Multi-metric Geographic Routing for Vehicular Ad hoc Networks

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Abstract-

Maintaining durable connectivity during data forwarding in Vehicular Ad hoc Networks has witnessed significant attention in the past few decades with the aim of supporting most modern applications of Intelligent Transportation Systems (ITS). Various techniques for next hop vehicle selection have been suggested in the literature. Most of these techniques are based on selection of next hop vehicles from fixed forwarding region with two or three metrics including speed, distance and direction, and avoid many other parameters of urban environments. In this context, this paper proposes a Multi-metric Geographic Routing (M-GEDIR) technique for next hop selection. It selects next hop vehicles from dynamic forwarding regions, and considers major parameters of urban environments including, received signal strength, future position of vehicles, and critical area vehicles at the border of transmission range, apart from speed, distance and direction. The performance of M-GEDIR is evaluated carrying out simulations on realistic vehicular traffic environments. In the comparative performance evaluation, analysis of results highlight the benefit of the proposed geographic routing as compared to the state-of-the-art routing protocols.

Keywords- Geographic routing; Multi-metric; Vehicular adhoc networks; Next hop vehicle

1. Introduction

A new wireless technology is innovated in recent years called Vehicular ad hoc network (VANET), which is a digital communication between Vehicle-to-Vehicle (V2V) or between Vehicles-to-Infrastructure (V2I) [1,2]. This technology provides smart way to make road transport safer and more comfortable while also reducing travel time [3]. VANET enables on road vehicles to locally share relevant traffic information via one-hop and multi-hop communications [4]. For that reason, it is considered as one of the most important and promising technologies that can serve most of the Intelligent Transport System (ITS) applications. These applications mainly include safety, comfort, and efficiency [5]. The safety applications are designed to provide awareness for the drivers along the road such as vehicle warning in case of emergency. The comfort applications are designed to provide comfort for the driver and passenger along the journey, such as, free music downloads and playing games [6,7]. The efficiency applications are designed to reduce the traveling time and fuel consumption including traffic management and road monitoring, which can promote intelligent traffic flow control and

vehicle tracking. Supporting such applications requires effective and reliable routing protocol to efficiently disseminate information in such dynamic environment [8, 9].

Many efforts have been made in recent past to address the issues related to next hop vehicle selection in urban vehicular environment [10-12]. Although, traditional ad hoc routing protocols have addressed the issues of traditional ad hoc networks [13-15], yet they encountered many challenges in vehicular traffic environment due to the high mobility of vehicles [16]. Geographical routing has been preferred in vehicular traffic environment due to its ability to exploit geographical positions of vehicles while making routing decision [17, 18]. The geographical routing techniques in literature are based on either selection of next hop vehicle from fixed forwarding region and/or two or three metrics including speed, distance and direction [19-34]. Some major parameters of urban vehicular environments have not been considered in the literature. Specifically, the techniques including Voronoi Diagram based Geographic Distance Routing (V-GEDIR) [19], Peripheral node-based Geographic Distance Routing (P-GEDIR) [20], Junction-based Geographic Routing (J-GEDIR) [21], Segment vehicle, Link quality and Degree of connectivity based Geographic Distance Routing (SLD-GEDIR) [22] are mainly based on fixed forwarding region. Whereas other techniques have focused on distance, and direction including Directional Greedy Routing (DGR) [28], Movement-Aware extension of the Greedy Forwarding (MAGF) [33], Greedy Stateless Perimeter Routing based on Motion Vector (GSPR-MV) [34].

In this context, this paper proposes a Multi-metric Geographic Routing (M-GEDIR) technique for next hop selection. It selects next hop vehicle from dynamic forwarding regions, and considers major parameters of urban environments including, received signal strength, future position of vehicles, and critical area vehicles at the border of transmission range, apart from speed, distance and direction. The key contributions of the paper are following.

1) The selection of next hop vehicle from dynamic forwarding region based on the concept of safety and unsafety area calculation considering critical border area vehicles, and the vehicles tightly moving towards the destination.
2) Multiple metrics for next hop vehicle selection to consider major parameters of urban vehicular environment including signal strength, future position, and critical area at border, apart from speed, distance, and direction.
3) The mathematical modeling of dynamic forwarding region identification and multiple metrics, along with the algorithms for next hop vehicle selection, and multiple metrics based geographic routing.
4) The comparative performance evaluations of M-GEDIR under realistic environment.

The rest of the paper is organized in the following sections. The related literature is qualitatively reviewed in section 2. The detail of the proposed M-GEDIR protocol is provided in section 3. Section 4 presents the simulation setting, and analysis of the results. Conclusion and future work are given in section 5.

2. Related Work

In this section, related literature on next hop vehicle selection in geographic routing is critically reviewed, by categorizing the theme in fixed forwarding region based techniques, and distance and direction metrics based techniques.

2.1 Fixed Forwarding Region based Techniques

In [19], a Voronoi Diagram based Geographic Distance Routing (V-GEDIR) was proposed. It offers two loop free methods VD-GREEDY and CH-MFR to assist current forwarder in selecting best next hop, whose voronoi region either intersects or covers the destination zone. However, it does not consider the mobility of the nodes during the formation of the voronoi diagram. In [20], authors present a Peripheral node-based Geographic Distance Routing (P-GEDIR) to improve routing decision by reducing the size of the forwarding region. P-GEDIR divides the transmission range of the current forwarder into the half strip. After that, the current forwarder selects the next peripheral vehicle from the front part of the half circle to reduce the number of hops from source to destination. However, the authors do not consider the quality of the link while selecting next hop, which could increase the possibility of link failure. Another geographic routing protocol known as Junction-based Geographic Distance routing (J-GEDIR) is proposed in [21] to disseminate data packets from destination towards the nearest junction's vehicle. J-GEDIR considers minimum angle method to determine the appropriate next junction's vehicle. Moreover, it uses a greedy distance estimation approach for sending data packet toward the destination vehicle to reduce the end-to-end delay. Furthermore, it deploys a recovery strategy to get out from void area. However, this protocol ignores the impact of obstacles in urban traffic scenario, which could degrade its performance. O. Kaiwartya et al. [22] propose a Segment vehicle, Link quality, and Degree of connectivity based Geographic Distance Routing (SLD-GEDIR) protocol for improving routing decision. This protocol suggests segmentation of the area for reducing the size of the forwarding region and the number of hops between source and destination. Three concepts namely, Segment vehicle, Link quality, and Degree of connectivity are used in this protocol for selecting the most reliable link. Firstly, SLD-GEDIR determines a set of segment vehicles located within the segmented area. Secondly, link quality it uses packet error rate to predict the quality of the underlying link and finally it computes degree of connectivity for each segment vehicle. SLD-GEDIR selects the most reliable next forwarder vehicle from a predetermined segment region, which has the highest degree of connectivity. SLD-GEDIR relies on the link quality while selecting optimal next hop. Results show that SLD-GEDIR shows good performance even with varying speed and density of vehicles. However, using segment area alone cannot always guarantee the selection of optimal next hop vehicle due to the different movements of one-road vehicles. In [23], road perception based geographical routing protocol (RPGR) is proposed for reliable next hop selection. In this protocol, authors determined mid area within current forwarder transmission range. Then, based on area selects the best vehicle considering distance and direction. Authors claim that the selection of mid vehicle improves reliability of the forwarding. However, mid vehicle increase hop count and leads to reduce the ratio of end-to-end delay specifically in dense urban environments. Further, if there is no mid vehicle available, RPGR selects next hop vehicle from border region without estimating the future position, which might leading to high ratio packet loss.

2.2 Distance and Direction based Techniques

Apart from reducing the size of the forwarding region as mentioned earlier, traditional greedy strategies and their improvements have focused on selecting border vehicle as next hop. In [24], authors propose a Perimeter Stateless Routing (GPSR) protocol. This approach uses greedy and perimeter strategies to deliver data packets to a known destination vehicle. In the data forwarding process, GPSR first utilizes greedy mode to forward data packets to the vehicle, closest to the destination than itself. However, if the data packet reaches to the target vehicle that has encountered void area, it switches to perimeter mode to get out from this area using Right Hand Rule (RHR). The concept of greedy forwarding is promising for MANET environment. However, it is not applicable in VANET as it does not consider characteristics of VANET environment. Geographic Source Routing (GSR) [25] is another protocol proposed to tackle the drawbacks of traditional GPSR by utilizing a static road map of the urban scenario. In GSR, the current forwarder depends on road map information and the current location of its neighbor vehicles to make the routing decision. The current forwarder injects a series of junctions into the packet header that a packet must traverse to reach its intended destination. Besides, it utilizes location service to obtain the location of destination vehicles.

Moreover, GSR uses Dijkstra's algorithm to determine the shortest path from source to destination. Results exhibit that GSR has achieved better packet delivery ratio and average delay as compared to GPSR. In spite of that, it has neglected traffic density and sparse scenarios, which reduces its applicability in VANETs scenarios. In [26], a Spatially Aware Packet Routing (SAR) was proposed. Similar to GSR, the proposed method aims to reduce the frequent occurrence of recovery mode in GPRS by considering a spatial model. This model utilizes Static Road Map (SRM) while selecting next appropriate hop. Although SAR effectively reduces the occurrence of recovery mode and improved end-to-end delay, still it neglects the network traffic density and the presence of obstacles along the roads. The authors in [27] propose an Anchor-based Street and Traffic-Aware Routing (A-STAR) to modify GSR and SAR by giving more priority for roads served by transit buses. Based on the bus lines, the proposed technique computes vehicular traffic density at each road. The higher weight was assigned to roads that possess less number of bus lines and vice versa. A-STAR also uses Dijkstra shortest path algorithm with the digital map to compute anchor points at each intersection. Moreover, A-STAR also presents a recovery strategy to get out from local maximum. Simulation results exhibit the superior performance of A-STAR as compared to the GSR and SAR in the urban scenario. However, A-STAR only prefers main roads and rarely chooses secondary roads even though these roads can provide an optimal path. Furthermore, it neglects the consideration of traffic density on the selected path. In [28], a Directional Greedy Routing (DGR) is proposed to improve the forwarding technique of GPSR based on weighting factors. The proposed protocol either selects a particular vehicle moving towards the destination using directional forwarding or selects vehicle closest to the destination than the source itself using greedy forwarding. Authors have also suggested a Predictive Directional Greedy Routing (PDGR) protocol to enhance DGR. PDGR predicts the future position of the direct neighbors before selecting a particular vehicle to act as next forwarder. In PDGR, the current forwarder obtains information from one hop and two-hop neighbors. It then uses this information to select the best next hop vehicle. Analysis of the simulation results clearly showed that DGR and its improvement outperforms traditional

GPSR routing protocol regarding transmission delay and packet delivery ratio, particularly with highway scenario. However, the performance of these protocols starts to decline particularly in urban environments because they neglected the impact of obstacles while selecting the next forwarder. Moez Jerbi, et. al. [29] proposed an improved greedy traffic-aware routing protocol (GyTAR), which has been also utilized by [30] to reduce packet loss while selecting next hop vehicle in urban scenario. In GyTAR, the current forwarder vehicle makes its routing decision after consulting its direct neighbor's table. It computes new position of its direct neighbors based on speed and direction, and then selects a vehicle that is nearest to the intended destination. The impact of obstacles on the transmitted signals is not consider in aforementioned protocols [29, 30]. In other attempts [31], have improved the routing decision of GyTAR by selecting the best next hop vehicle which are predicted to be within its own transmission range and have a strong signal power. Although, the strength of the signal shows significant improvement during next hop selection. However, estimating the strength of the received signal from neighbouring vehicles is completely missing in this work, which is very important for determining unreachable vehicles. Darwish, T, et. al.[32] used the process of next hop selection that is suggested by [31] in order to forward data packet between two consecutive junctions. Brahmi, N, et. al. [33] propose a Movement-Aware extension of the Greedy Forwarding (MAGF) protocol. MAGF aims to improve the forwarding mechanism of traditional GPSR by considering velocity and direction. The next hop vehicle selection in this scheme depends upon link lifetime and weight factors, which reduces the occurrence of the local maximum. Simulation results show the superiority of MAGF over GPSR in-terms of packet delivery ratio. However, the performance of this protocol starts to degrade in the presence of obstacles, particularly in urban scenarios. Another position based routing protocol for VANETs called GPSR-MV was suggested in [34] to enhance traditional GPSR by considering Motion Vector. In this protocol, a current forwarder first predicts the future positions its direct neighbors before it selects the next hop towards the destination. Furthermore, GSPR-MV improves perimeter strategy to avoid loop problem. Simulation results showed the superiority of GPSR-MV in terms of packet delivery ratio, transmission delay, and number of hops as compared with GPSR. However, the strength of the transmitted signal was not consider in this work.

3. Multi-metric Geographic Routing

The geographic routing techniques exploit location of neighboring vehicles on making forwarding decisions towards destination in vehicular environments. The multi metric geographic routing technique is the extension of geographic routing focusing on dynamic forwarding region, and multiple metrics based next hop vehicle selection. The detail of M-GEDIR is presented in following sections, starting with some assumptions:

- It is a V2V cooperative scheme and there is no consideration of Roadside Units (RSUs).
- A vehicle can recognize each vehicle exceeding the current forwarder's communication range.
- All vehicles have equal maximum communication range.
- Vehicles can communicate with each other, using wireless technology called Dedicated Short Range Communications (DSRC) [35].
- All on-road vehicles are equipped with On-Board Unit (OBU) and sensors for location, speed, direction, and distance measurement with sufficient accuracy.

- All on-road vehicles are equipped with digital maps to obtain their roads structures and IDs.
- Hello message is a control packet that is used by current forwarder and its direct neighbors to share their important information.
- Data link layer protocol (MAC) and Physical layer protocol (PHY) are considered as lower layers.
- Signal attenuation and channel fading are taken into consideration in this protocol.

Table 1. Nomenclature

Notation	Description
$RREQ_i$	Route request control packet broadcasted from C_F to S_{dn}
$RREP_i$	Route reply control packet received by C_F from S_{dn}
δ	Threshold value used to determine the outage probability of the received power from S_{dn}.
C_F	Current forwarder vehicle
S^{C_F}	Speed of C_F
S^{U^v}	Speed of U^{vi}
Fr_c	Front part of the half circle of the C_F communiction range
S_{dn}	Set of direct neighbor vehicles located in Fr_c
NHV	Next Hop Vehicle
Vi	i^{th} individual vehicle belonging to S_{dn}
US_{area}	Unsafety area
S_{area}	Safety area
U^{vi}	Set of unsafety vehicles
S^{vi}	Set of safety vehicles
$S^{U^{vi}}$	The maximum speed of a particular unsafety vehicle
R	Radius of US_{area}
R'	Radius of S_{area}
V_D	Destination vehicle within geocast region
S_{max}	The maximum speed of a particular Vi
P_r	Received signal strength from Vi
$F^{U^{vi}}$	Future position of U^{vi}
D	Distance between C_F and Vi
Θ	Sector angle
$D_{is}[]$	Distance of Vi
$S_p[]$	Speed of Vi
$A_n[]$	Angle of Vi
M_D	Vi with the Maximum distance
M_S	Vi with the Maximum speed
Mi_a	Vi with the Minimum angle
$T_D[i,3]$	Two dimension array where i represents all Vi and 3 represents D_{is}, S_p and A_n of the Vi respectively
$W_f[]$	One dimensional array for Weight factor
$Wv[]$	One dimensional array for determining weight factor of Vi.

3.1 Dynamic Forwarding Region

In M-GEDIR, all vehicles have equal communication range (say: R) that is predetermined. All the vehicles located within the communication range of the current forwarder vehicle C_F like (A) in Figure 1 are called direct neighbors. All direct neighbors exchange their important information such as velocity, position, direction, signal power, and time through periodical exchanges of "hello messages". The dashed area bounded by arcs BC and $B'C'$ is called Unsafety area (US_{area}). All vehicles belonging to this area are known as Unsafety vehicles (U^v). The inner sector area $AB'C'$ is called Safety area (S_{area}) and the vehicles located within this area are known as Safety vehicles (S^v).

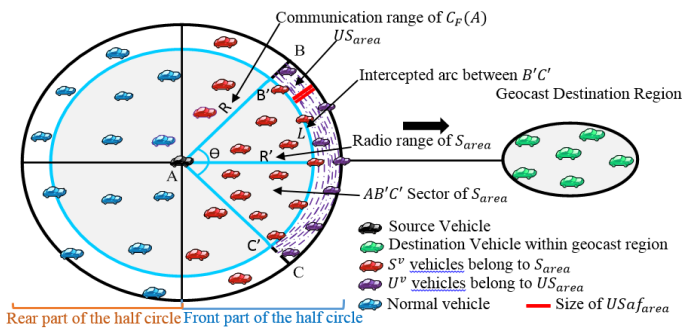

Figure 1. Safety and Unsafety areas within the communication range of the current forwarder, A

The C_F determines these two areas within its communication range after obtaining the velocities of its direct neighbors that are located within the front part of the half circle as shown in Figure 1. Afterward, it finds the difference in speed between the maximum speed of its direct neighbors S_{max} and its own speed S^{C_F}. If the S_{max} is less than S^{C_F}, that means there is no US_{area}. In contrast, when the S_{max} is greater than S^{C_F}, there will be US_{area}, which can be calculated as given in Equation (1).

$$US_{area} = \text{Area of sector } ABC - \text{Area of sector } AB'C'$$

$$US_{area} = \frac{\Theta}{360^0}\pi R^2 - \frac{\Theta}{360^0}\pi R'^2 \tag{1}$$

where $R = AB$, $R' = AB'$, L is the length of the intercepted arc between B' and C' points and $\Theta = \frac{L}{R'}$. The consideration of safety and unsafety area is more significant due to the dynamic vehicular environment (very small speed change interval). The consideration ease the next hop selection by clearly identifying the level of dynamism in the vehicles in terms of speed and direction. By considering these assumptions, Equation (1) can be further simplified as shown in Equation (2).

$$US_{area} = \left(R \times \frac{L}{2}\right) - \left(R' \times \frac{L}{2}\right) \tag{2}$$

The C_F calculates the approximate distance $d^{US_{area}}$ of unsafety area by multiplying the difference in speed Δs by factor of safety as expressed in Equation (4).

$$\Delta s = S_{max} - S^{C_F} \tag{3}$$

$$d^{US_{area}} = \Delta s * T \tag{4}$$

Where $\boldsymbol{T}$ represents the factor of safety time in seconds ($\boldsymbol{T}$ = "**hello messages**" **time** $*$ **processing time**). Doing this enables $\boldsymbol{C_F}$ to find the radius of safety area $\boldsymbol{R'}$ as given in Equation (5).

$$R' = R - d^{US_{area}} \tag{5}$$

Where R is the radius of current forwardr's communication range. The main reason for determining S_{area} and US_{area} is to maintain durable connectivity when making routing decision. This is carried out by separating US_{area} from S_{area} and giving higher priority to Unsafety vehicles (U^v) for optimal NHV selection. The reason behind this is to reduce hop counts in case of their availability otherwise, Safety vehicles (S^v) will be considered for optimal NHV selection. All U^v considered for optimal NHV selection must have speed less than the S_{max} and S^{C_F}, and must also satisfy the conditions presented in subsections 3.2.2 and 3.2.3 below. However, the considered S^v only need to satisfy the conditions presented in section 3.2.2 below. The process of selecting optimal NHV is based on the concept of weighting factors as described in Section 3.3.

3.2 Multiple Metrics

The derivation of multiple metrics including location calculation, signal strength estimation, future location prediction is presented below.

3.2.1 Determination of Vehicle Locations

In this subsection, the distance between C_F and each direct neighbor located in front part of the half circle is estimated to determine the location of each vehicle whether it is located within the S_{area} or US_{area}. For that reason, Inter Vehicle Distance (IVD) is utilized as one of the most important parameters for maintaining durable connectivity [36]. The case of instantaneous non-reception of location information from GPS is not consider in this work. IVD is computed as expressed in Equation (7).

$$D = \sqrt{\left\{\left(r'\cos\Theta_1 - r\cos\Theta_2\right)^2 + \left(r'\sin\Theta_1 - r\sin\Theta_2\right)^2\right\}} \tag{6}$$

Where $(r'\cos\Theta_1, r'\sin\Theta_1)$ and $(r\cos\Theta_2, r\sin\Theta_2)$ represents the location of direct neighbor vehicle and the C_F, respectively. By considering $\sin^2\Theta + \cos^2\Theta = 1$ and

$\cos\Theta_1 \cos\Theta_2 + \sin\Theta_1 \sin\Theta_2 = \cos(\Theta_1 - \Theta_2)$, Equation (6) can be further simplified as shown in Equation (7).

$$D = [r'^2 + r^2 - 2r'r\cos(\Theta_1 - \Theta_2)]^{1/2} \tag{7}$$

The usage of IVD makes C_F aware of the locations of all safety vehicles (S^v) and unsafety vehicles (U^v) within its communication range. This is achieved by comparing the value of D with the radius R′. If D is greater than R′, this indicates that the vehicle belongs to US_{area}, otherwise, it belongs to S_{area}.

3.2.2 Estimation of Received Signal Strength

Maintaining durable path requires efficient routing strategy in order to select a stable link to act as NHV. The unique VANETs characteristics and presence of mobile and stationary obstacles, such as big vehicles and buildings in urban environments as illustrated in Figure 2 (a) and (b), respectively. Such obstacles increase the variation in the transmitted signals that mainly occur due to their shadow, which hinder the quality of transmitted signals from reaching its intended destination. This is referred as shadowing or shadow-fading in vehicular environments [37]. The impact of these obstacles can easily degrade the performance of the routing protocol and leads to increases the ratio of packet loss. To this end, the C_F calculates the strength of the received signal power SP_{dvi}^{R} from its ith direct neighbor vehicle (dvi) using shadow-fading model. Afterward, C_F estimate the outage probability of its direct neighbor's link. The probability of received signal being less than the ideal received signal requirement $SP_{ideal}$is considered as outage probability. Here, it is obtained by comparing the received signal strength with ideal signal strength requirement in terms of percentage as $\left({SP_{dvi}^{R}}/{SP_{ideal}} \right) \geq \delta$, where, δ represents the threshold value used to determine the outage probability of the received power from direct neighbor. By doing this, the C_F become aware of all unreachable vehicles, which were affected in the shadow of the obstacles in order to avoid them when making routing decision. Consequently, a direct neighboring vehicle is considered reachable if the SP_{dvi}^{R} is greater than or equalδ. Once the C_F receives the location information from its ith direct neighbor vehicle (dvi), it starts calculating SP_{dvi}^{R}using Equation (8) [38].

$$SP_{dvi}^{R} = SP_{dvi}^{T} \left\{ 10 \log_{10} C_0 - 10\omega_0 \log_{10} \left(\frac{D_{C_F dvi}}{D_0} \right) - \tau_0 \right\} \tag{8}$$

Where SP_{dvi}^{T} is the transmitted signal power from i^{th} direct neighbour vehicle dvi, $D_{C_F dvi}$ is the distance between C_F and the direct neighbour vehicle dvi. The announced location of ith direct neighbour vehicle dvi in terms of latitude and longitude is represented as $L_{la1\,lo1}(dvi)$, τ_0 represents Gaussian random variable, C_0 denotes a constant representing antenna characteristics and channel attenuation, ω_0 represents the path loss exponent, and D_0 is the reference distance for antenna.

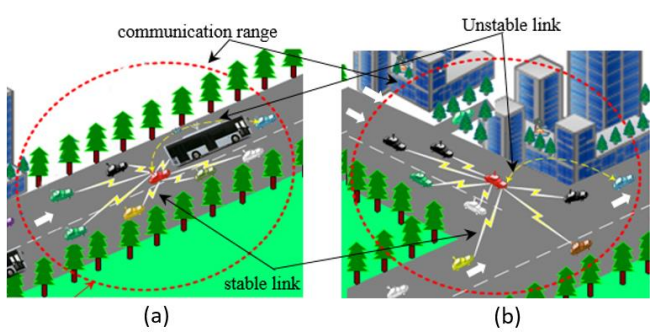

Figure 2. Mobile and stationary obstacles in the C_F communication range

3.2.3 Prediction of Future Positions

Future position prediction is one of the most important traffic parameters that needs to be considered in order to maintain stable links when selecting optimal NHV. In M-GEDIR, the prediction only applies to unsafety vehicles U^v to increase awareness of C_F regarding those

vehicles trying to exceed its communication range. By this way, the C_F becomes able to avoid unstable vehicles that lead to break the link during data forwarding. Figure 3 clearly depicts the process of predicting future position of C_F and its individual U^v using Equation (9);

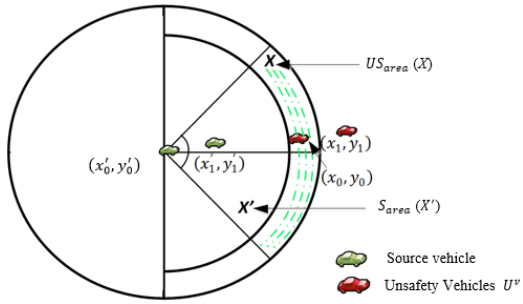

Figure 3. Prediction future position of C_F and its individual unsafety vehicle U^v

$$N_{P_{d^2}} = \left(\left(X'_0 + V_{x'_0}\,\Delta t\right) - \left(X_0 + V_{x_0}\,\Delta t\right)\right)^2 + \left(\left(Y'_0 + V_{y'_0}\,\Delta t\right) - \left(Y_0 + V_{y_0}\,\Delta t\right)\right)^2 \quad (9)$$

Where, $N_{P_{d^2}}$ represents projected distance between C_F and its individual unsafety vehicle U^v , (X_0', Y_0') and (X_0, Y_0) represent the initial positions of C_F and U^v at time t_0 , respectively. (X_1', Y_1') and (X_1, Y_1) represent the predicted positions of C_F and U^v at time t_1 , respectively. Δt is the difference between the predicted time and the initial time of U^v and C_F ($t_1 - t_0$) , respectively. $(V_{x'_0}, V_{y'_0})$ and (V_{x_0}, V_{y_0}) represent the initial and predicted velocities of C_F and U^v , respectively.

3.3 Selection of Next Hop Vehicle

The process of selecting a next hop vehicle is based on the vehicles that have satisfied the conditions mentioned in Section 3.1. The final decision is made by M-GEDIR to select optimal NHV that have the summation of its weighting factors higher than others. M-GEDIR, first looks to unsafety area to select optimal NHV but in case there is no unsafety vehicle available, it looks on the safety area to make its optimal selection. The weighting factors are assigned to three important traffic parameters namely, distance W_d, velocity W_v, and minimum angle W_{Ma} with initial values 60 %, 30 % and 10 % , respectively. Distance, speed and direction have been given relatively lower importance in order. The W_{Ma} has been given relatively lower importance in next hop vehicle selection due to the consideration of only those vehicles closer to the destination comparatively from current forwarder, during safety and unsafety area identification itself. In M-GEDIR, minimum weight has been given to angle parameter, which is beneficial to cope with the situation as depicted in Figure 4, when three vehicles having same speed and distance moving toward the destination. In this situation, the C_F (A) selects vehicle (C) to act as optimal NHV because it has minimum angle as compared to B and D. The proposed protocol is based on two forwarding mechanisms; namely, vehicle to next junction's vehicle or vehicle to next vehicle not at junction. A complete description regarding NHV selection is provided in procedure 1 below.

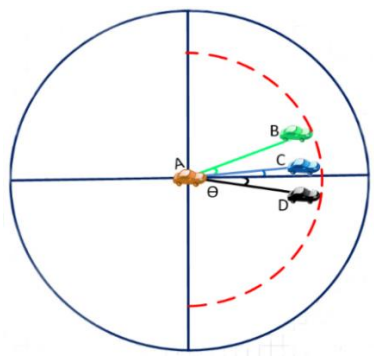

Figure 4. Selection of optimal next hop vehicle.

Procedure 1: Next Hop Vehicle Selection

Notations **See Table 1.**

Process

1. **Initialization**

   $M_D = D_{is}[0]$; $M_S = S_p[0]$; $Mi_a = A_n$

   [0]; $W_f[]$ = {60,30,10};

   S=0; i =0; j =0; $k = 0$;

2. **for each** $Vi \in S_{dn}$

3. **if** ($D_{is}[i]$> M_D) **then**

   M_D =$D_{is}[i]$

   if ($S_p[i]$> M_S) **then**

   M_S =$S_p[i]$

   if ($A_n[i]$> Mi_a) **then**

   Mi_a =$A_n[i]$

   $i++$

   end for

4. **for each** $Vi \in S_{dn}$

.

   if ($M_D == D_{is}[i]$) **then**

   $T_D[i,0]$=1;

   else

   $T_D[i,0]$=0;

   if ($M_S == S_p[i]$) **then**

   $T_D[i,1]$=1;

   else

   $T_D[i,1]$=0;

   if ($Mi_a == A_n[i]$) **then**

   $T_D[i,2]$=1;

   else

   $T_D[i,2]$=0;

   $i++$

   end for

5. **for each** $Vi \in S_{dn}$
6. **for** $j < 3$
$S = S + T_D[i, j]^* W_f[j]$
$i++;\ j++;$
end for
$Wv[i] = S;$
7. **for each** $Vi \in S_{dn}$
if $(Wv[i] > Wv[k])$ **then**
$k = i$
end for
8. $NHV = k$
9. **exit**
Output: A vehicle with the maximum summation of its weighting factors

3.4 M-GEDIR Algorithm

In this subsection, the aforementioned determination of safety and unsafety area, estimation of received signal strength, and future position prediction are considered to improve routing decisions. These considerations have increased the awareness of the C_F regarding the status of its direct neighbors to select the optimal neighbor as described in section 3.3. The complete geographic routing algorithm of M-GEDIR is presented in Fig. 5.

Algorithm 1: M-GEDIR

Notations **See Table 1.**
Process

1. **Initialization**
$C_F = \phi; S^{vi} = \phi; U^{vi} = \phi; \Theta = 180^0;$
2. S_{dn} = {Set of direct neighbor vehicles that located in Fr_c}
C_F broadcast $RREQ_i$ to S_{dn}
3. **if** ($RREPi$ not received) **then**
C_F carry the packet until Vi find
4. **else if** ($V_D \in S_{dn}$) **then**
Forward the data packets to V_D using available direct link
then V_D broadcasts the data packet within geocast region
exit
5. **else**
while ($C_F \neq V_D$)
6. **for all** $Vi \in S_{dn}$find the S_{max}
Calculate Δs using Equation (3)
if ($\Delta s > 0$) **then**
Calculate approximate $d^{US_{area}}$ using Equation (4)
else
$R' = R$
endif
endfor
a. U^{vi} = {Set of unsafety vehicles}
b. Calculate US_{area} using Equation (2) & (4) to find U^{vi}
c. S^{vi} = {Set of safety vehicles}
d. Calculate S_{area} using Equation (5) to find S^{vi}

7. **for** each $Vi \in S_{dn}$

Calculate D using Equation (7)

e. If $(D > R')$ **then**

f. If $(\mathrm{P_r} \geq \delta)$ **then**

g. If $(S_{max} > S^{U^{vi}})$ && $(S^{C_F} > S^{U^{vi}})$ **then**

h. If $(F^{U^{vi}} \leq R)$ **then**

Select optimal unsafety vehicle from US_{area} using **Procedure 1**

8. else If $(\mathrm{P_r} > \delta)$ **then**

Select optimal safety vehicle from S_{area} using **Procedure 1**

endif

endfor

9. Select NHV = A vehicle has highest weight factor

10. Transmit the data packet to NHV and $NHV = C_F$

endwhile

endif

11. exit

Output: Optimal NHV from either S_{area} or US_{area}

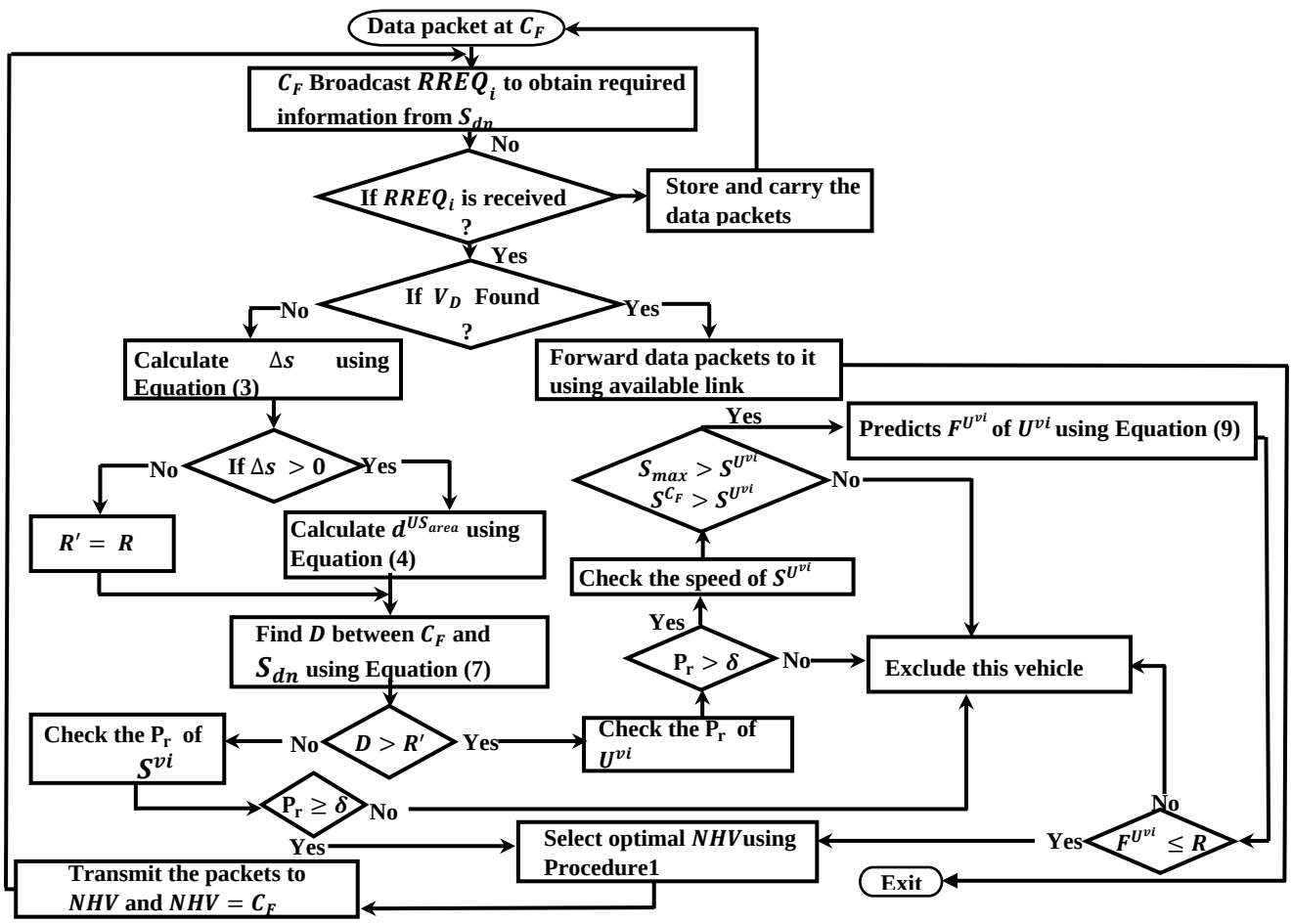

Figure. 5 Flowchart to determine the process of selecting optimal NHV

3.4.1 Explanation of Steps of M-GEDIR

When C_F have data packets and needs to send it to its intended destination V_D , the C_F must follow the steps mentioned in algorithm 1. In step 1, the initialization of variables is performed. In step 2, S_{dn} is identified as a set of direct neighbor vehicles of C_F. In step 3, if the C_F did not received reply ($RREP_i$) from any i^{th} vehicle belong to S_{dn} , it starts to carry the data packets until any individual vehicle enter into its communication range. Otherwise, step 4 is executed to checks whether V_D belongs to S_{dn} or not. If V_D belongs to S_{dn} , then the C_F transmits the data packets to V_D using available direct link and exits from algorithm. Otherwise, the C_F executes steps 5 and 6 in which the maximum speed S_{max} among all i^{th} vehicles that belongs to S_{dn} is determined. Afterward, the difference in speed between C_F and S_{max} is calculated using Equation (3). If the difference is greater than 0, this means that the size of US_{area} can be calculated using Equation (4). Otherwise, there will only be S_{area} because the radius of US_{area} and S_{area} are equal. In step 7, the distance D between C_F and each ith direct neighbor vehicle that belongs to S_{dn} is calculated using Equation (7) to determine the location of each ith whether it located within S_{area} or US_{area}. If D is greater than radius R' , this implies that the vehicle is located in US_{area}. In order to select the optimal vehicle from US_{area} , the following conditions need to be passed. 1) Received signal strength power P_r should be greater than or equal threshold value($P_r \geq \delta$) to indicate that there is no outage probability. 2) The maximum speed of unsafety vehicle U^{vi} should be less than C_F speed and S_{max} to indicate that U^{vi} is still within C_F communication range. 3) The predicted future position of U^{vi} should be less than or equal R to indicate that U^{vi} does not exceed C_F communication range. After passing the above conditions, procedure 1 is utilized to select the optimal NHV among all U^{vi} . Step 8 is executed when the value of D is less than or equal $R'$to select optimal NHV among safety vehicles that have passed the first condition mentioned above($P_r \geq \delta$). In step 9, the optimal NHV is selected to further forward the data packets. Step 10, the data packet is delivered to the NHV and the NHV becomes C_F. The steps from 1 to 10 are utilized at each C_F until the data packets reaches to V_D.

3.4.2 Complexity Analysis

The complexity of M-GEDIR algorithm can be presented in terms of time and space complexity. It is worth noting that the on-board unit of vehicles has sufficient storage capacity required for distributed computation in vehicular traffic environment. To this end, time complexity is the major component in the complexity analysis of the proposed routing technique. Let, N_{dv} is the number of vehicle in the set S_{dv} of direct neighboring vehicles of the current forwarder vehicle C_F. Considering half of direct neighbor vehicles in safety area S_{area} and the remaining half in unsafety area US_{area}, the number of packet flows N_{tf} depends on the selection of the area for next hop vehicles selection. The number of packet flows of current forwarder C_F is constrained as $N_{tf} < N_{dv}$ considering selection of either of the area for forwarding. The constraint defines maximum number of retransmission N_{rt} required for successful transmission of a packet, which is also constrained as $N_{rt} < N_{dv}$. By utilizing these notations, the execution time complexity of M-GEDIR can be represented as $O(\frac{N_{dv}}{2} log(\frac{N_{dv}}{2}))$. The proposed routing technique considers the division of forwarding region into safety and unsafety area, and further process the selected region for selecting reliable next hop vehicle. Although the execution time complexity of the state-of-the-art techniques including SLD-GEDIR, P-GEDIR and J-GEDIR has not been mentioned specifically. However, it can be estimated considering the major process components

in next hop vehicle selection. SLD-GEDIR's forwarding region reduction is based on segment area calculation. Its complexity can be expressed as $O(N_{sv} log(N_{dv}))$, where N_{sv} represents the number of vehicles in segment area. The next hop selection of P-GEDIR is based on border region vehicles where it is based on vehicles at junction in case of J-GEDIR. The complexity is close to $O(N_{bv}^2)$ for P-GEDIR and $O(N_{jv}^2)$, where N_{bv} is the number of vehicles in border area and N_{jv} is the number of vehicles in junction area. This due the non-reduction of forwarding region before next hop vehicle selection in both these protocols.

4. Performance Evaluation

This section provides the detail of comparative performance of the proposed M-GEDIR. The comparative evaluation is based on various performance metrics including end-to-end delay, link failure, throughput under two different traffic scenarios, namely, varying speed and density of vehicles. For comparative analysis of simulation results, state-of-the-art protocols including SLD-GEDIR, P-GEDIR and J-GEDIR have been considered.

4.1 Simulation Environment

Simulations are carried out using network simulator NS-2 with the help of vehicular mobility model generator MOVE. The features of MOVE are utilized for configuration of road network and vehicular environments in simulations. The road editor module is used for road network configuration including number of lanes in each road, number of junctions in the generated area, number of road segments linked to junctions, buildings alongside roads, and number of traffic lights on the generated network. The vehicle movement editor is used for vehicular network configuration including number of vehicles, speed of individual vehicle, lane change probability, speed at lane level, different types of vehicles, and probability of left and right turns in junction points.

A road network of sixteen junction points with two lanes in each road segment is configured. Each junction points are 1000 m away from others, and lane width is 5 m in simulation area. The number of mobile vehicles on the considered lanes are in the range of 100-500 vehicles. Different types of vehicles (big and small) are considered, to realize the presence of obstacles in vehicular environments. Speed range for mobile vehicles is considered in the range of $10 - 60\ Km/h$. Speed change interval is one of major parameters that is needed to be considered for urban environments in the range of $60 - 300\ s$. Transmission range of mobile vehicle is considered as $300\ m$. Packet size of 512 bytes, wireless channel type, CBR traffic type, shadowing propagation model, Omni directional antenna model, and 802.11p MAC protocol are the other basic parameters considered while simulating M-GEDIR and the state-of-the-art techniques. A summary of simulation parameters is provided in Table 2, which is approximately similar to the one considered in [22, 39]. Simulations are performed after configuring the network and on-road traffic environment with the value of parameters. Different source vehicle and geographic regions are randomly selected from two pre-determined junction points, which is kept same for all the ten simulation runs for recording the simulation metric points used in results. Average of the ten different simulations run for each specific value was used with 95% confidence interval in result preparation.

Table 2. Simulation Parameters

Parameters	Values	Parameters	Values
Simulation area	$3000 \times 3000\ m^2$	Network simulator	ns-2.34 and MOVE
Speed change interval	$60 - 300\ s$	Channel type	$Wireless$
Vehicle speed	$10 - 60\ Km/h$	Antenna model	$Omni\ directional$
Number of vehicle	$100 - 500$	Propagation model	$Shadowing$
Packet senders	15	MAC data rate	$5\ Mbps$
Transmission range	$300\ m$	MAC protocol	$IEEE\ 802.11p$
Traffic type	CBR	Hello timeout	$0.5\ s$
Packet type	UDP	Query period	$2.5\ s$
Packet size	$512\ bytes$	Frequency	$5.9\ GHz$
Thresholds (δ)	0.9	Routing protocol	M-GEDIR, state-of-the-art
Weighting factors	(60, 30, 10)	Ifqlen	50

4.2 Analysis of Results

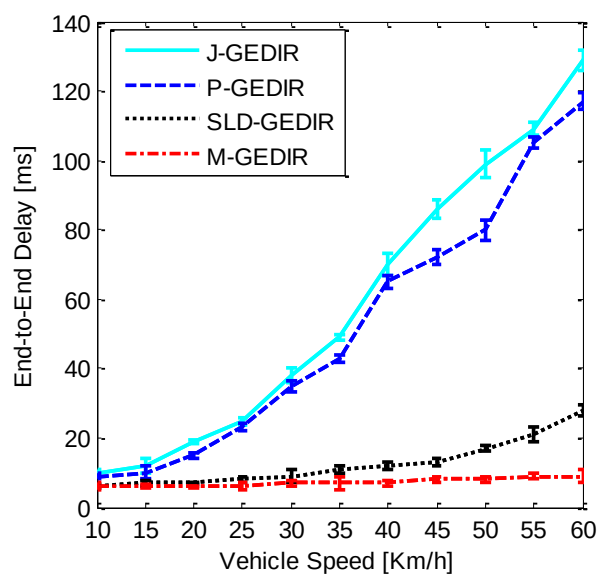

Figure 6. Impact of speed on end-to-end delay of M-GEDIR and the state-of-the-art protocols

Results in Figure 6 clearly show that increasing vehicle speed do not have significant effect on the end-to-end delay of M-GEDIR as compared to the state-of-the-art protocols. Obviously, the end-to-end delay of the proposed protocol is comparably lower and remain almost the same as compared to that of the state-of-the-art protocols. In particular, end-to-end delay of the proposed protocol is approximately in the range $6 - 8\ ms$ for the considered range of speed, whereas it is approximately in the range $8 - 28\ ms$, $10 - 118\ ms$, and $12 - 130\ ms$ in case of SLD-GEDIR, P-GEDIR, and J-GEDIR, respectively. This is because the routing decision of M-GEDIR is more effective in considering multi parameters when selecting optimal vehicle from safety or unsafety

area. Next hop vehicle selection by SLD-GEDIR only focused on segment area, taking into account the link quality and degree of connectivity. However, relying only on the availability of segment vehicle during NHV selection might not always be guaranteed due to high movements of on-road vehicles. Therefore, the end-to-end delay of SLD-GEDIR starts increasing with increasing vehicle speed specifically after 30 speed. On the other hand, minimum angle method, distance and recovery strategy were utilized to select farthest intersection vehicle in J-GEDIR, whereas P-GEDIR has just focused on reducing the size of the forwarding region and selecting border vehicle. Thus, the forwarding strategies of J-GEDIR and P-GEDIR are inappropriate in urban traffic environment because they ignore impact of obstacles and future position when selecting NHV, which makes them inapplicable with increasing vehicle speed.

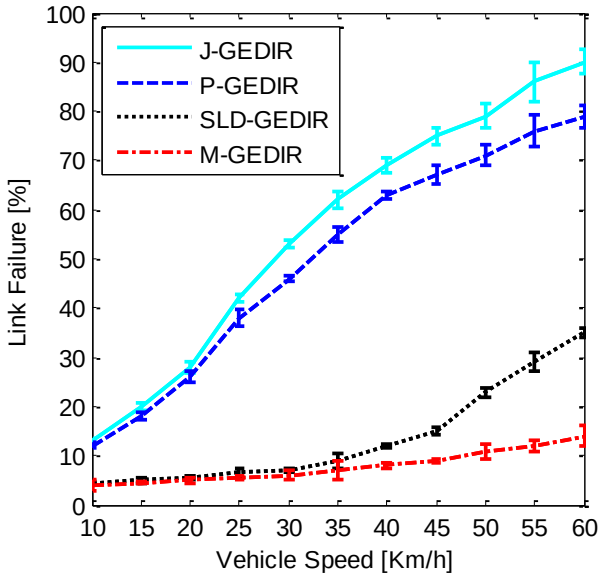

Figure 7. Impact of speed on link failure of M-GEDIR and the state-of-the-art protocols

Figure 7 shows the comparison between impact of speed on link failure of M-GEDIR and the state-of-the-art protocols. It is clear that link failure of the proposed protocol is insignificant in comparison with that of the state-of-the-art protocols particularly in the speed range of $10-45km/h$. The reason behind this is that M-GEDIR considers speed, outage probability, and future position before selecting a stable vehicle from unsafety area using procedure 1, while only outage probability is considered before selecting a stable vehicle from safety area using the same procedure. Therefore, the link failure of the proposed protocol is approximately in the ranges $5-15\%$ which means there is only slight increase at speeds above $45km/h$. On the other hand, the one hop link failure of SLD-GEDIR which is approximately in the range of $5-34\%$ seems better than P-GEDIR and J-GEDIR which are approximately in the range of $11-79\%$ and $12-90\%$, respectively. This is because its forwarding technique is based on link quality and degree of connectivity when selecting next hop vehicle from segment area. Obviously, the one hop link failure in the case of P-GEDIR and J-GEDIR increases rapidly. Particularly, at speeds above $20km/h$ because both techniques did not take the future position of the direct neighbors

into account. Thus, it is noted that the proposed protocol outperforms other state-of-the-art protocols in terms of one hop link failure at increasing vehicle speed.

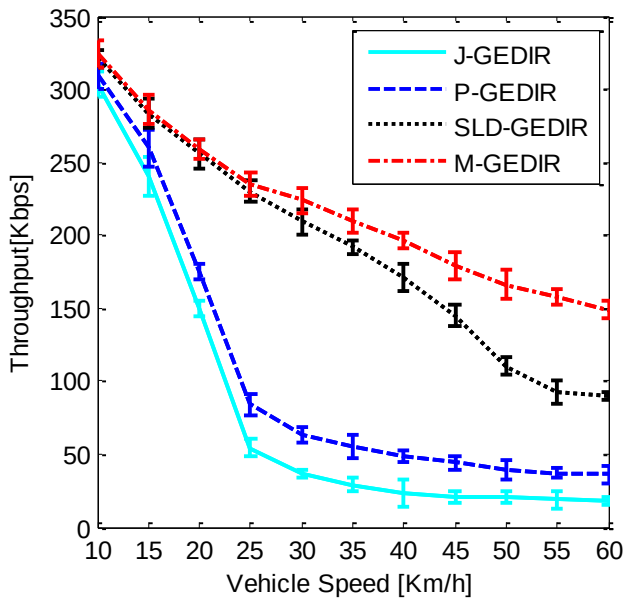

Figure 8. Impact of speed on throughput of M-GEDIR and the state-of-the-art protocols

The results in Figure 8 clearly show the comparison of throughput between M-GEDIR and other protocols: SLD-GEDIR, P-GEDIR and J-GEDIR under different speeds. It was observed that the network throughput of M-GEDIR is comparably higher than that of the state-of-the-art protocols. Particularly on average, M-GEDIR has achieved 14.04%, 106.64% , and 158.36% throughput higher than SLD-GEDIR, P-GEDIR, and J-GEDIR, respectively. This can be attributed to the fact that the M-GEDIR aware of all unreachable vehicles and the vehicles that trying to exceed current forwarder's communication range resulting in lower packet loss. In this way, the bandwidth is saved with M-GEDIR as compared to that of the state-of-the-art protocols because it required less retransmission. The throughput of SLD-GEDIR is nearly equaled to M-GEDIR at vehicle speed $24km/h$, but it linearly decreases with increasing vehicle speed because it ignores the presence of obstacles when selecting NHV. However, the results demonstrate that the throughput is sharply decreasing for P-GEDIR and J-GEDIR, respectively. This is because P-GEDIR and J-GEDIR did not predict the future position of their direct neighbors and neglected the impact of obstacles when selecting NHV resulting in higher packet loss. As a result, excessive consumption of bandwidth occurs with P-GEDIR and J-GEDIR because they require frequent retransmission.

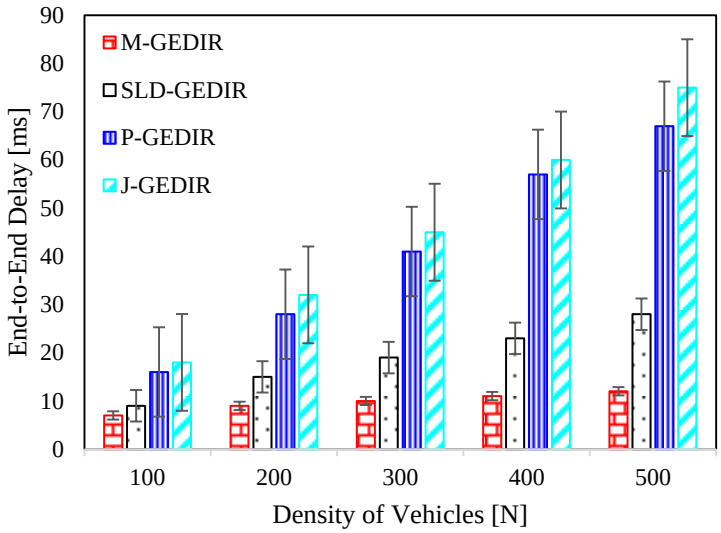

Figure 9. Impact of vehicle density on end-to-end delay of M-GEDIR and the state-of-the-art protocols

Figure 9 shows the comparison between M-GEDIR and the state-of-the-art protocols in terms of impact of number of vehicles on end-to-end delay. Results state that the end-to-end delay of the proposed protocol is relatively stable and lower when compared to that of the state-of-the-art in the range of $100 - 500$ vehicles. This is because M-GEDIR takes a precise routing decision considering different metrics described in the previous section, which helps in reducing packet loss. Thus, large number of data packets arrive at the intended destination. It is also observed that M-GEDIR is not affected with increasing vehicle density due to its ability to determine optimal vehicle that has the highest weighting factors. As illustrated in Figure 8 above, the end-to-end delay of M-GEDIR, which is relatively stable around 10 ms appears better than SLD-GEDIR, P-GEDIR, and J-GEDIR with rapid increases in the range of 9-18, 17-68, and 19-74, respectively. Impact of increasing number of vehicles on end-to-end delay for SLD-GEDIR is significantly smaller as compared to P-GEDIR and J-GEDIR protocols. This is mainly because SLD-GEDIR reduces packet loss due to its reliable routing decision, which not only consider segment vehicle but also consider link quality and degree of connectivity when selecting next hop. P-GEDIR and J-GEDIR did not take into account the quality of the link when selecting NHV leading to long path due to the frequent use of recovery strategy. As a result, the considered state-of-the-art protocols have shown lower performance as compared to M-GEDIR.

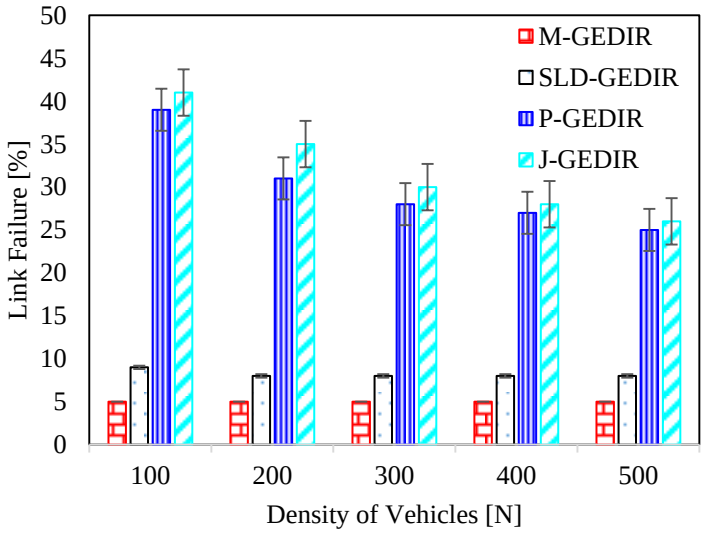

Figure 10. Impact of vehicle density on link failure of M-GEDIR and the state-of-the-art protocols

Figure 10 presents the comparison of the impact of number of vehicles on link failure between M-GEDIR and the considered state-of-the-art protocols. Results show that link failure of the proposed protocol almost stables at low rate with increasing number of vehicles as compared to the considered protocols. In particular, link failure of the proposed M-GEDIR protocol was at 5% rate and remains same with increasing number of vehicles in the range of 100-500, whereas the rate of the state-of-the-art protocols have link failure rates between 8% to 42%. This can be attributed to the fact that the routing decision of M-GEDIR is more accurate because it is aware of all unreachable vehicles that have unstable links. The rate of SLD-GEDIR is still lower than P-GEDIR and J-GEDIR with increasing number of vehicle because it predicts link quality based on packet error rate. However, link failure increases with increasing number of vehicles in the case of P-GEDIR and J-GEDIR. This is mainly because they are not aware of unstable links and have ignored the future position prediction of their direct neighbors when selecting NHV. Thus, the performance of M-GEDIR seems better than the compared state-of-the-art protocols in terms of link failure.

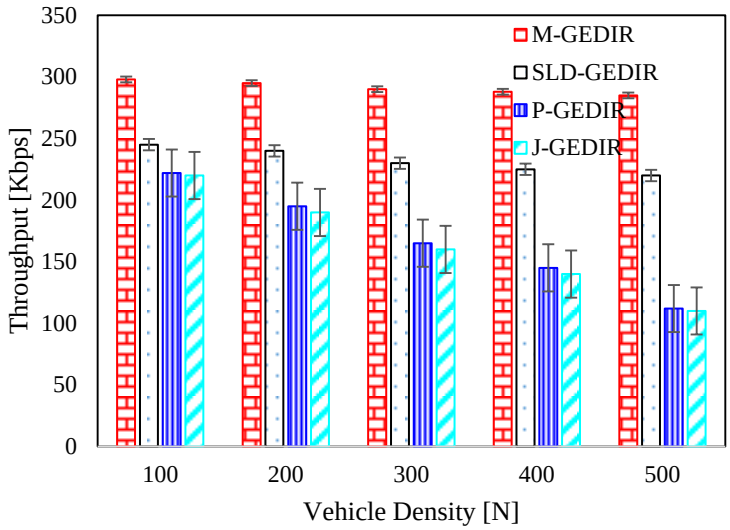

Figure 11. Impact of vehicle density on throughput of M-GEDIR and the state-of-the-art protocols

Results in Figure11 illustrate that M-GEDIR improves network throughput as compared to that of the state-of-the-art protocols. It can be clearly observed that with increasing number of vehicles, the throughput of M-GEDIR is also relatively stable and higher than those of the state-of-the-art protocols. Specifically, the throughput of M-GEDIR is in the range 256-299kbps for the considered range of vehicle density, whereas SLD-GEDIR, P-GEDIR, and J-GEDIR have throughput in the range of 210-248kbps, 110-220kbps, and 115-225kbps, respectively. This can be attributed to the fact that M-GEDIR reduces retransmission due to its ability to avoid unreachable vehicles that lead to more packet loss. Obviously, the rate of decrement of throughput with the increasing number of vehicles is low for M-GEDIR as compared to the considered state-of-the-art protocols. This is because the proposed protocol utilizes different metrics to make routing decisions, help in reducing packet loss. Furthermore, M-GEDIR did not consume more bandwidth, and gives opportunity to other packets to transmit in the network. Unlike P-GEDIR and J-GEDIR, SLD-GEDIR has higher throughput and it is more stable because it considers quality of the link, which result in lower packet loss. Consequently, the network throughput of M-GEDIR is higher than the considered state-of-the-art protocols.

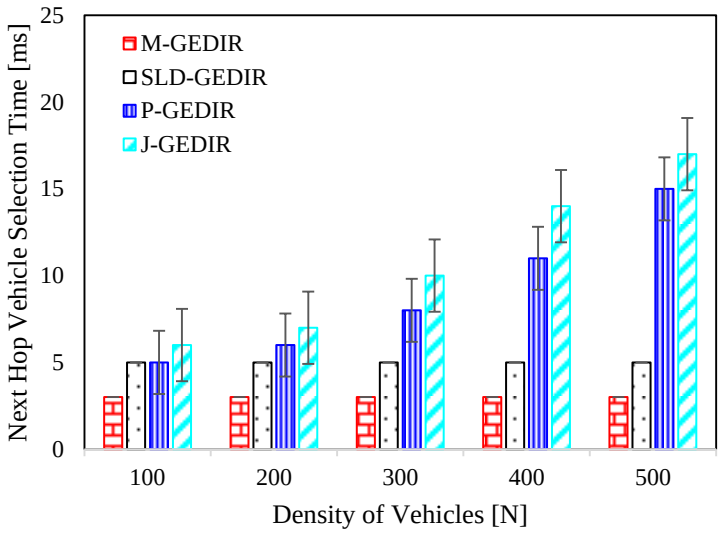

Figure 12. Comparsion of time complexity of next hop vehicle selection

The comparison of computation time of next hop vehicle selection between M-GEDIR and the state-of-the-art routing protocols is shown in Fig. 12. It is explored with increasing density of vehicles to assess the complexity of next hop vehicle selection. It is evident that the impact of density of vehicles is lower on the next hop vehicles selection time of M-GEDIR. This can be attributed to the complexity $O(\frac{N_{dv}}{2} log(\frac{N_{dv}}{2}))$ of the proposed geographic routing. The complexity is lower as compared to complexities of the state-of-the-art routing protocols. The next hop vehicles selection time of SLD-GEDIR is also lesser affected by the increasing density of vehicles. It supports the complexity analysis of these protocols. It is observed that the complexity of SLD-GEDIR is lower as compared to P-GEDIR and J-GEDIR. It is due to the consideration of segment area which is quite better than the border area and junction area based next hop vehicle selection.

5. Conclusion

In this paper, Multi-metric Geographic Distance Routing (M-GEDIR) protocol for vehicular network has been presented. M-GEDIR is based on next hop vehicle selection from dynamic forwarding region considering multiple metrics. The safety area and unsafety area have been determined for optimal next hop vehicle selection. The outage probability of safety and unsafety vehicles have been estimated to avoid selecting unreachable vehicle. Future position has been estimated for all unsafety vehicles to avoid unstable vehicles. The usage of weighting factors has enabled M-GEDIR to select optimal vehicle resulting in higher throughput. It also reduces hop count without affecting the quality of connectivity resulting in lower end-to-end delay. The accurate routing decision of the proposed protocol reduces the probability of link failure resulting in lower rate of path disconnection. The performance of M-GEDIR with varying vehicle speed and density has been evaluated and compared with state-of-the-art protocols in terms of throughput, link failure, and end-to-end delay. Analysis of the simulation results clearly

indicates that the routing decision of M-GEDIR is more effective and reliable for urban vehicular scenarios as compared to the considered state-of-the-art protocols. In future, authors will explore the impact of traffic light on next hop vehicle selection of geographic routing. The integration of traffic light behavior, and incorporation of real time traffic status as metrics will also be the quest.

Acknowledgements

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