding when a destination node is in front of a source node.

Algorithm 3 Best Route Discovery

Input: S, D, and NG_S

Output: B_f and the Best possible route to the destination node

Begin:

  For i = 0 **To** NG_S - 1

    $\Delta_i \longleftarrow$ L1-norm (NG_{S_i}, D)

    $H_i \longleftarrow H$ (NG_{S_i}, S)

      If $H(S, D) = 1$ **Then**

        If S = Rear & D = Front node **Then**

          $\delta_i \longleftarrow \frac{\Delta_i}{H_i}$

        Else

          $\delta_i \longleftarrow \Delta_i \; H_i$

        End If

      Else

        If S, D move towards each other **Then**

          $\delta_i \longleftarrow \frac{\Delta_i}{H_i}$

        Else

          $\delta_i \longleftarrow \Delta_i \; H_i$

        End If

      End If

  End For

  $B_f \longleftarrow$ Min(δ)

  Return B_f

End

directions, in addition to the distance parameter, for identification of the best route for warning messages to reach a certain destination node. The outputs of Algorithm 3 include the selection of the B_f and the best possible route to reach D. To investigate the significance of the additional parameters introduced by DABFS for routing performance enhancement, five different cases are considered. These cases include all possible distinct scenarios with respect to the relative positions of source and destination nodes on a bi-directional highway and are detailed in the following subsections.

1) Case 1: In this case, we consider a scenario depicted in Fig. 2 with specifications of source and destination nodes as under:

- Source Node A is the rear node.
- Destination Node G is the front node.
- Both source and destination nodes are moving in the same direction.

In the aforementioned scenario, suppose there are two possible routes to reach the destination Node G from the source Node A. The first route is on the opposite side of the road to source node, i.e., A >> H >> I >> J >> K >> L >> G, whereas, the second route is A >> B >> C >> M >> E >> F >> G. Since, Node H is at a lesser distance to the destination than Node B, by following the conventional greedy routing, Node H will be preferred for packet forwarding, consequently, selecting the first route among the given options. Similarly, the direction-based approaches, which select a hop near the transmission range boundary of the source in the direction towards the destination, will also prefer the same node as the next hop. Such priority-based protocols fail to produce better results in VANETs where nodes move in different directions.

The direction of nodes affects the number of hops on the route. Since, the number of hops on a route remains proportional to the latency in transmission of warning messages, it does not remain a wise decision to adopt a certain route with fewer number of hops on a specific time step without considering the relative positions and direction of nodes on the route. For example, considering our aforementioned routes to the destination Node G, the first route happens to be A >> H >> I >> J >> K >> L >> B >> C >> M >> E >> F >> G on successful delivery of warning message. Since, Node L is moving in the opposite direction, by the time the packet is received on this node the destination Node G has moved out of its communication range. To overcome such a situation, Node L needs further intermediary relay nodes to make possible the successful delivery of warning messages.

In such a scenario, there are two possibilities:

1) Node L does not find any forwarder further to reach the destination Node G.
2) Node L finds a forwarder B and goes into a path reconstruction process.

It must be noted here that the situation becomes extremely critical when there is no other forwarder available, as Node L, bearing opposite movement direction to the destination node, carries the packets with itself that results in a message drop. In the second case, when a forwarder remains available, a path reconstruction process is initiated, which includes additional nodes to the previously defined path. On the newly constructed route, Node L reaches the destination Node G through further Nodes B, C, M, E and F, respectively. This results in an increased number of hops on the first route.

On the other hand, since all nodes on the second route, selected by DABFS, are moving in the same direction as the direction of destination node, no change in the number of hops occurs. This clearly shows that direction of intermediary relay nodes in a route has a significant impact on fast and reliable delivery of warning messages. For assignment of such direction-based priority to routes in a scenario where the source node is at rear and the destination node is at front while both are moving in the same direction, we propose the computation of the final distance for the next hop with destination node as

$$\delta_i = \frac{\Delta}{H(NG_{S_i}, S)}, \tag{1}$$

where δ_i represents the final distance of NG_{S_i} (i.e., the next hop to which the warning message can be forwarded) from the destination node, Δ represents the L1-norm distance between NG_{S_i} and the destination node, and $H(.)$ is the Hamming distance function. The significance of Hamming distance is that it provides difference between any two objects based on a given metric [45]. We propose the use of direction of nodes as a metric in this regard. The outcome of $H(.)$ is 0 if the direction of any two nodes is opposite to each other, and 1 if the direction is the same. Moreover, the robust nature of L1-norm distance makes it more suitable as opposed to the L2-norm distance that squares the error, if there is any [46].

In our proposed DABFS protocol, if $H(S, D) = 1$ and S remains rear to D, the node with the smallest distance, computed using (1), is preferred as a B_f over the other nodes. This completes our direction-based priority assignment process in defining the B_f node, which reduces the number of hops as well as latency during transmission of warning messages. Furthermore, it improves reliability in delivery of these warning messages by minimizing packet drops. These low-delay and low-loss features make our proposed DABFS protocol robust, as shall be discussed in Section IV. The other case, where $H(S, D) = 1$ and S remains in front of the D, is detailed in the following case.

2) Case 2: In this case, we consider a scenario depicted in Fig. 3 with specifications of source and destination nodes as under:

- Source G is the front node.
- Destination A is the rear node.
- Both source and destination nodes are moving in the same direction.

In this scenario, initially suppose there are two possible routes to reach the destination Node A. The first route is on the opposite side of the road, i.e., G >> L >> K >> J >> I >> H >> A, and the second route on the same side of the road is G >> F >> E >> M >> C >> B >> A. Here, an existing greedy protocol (including direction-based greedy protocols) may forward the warning message to Node F instead of Node L. However, our proposed DABFS prefers Node L as next hop. Since Node L is moving in opposite direction towards the destination node, the final route becomes G >> L >> K >> A on successful delivery of the message. This is because by the time a warning message is received on Node K, the destination Node A comes in its communication range, which results in forwarding the message directly to Node A, instead of following the initially defined route. In such a scenario, where $H(S, D) = 1$ and the source node remains in front of the destination node, we propose (2) for the selection of B_f, i.e.,

$$\delta_i = \Delta \; H(S, NG_{S_i}), \tag{2}$$

where δ_i, Δ, S, NG_{S_i} and $H(.)$ are as defined in (1). In this way, Node L is preferred over Node F, which again reduces the number of hops as well as latency. It also provides reliable transmission of warning messages from source to the destination node by minimizing the message drops.

3) Case 3: In this case, we consider a scenario depicted in Fig. 2 with specifications of source and destination nodes as under:

- Source A is the rear node.
- Destination L is the front node.
- Both source and destination nodes are moving in the opposite direction towards each other.

This case remains similar to Case 1 in terms of positions of the source and destination nodes. However, since the two nodes lie on different sides of the road moving the opposite direction to each other, the scenario becomes totally different. Again, besides the distance between nodes, the direction component remains extremely critical.

In the scenario depicted in Fig. 2, initially suppose there are two possible routes to reach the destination Node L. The first route is A >> B >> C >> M >> E >> L, whereas the second route includes A >> H >> I >> J >> K >> L. The existing greedy and direction-based approaches will select Node H as B_f on the basis of lesser distance in comparison to Node B. However, in our proposed DABFS, when $H(S, D) = 0$ and the nodes are moving towards each other, (1) is used to set the priorities among nodes in NG_S. To that end, DABFS prefers Node B as B_f. Hence, by employing our direction-based priority assignment process, the final route becomes A >> B >> C >> L, as the destination Node L is moving in the opposite direction and by the time the warning message reaches Node C, the destination node comes within

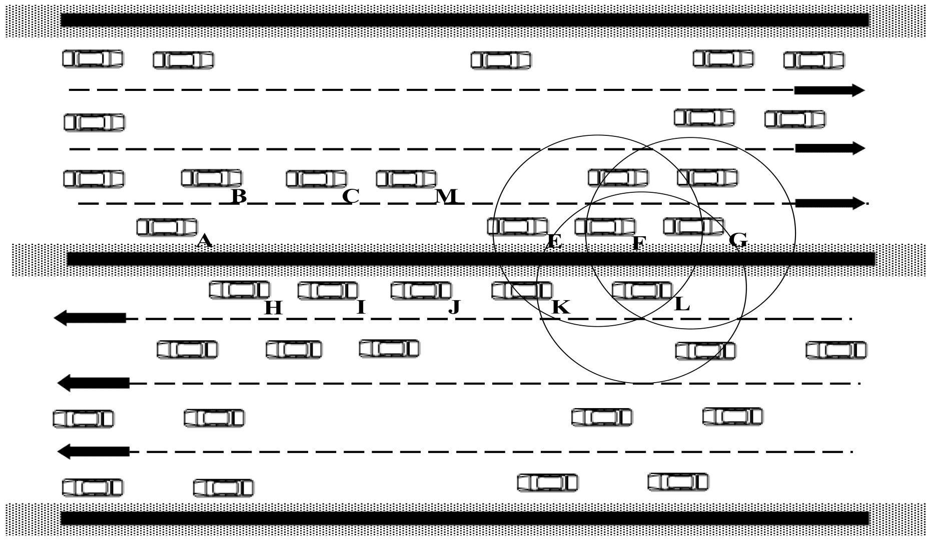


Fig. 3: Greedy mode forwarding when a source node is in front of a destination node.

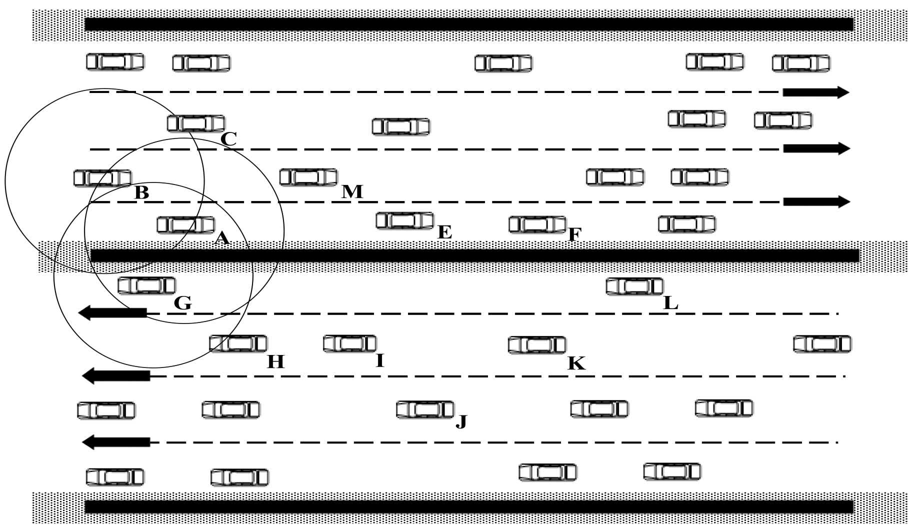


Fig. 4: Recovery mode forwarding when a destination node is in front of a source node.

its communication range. This enables forwarding warning message directly to Node L, hence, reducing the number of hops and latency. Moreover, it also improves reliability in transmission of the warning message by reducing packet drops.

4) Case 4: In this case, we consider a scenario depicted in Fig. 3 with specifications of source and destination nodes as under:

- Source G is the front node.
- Destination H is the rear node.
- Both source and destination nodes are moving in the opposite direction away from each other.

This case resembles Case 3 with respect to positions of the source and destination nodes on the road. However, since the direction of source and destination nodes is away from each other in this case, the scenario remains a complex one to deal with.

Here, initially suppose the two possible paths to reach the destination Node H from Node G are G $>>$ L $>>$ K $>>$ J $>>$ I $>>$ H and G $>>$ F $>>$ E $>>$ M $>>$ C $>>$ H. Again, the conventional greedy protocols will select Node F as B_f, however, as the nodes moves on, the route selected will result in greater number of hops compared to the other route, i.e., G $>>$ F $>>$ E $>>$ M $>>$ C $>>$ B $>>$ A $>>$ K $>>$ J $>>$ I $>>$ H. This is because, by the time the warning message reaches Node C, the destination node has gone out of its communication range. Therefore, a path reconstruction process occurs and the packets are routed on the new path as B $>>$ A $>>$ K $>>$ J $>>$ I $>>$ H. The situation becomes more critical when Node C does not find any node to forward the message. To that end, our proposed DABFS protocol, by using (2), prefers Node L. This results in transmission of the warning message through the second possible route, when $H(S, D) = 0$ with source and destination moving away from each other. This also reduces the number of hops and minimizes latency. Furthermore, it improves the reliability factor during transmission of messages, as the messages forwarded on this route will be dropped if Node C does not find any intermediary relay node in its neighborhood.

5) Case 5: In this case, we consider a scenario depicted in Fig. 4 with specifications of source and destination nodes as under:

- Source A is the rear node.
- Destination L is the front node.
- Both source and destination nodes are moving in the opposite direction towards from each other.

It is not possible to ensure availability of intermediary relay nodes in the range of a source node that bears smaller distance with the destination node compared to the source node. Such a scenario refers to recovery mode [23] in the conventional greedy routing protocols. Assume, in the given scenario, that the source Node A intends to transmit a warning message to destination Node L. Since there are no nodes that bear lesser distance from the destination node as compared to the source node, the source node will forward the message to one of its neighbor node on its rear side. Suppose the first route to the destination nodes is A $>>$ G $>>$ H $>>$ I $>>$ J $>>$ K $>>$ L, whereas the second route includes A $>>$ B $>>$ C $>>$ M $>>$ E $>>$ F $>>$ L. In this case, while adopting the first route, if Node H moves out of the communication range of Node G, then the message gets dropped. Here, our direction-based DABFS prefers the selection of Node B as B_f instead of Node G, in a similar manner as in the aforementioned Case 3. Moreover, due to movement in the opposite direction, Node L comes in the communication range of Node M by the time the message is received on Node M. This results in the final route as A $>>$ B $>>$ C $>>$ M $>>$ L through which the message is transmitted in real time. This again reduces the number of hops and minimizes latency with improved reliability during message dissemination.

Table II presents analytical results, obtained on MATLAB R2018a, with respect to the aforementioned five cases for 150 nodes. These results show a comparative analysis of our proposed DABFS protocol with ID-LAR [5], PA-GPSR [6], CADD [53], and GPSR [7]. DABFS shows a considerable reduction in latency for warning messages dissemination.

6) Other cases: Case 1 through Case 5 present all possible distinct scenarios with respect to relative positions of source and destination nodes on a bi-directional highway. Apart from the aforementioned five cases, no other cases are possible except for a few discussed below. However, since the cases discussed below will cause unnecessary repetition, we have not listed them as distinct cases. For example, we can consider a case with Node L as source and Node A as destination for the scenario depicted in Fig. 2. However, this scenario is identical to Case 3 and will cause a repetition. Similarly, another case having Node H as the source and Node G as the destination, for the scenario depicted in Fig. 3, is also possible but is identical to Case 4. In a similar way, any other case for warning messages forwarding with respect to relative positions of source and destination nodes in the recovery mode will also cause a repetition and, hence, is omitted.

D. Time complexity

Time complexity refers to the number of steps required to accomplish the routing process. In the proposed DABFS protocol, Algorithm 1 consists of a loop that enables the transmission of warning messages. This algorithm includes a conditional statement, where the *Else* part executes when a destination node is not a neighbor of the source node. This initiates the building process of NG by employing Algorithm 2, which consists of a loop. Hence, the worst case time complexity of Algorithm 2 becomes $O(k)$, where k represents the number of neighbors for a particular node. The establishment of NG is followed by the identification of B_f using Algorithm 3, which also consists of a loop having the worst case time complexity of $O(k)$. Since, Algorithm 2 and Algorithm 3 execute inside Algorithm 1 independent of each other, and Algorithm 1 through Algorithm 3 constitute the proposed DABFS protocol, the overall time complexity of DABFS becomes $O(k^2)$.

IV. Performance Evaluation

In this section, the performance of our proposed DABFS protocol is evaluated in comparison with ID-LAR [5], PA-GPSR [6], CADD [53], and GPSR [7]. The reasons for selecting these VANET routing protocols for comparison are given in Section II. Simulation results are derived using VANET Simulator [47]. Unless otherwise stated, all simulations are based on the scenarios presented in Case 1 through Case 5 and depicted in Fig.2 through Fig. 4 in Section III. Table III lists the parameters used in performance assessment of the aforementioned protocols. Nodes are randomly deployed and are equipped with omni directional antennas. Movement of nodes remains bi-directional with variable speeds belonging to a set, χ, having the upper and lower bounds as 0 m/s and 42 m/s, respectively. The acceleration or deceleration attained by nodes is taken within the range of 1 m/s^2 to 6 m/s^2. Moreover, the nodes density on the highway is classified into sparse, medium and dense, as shown in Table IV. This classification normalizes the nodes density in accordance with the real-life traffic [58].

The performance evaluation metrics include packet loss rate (P_r), end-to-end delay (E_r), and throughput (T_r), which are commonly used in state-of-the-art to evaluate VANET routing protocols for reliable delivery of warning messages with minimum delays and fewer packet losses [6, 23]. Simulation results for each metric are shown in Fig. 5 through Fig. 7. In each figure, the Sub-figures (a)-(e) correspond to the five distinct scenarios described in Case 1 through Case 5 of Section III-C, respectively. Simulation results of the proposed DABFS protocol are validated through analytical results obtained on MATLAB R2018a. Each result presented is averaged over 25 replicated simulation runs by keeping all parameters fixed and changing the random seed values.

TABLE II: Latency experienced during successful delivery of warning messages

	Source node	Destination node	Scenario presented in	Latency (ms)				
				DABFS	ID-LAR	PA-GPSR	CADD	GPSR
Case 1	A	G	Fig. 2	13	17	19	21	22
Case 2	G	A	Fig. 3	12	17	20	21	23
Case 3	A	L	Fig. 2	10	20	22	24	26
Case 4	G	H	Fig. 3	11	19	24	25	28
Case 5	A	L	Fig. 4	13	19	20	22	28

TABLE III: Simulation parameters

Parameter	Configuration
Simulation area	5000 m^2
Traffic type	Bi-directional highway traffic
Number of nodes	0 - 500
Speed of nodes, χ	0 m/s - 42 m/s
Acceleration/ deceleration attained by nodes	1 m/s^2 - 6 m/s^2
Transmission range of nodes	150 m
$Hello$ packet interval	1 s
Simulation time	300 s

TABLE IV: Classification of nodes with respect to density

Network type	Number of nodes per 2500 m^2
Sparse	001 $<= N <=$ 200
Medium	201 $<= N <=$ 400
Dense	401 $<= N <=$ 600

A. *Packet loss rate*

This metric refers to the ratio of packets dropped, which can be computed as

$$P_r = \frac{\sum_{i=1}^{P_l} P_{l_i}}{P_t}, \tag{3}$$

where P_r represents the packet loss rate, P_{l_i} represents a dropped packet, and P_t refers to the total number of packets transmitted across the network. The route selection decision during transmission of a warning message remains critical due to the frequent changes on the network. High-speed nodes moving in different directions produce frequent topological changes in VANETs. The nodes enter and leave communication ranges of each other continuously. As a result, routes are broken and new routes are defined at regular intervals, which may cause network partitions. The probability of occurrence of such network partitions remains greater in sparse networks, as opposed to dense networks, because an increase in the number of nodes improves network connectivity, thereby reducing packet drops. Such a behavior can be seen in the results shown in Figs. 5(a)-5(e) for all five protocols.

Furthermore, the results depicted in Fig. 5(a) show reduced packet loss rate for ID-LAR compared to PA-GPSR, CADD, and GPSR. Since the direction of intermediary relay nodes plays a vital role in minimizing the probability of route breakage, the direction-based next hop selection by ID-LAR produces considerably improved performance. However, DABFS shows further improvement as it considers the relative positions of source and destination nodes in addition to the other aforementioned parameters. Similarly, minimized packet loss rate is also observed in the results shown in Fig. 5(b), under the proposed DABFS, where it outperforms ID-LAR, PA-GPSR, CADD, and GPSR by a considerable margin.

The direction component becomes even more critical, when the source and destination nodes lie on the opposite side of the road. In such a situation, relative positions of the source and destination along with the direction component become even more important. Hence, DABFS is capable of identifying nodes that are moving towards the destination node, thereby, producing fewer packet losses than ID-LAR, PA-GPSR, CADD, and GPSR, as shown in Fig. 5(c). Moreover, the position of source and destination nodes on the opposite side of the road while bearing movement in the directions away from each other (Case 4, Section III-C) weakens the use of distance-based as well as conventional direction-based forwarding. DABFS is capable of efficiently handling such situations, whereas packet losses in ID-LAR, PA-GPSR, CADD, and GPSR remain higher, as shown in Fig. 5(d).

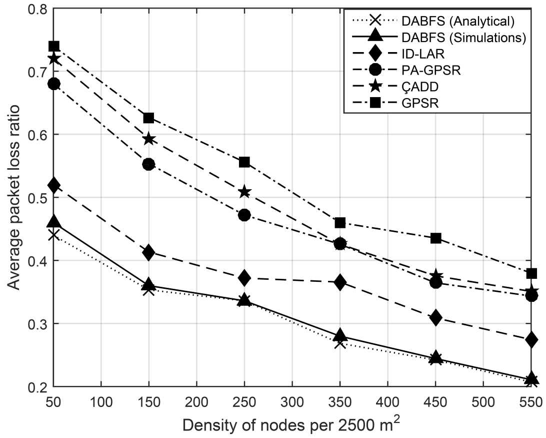
Finally, Fig. 5(e) presents results for recovery mode packet forwarding, where DABFS keeps the packets drop rate considerably lower than the other protocols. Considering Case 5, since all the other schemes do not take into account the relative positions as parameters, there remains a strong possibility that the nodes moving in the direction opposite to the destination node, when selected as next hop, carry the packets with them if they do not find any other node in their neighborhood. This leads to the loss of packets that are forwarded on this route.

B. *End-to-end delay*

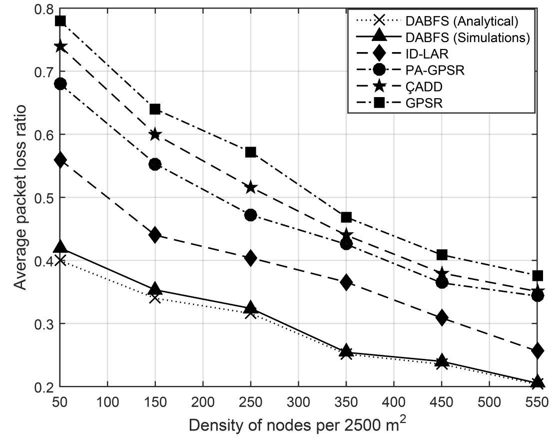
End-to-end delays can be computed as

$$E_r = \frac{\sum_{i=1}^{R_p} E_{d_i}}{R_p}, \tag{4}$$

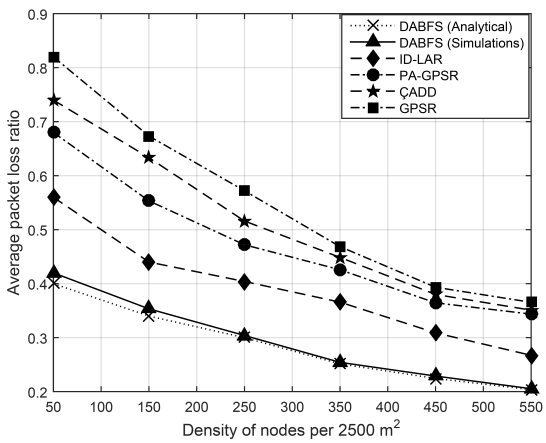
where E_r represents the end-to-end delay ratio, E_{d_i} is the delay experienced by a single packet, and R_p refers to the total number of packets received. Due to the increased number of hops in ID-LAR, PA-GPSR, CADD, and GPSR as a result of path reconstruction process, as detailed in Section III-C-1, the number of send and receive operations also increases.



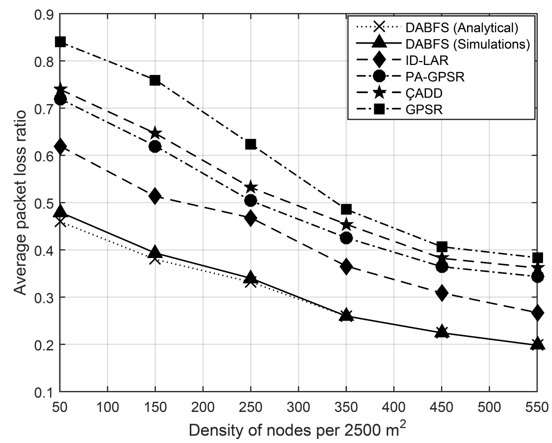
(a) Case1: $H(S, D) = 1$, S is rear and D is front node.



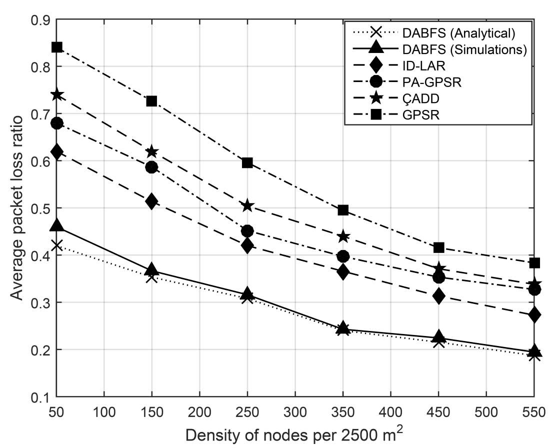
(b) Case2: $H(S, D) = 1$, S is front and D is rear node.



(c) Case3: $H(S, D) = 0$, S and D are moving towards eachother.



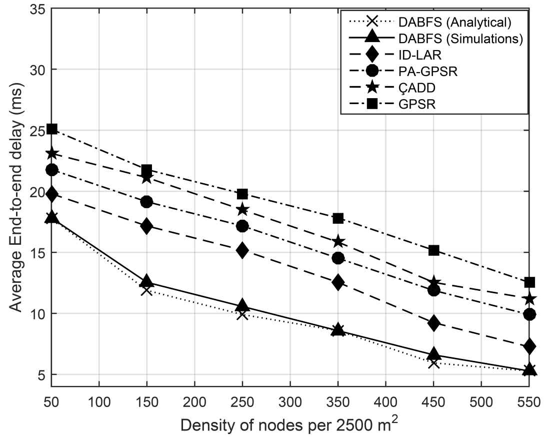
(d) Case 4: $H(S, D) = 0$, S and D are moving away from eachother.



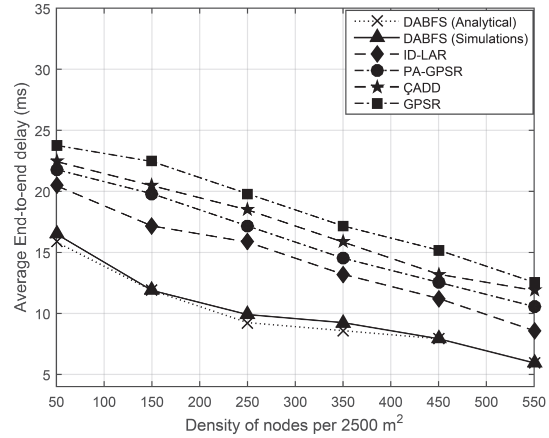
(e) Case 5: $H(S, D) = 0$, S and D are moving towards eachother.

Fig. 5: Average packet loss rate during transmission of warning messages.

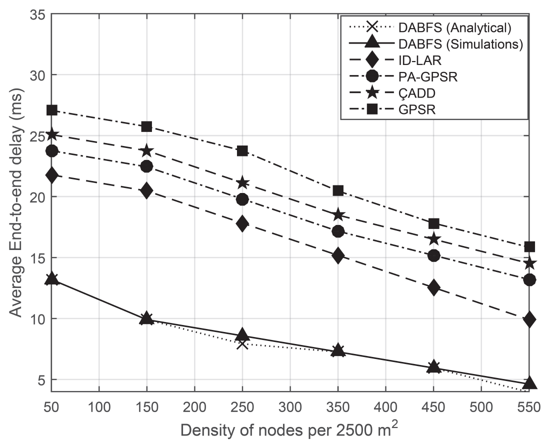
Since send and receive operations are costly in terms of time [48, 59], the increased number of these operations adversely affects the performance of ID-LAR, PA-GPSR, CADD, and GPSR. On the other hand, DABFS minimizes this delay by selecting next hops that are moving towards the destination node. Results shown in Fig. 6(a) warrant the significance of DABFS by showing a considerable improvement in minimizing latency during transmission of packets to the destination node in comparison to the other protocols. A similar kind of improvement in latency reduction can also be seen in Fig. 6(b)



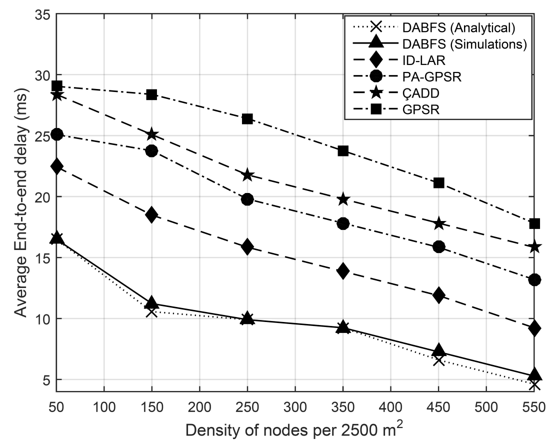
(a) Case1: $H(S, D) = 1$, S is rear and D is front node.



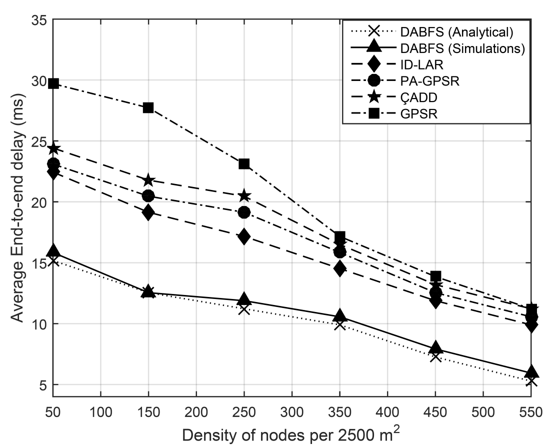
(b) Case2: $H(S, D) = 1$, S is front and D is rear node.



(c) Case3: $H(S, D) = 0$, S and D are moving towards eachother.



(d) Case 4: $H(S, D) = 0$, S and D are moving away from eachother.

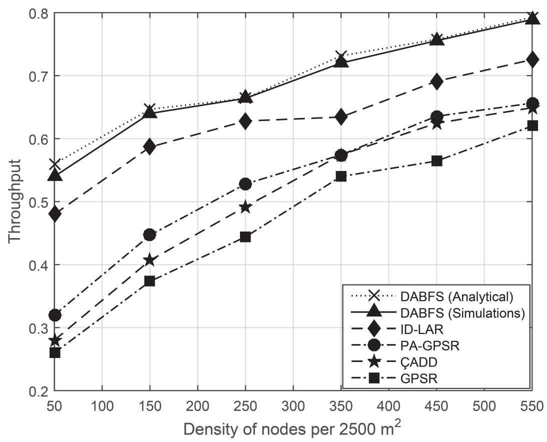


(e) Case 5: $H(S, D) = 0$, S and D are moving towards eachother.

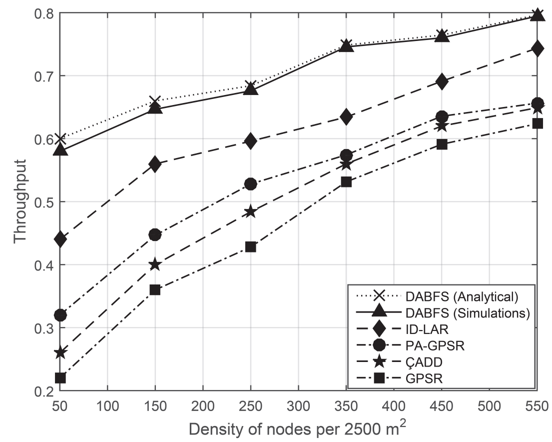
Fig. 6: End-to-end delay during transmission of warning messages.

by DABFS compared to the other protocols.

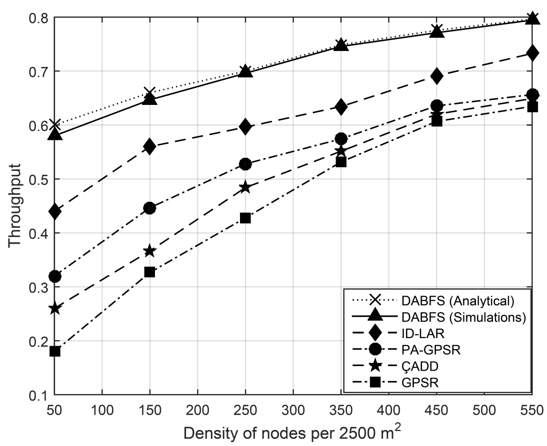
Considering results depicted in Fig. 6(c), DABFS not only takes into account the distance but also the inwards direction, which improve the transmission process significantly, as compared to ID-LAR, PA-GPSR, CADD, and GPSR protocols. Furthermore, in Fig. 6(d), the latency observations taken for the case where the source and destination bear movement direction away from each other, DABFS yields better result as compared to ID-LAR, PA-GPSR, CADD, and GPSR. The final scenario in Case 5 requires the protocols to enter a



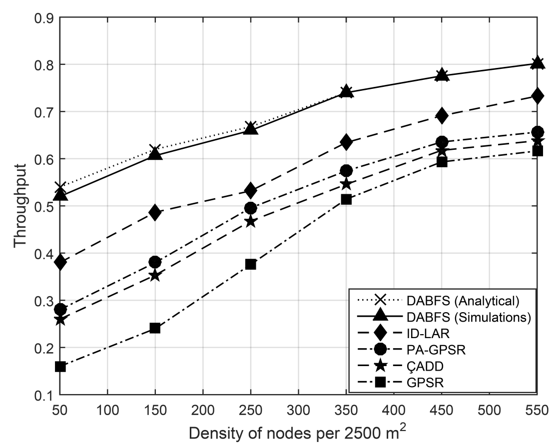
(a) Case1: $H(S, D) = 1$, S is rear and D is front node.



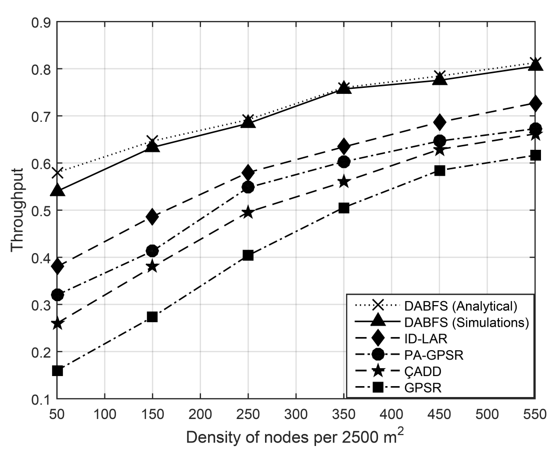
(b) Case2: $H(S, D) = 1$, S is front and D is rear node.



(c) Case3: $H(S, D) = 0$, S and D are moving towards eachother.



(d) Case 4: $H(S, D) = 0$, S and D are moving away from eachother.



(e) Case 5: $H(S, D) = 0$, S and D are moving towards eachother.

Fig. 7: Throughput during transmission of warning messages.

recovery mode. Again, DABFS performs better than ID-LAR, PA-GPSR, CADD, and GPSR, as shown in Fig. 6(e).

C. Throughput

This metric refers to the ratio of packets received on the destination nodes to the total number of packets transmitted by the source nodes, which can be computed as

$$T_r = \frac{\sum_{i=1}^{R_p} R_{p_i}}{P_t}, \quad (5)$$

where T_r represents the network throughput achieved, R_{pi} represents an individual packet received by a destination node, and P_t refers to the total number of packets transmitted by the source nodes. Throughput is an important metric for performance evaluation as it measures the number of packets successfully delivered to destination nodes. Packet losses and end-to-end delays affect throughput of a network. Results presented in Figs. 7(a) and 7(b) show improved throughput of DABFS compared to ID-LAR, PA-GPSR, CADD, and GPSR due to the use of our novel direction-based route selection. Moreover, in complex scenarios, where the source and destination lie on the opposite side of the road, DABFS follows the same pattern by providing a significant improvement in enhancing throughput, as shown in Figs. 7(c) and 7(d). Furthermore, DABFS outperforms the other protocols with respect to throughput enhancement in recovery mode packet forwarding, as shown in Fig. 7(e).

D. Discussion

Simulation results presented in the previous subsections indicate the robustness of the proposed DABFS protocol. For performance evaluation, five distinct cases were presented in Section III-C. These cases demonstrate how the direction component and relative positions of source and destination nodes impact the selection of the best route for message delivery in greedy as well as recovery mode forwarding. Simulation results are validated through analytical results mapped onto the aforementioned five distinct cases, as detailed in Section IV-A through Section IV-C.

This study reveals that the use of direction component along with relative positions of source and destination nodes (i) improves network throughput and minimizes end-to-end delay and packet losses; and (ii) helps a VANET routing protocol to cater for topological changes during transmission of packets to enhance reliability. Simulation results for packet loss rate demonstrate an average improvement of DABFS by 5%, 14%, 17%, and 19% compared with ID-LAR, PA-GPSR, CADD, and GPSR, respectively. Furthermore, DABFS minimizes average end-to-end delay by 4.4 ms, 6.3 ms, 7 ms, and 8 ms compared to ID-LAR, PA-GPSR, CADD, and GPSR, respectively. The low-loss and low-delay characteristics of our proposed protocol makes it more robust as compared to eminent VANET routing protocols. Moreover, DABFS enhances average network throughput by 4%, 13%, 16% and 18% as compared with ID-LAR, PA-GPSR, CADD, and GPSR, respectively. The higher throughput of DABFS makes it more efficient as compared to eminent VANET routing protocols. We find that all the protocols compared in this paper demonstrate enhanced performance in terms of packet loss rate, end-to-end delay and throughput as the network density increases. However, DABFS outperforms the other protocols for all density levels. This increased efficiency and robustness enhances reliability in warning messages transmission.

DABFS is designed for routing of warning messages in bi-directional highway traffic and is not suitable for the urban environments that consists of intersections. Moreover, DABFS relies on GPS for localization, which may limit its performance due to inaccuracy, signal failure, and privacy issues in GPS technology. Our future work aims to address these limitations.

The world is shifting from the conventional highway systems to Intelligent Transportation Systems (ITSs) [40]. These intelligent systems aim at conversion of ordinary nodes into smart nodes, which enables them to learn from their surroundings automatically. Such an automated learning system helps drivers to foresee an emergency event and enables them to communicate the gathered information in a random multi-hop dynamic topology. Besides the identification of a possible collision among nodes [49-50], robust and reliable delivery of warning messages remains equally important [51-52]. To that end, employing our proposed DABFS protocol in ITSs will reasonably improve performance and enable a safe driving environment.

V. Conclusion and Future Work

Vehicular collision avoidance primarily relies on transmission of warning messages to prevent road accidents. Delays or packet drops during transmission of warning messages may cause inter-vehicular collisions. To that end, we have presented a novel Direction Aware Best Forwarder Selection (DABFS) protocol that takes into account two parameters, in addition to the distance parameter, to cater to the dynamic nature of bi-directional highway environments and provide efficient route selection. The first parameter includes a node's movement direction determined through Hamming distance, while the second parameter is the relative positions of source and destination nodes. We show that these parameters are critical for the selection of next hop in bi-directional traffic. This study has revealed that the use of the aforementioned parameters for routing of warning messages leads to increased throughput and reduced packet loss and delay, and allows to cater to the topological changes during transmission. Analytical and simulation results demonstrate considerable performance improvement of DABFS over eminent VANET routing protocols. Our future work includes extension of DABFS for urban environments with GPS-less localization. Moreover, determining the effect of channel conditions upon the delivery of warning messages and secure transmission can also be taken as future directions.

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Competing interests:

The authors declare that they have no competing interests.