Journal of King Saud University – Computer and Information Sciences 31 (2019) 72–81

Contents lists available at ScienceDirect

Journal of King Saud University – Computer and Information Sciences

journal homepage: www.sciencedirect.com

AMGRP: AHP-based Multimetric Geographical Routing Protocol for Urban environment of VANETs

N.V. Dharani Kumari [a,*], B.S. Shylaja [b]

[a] Department of Computer Applications, Dr. Ambedkar Institute of Technology, Bengaluru 560056, India
[b] Department of Information Science and Engineering, Dr. Ambedkar Institute of Technology, Bengaluru 560056, India

ARTICLE INFO

Article history:
Received 6 July 2016
Revised 10 December 2016
Accepted 4 January 2017
Available online 13 January 2017

Keywords:
Analytic Hierarchy Process
Geographical routing
Vehicular ad hoc networks
Multimetric
DSRC
SUMO

ABSTRACT

The work presented in this paper proposes an efficient routing protocol named AHP-based Multimetric Geographical Routing Protocol (AMGRP) as it adopts an Analytical Hierarchical Process (AHP) while considering multiple routing criteria such as mobility metric, link lifetime, node density and node status which have been accepted as crucial factors for better performance of a protocol. The protocol implements the computed single-weighing function to identify a next hop node within a defined range which can ensure an enhanced forwarding process. The simulation results in the paper have proved that the designed protocol performs better when compared with GPSR and SLD-GEDIR protocols in an obstacle modelled urban vehicular environment.

1. Introduction

Recent developments in the wireless technology and automotive industry have been fascinating the researchers on vehicular ad hoc network. VANET is a highly dynamic wireless ad hoc network for communication between the vehicles without any pre-deployed infrastructures (Bernsen and Manivannan, 2009). The Federal Communications Commission (FCC) has allocated 75 MHz in 5.9 GHz band for licensed Dedicated Short Range Communication (DSRC) for vehicular communication. The vehicles equipped with Wireless Access for Vehicular Environment (WAVE) (Little et al., 2010) that can communicate with each other is known as Vehicles to Vehicle (V2V) communication and that can communicate with Road Side Units (RSUs) are known as Vehicle-to-Infrastructure Communication (V2I). VANET is a key technology to facilitate an Intelligent Transportation System (ITS) to provide safety-related applications such as hazard warning, cooperative traffic management and infotainment-related applications such as chatting and surfing for the convenience of the commuters (Research and Innovative Technology Administration, ITS). An imperative requirement for the successful deployment of these applications relies on efficient and reliable multi-hop routing protocols.

Routing in VANETs poses different limitations due to its dynamic network topology, highly scalable network and frequent network fragmentations. The reliable routing path among vehicular nodes to forward the data packets has remained to be a challenge. As the modern vehicles are embedded with navigation systems the geographical routing protocols are more acceptable for VANET as it depends on the geographic position information (Lochert et al., 2003; Bernsen and Manivannan, 2009). Most of the existing position based routing protocol adopts the simple greedy approach to forward the data packets using geographical coordinates of vehicles (Karp and Kung, 2000; Lochert et al., 2003, 2005). The greedy approach has been associated with few shortcomings.

i. The position information cannot be relied upon for deciding on the forwarding node.
ii. Selecting the node with maximum progress toward the destination might not be an optimal choice in all situations.
iii. Routing protocols may suffer a local maximum problem.

The dynamic nature of VANET demands a routing protocol that can be tuned to the frequent changes in the environment such as

* Corresponding author.
E-mail address: dharani.drait@gmail.com (N.V. Dharani Kumari).

Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.jksuci.2017.01.001
1319-1578/

unpredictable traffic conditions, dynamic road topologies. The present work proposes a novel geographical forwarding strategy by considering the interrelated multiple routing metrics such as mobility parameter, link lifetime, node status and node density under the systematic framework called Analytic Hierarchy Process (AHP). The routing metrics along with the geographical coordinates establishes an enhanced multi-hop routing path with an efficient forwarding strategy. An AHP based Multimetric Geographical Routing Protocol (AMGRP) has been proposed and the performance is compared with SLD-GEDIR (Kaiwartya et al., 2014) and GPSR (Karp and Kung, 2000).

The contributions of AMGRP can be highlighted as

1. The source vehicle calculates the weight of its one hop neighbors by considering the node density, link lifetime, mobility information and node status in the forwarding decisions. The neighbor vehicle with minimum weight is selected as the next forwarding node through which the data packet is to be forwarded. The AHP has been adopted to combine these intangible interrelated multiple decision criteria and adapt to the modifying priorities of criteria for different scenarios.
2. Since the movement of a vehicle depends on various factors such as road topology, moving speed and direction, multiple mobility metrics are considered along with other interrelated parameters for the forwarding decision.
3. The realistic wireless communication channels are prone to error due to signal attenuation caused by obstacles in a realistic urban scenario. Therefore the link lifetime between the vehicles is estimated and serves as a routing metric.
4. The network load at each neighbor node is measured in terms of buffer queue length and is utilized for balancing the congestion level in a vehicular node.
5. Since the traffic density is an identified vital routing metric, the one hop node density of all neighbor nodes is availed.
6. A simulation analysis carried out ensures the efficiency of AMGRP with multiple routing metrics.

The remainder of this paper is organized as follows: A brief overview of the related works are discussed in Section 2. Section 3 provides an overview of the proposed AMGRP protocol, significance of the routing metric and the designed AHP decision making system. Section 4 presents the simulation results of the proposed AMGRP protocol. The results are compared and analyzed with the SLD-GEDIR and GPSR in a realistic urban VANET environment with obstacle modeling. Finally the paper is concluded in Section 5.

2. Related work

There is a requirement for an efficient routing protocol to handle the highly dynamic vehicular ad hoc network. Hence position-based routing protocols have emerged as a promising solutions for routing in VANETs (Wang et al., 2012; Okada et al., 2009; Zhao and Cao, 2008; Sharef et al., 2014). A brief overview of the related works is discussed below.

Greedy Perimeter Stateless Routing (GPSR) is a position based routing protocol where the forwarding node sends the packet to the neighbor having the minimum geographical distance to the destination node. It shows poor performance in urban environment due to the following reasons: (i) Unpredictable traffic condition such as sparse and dense road environment and frequently varying network topology. (ii) The wireless communication channels are attenuated due to obstacles such as building and trees in urban environment. Graph planarization in urban environment leads to network partition which in turn increases the local maximum. Perimeter forwarding in recovery mode increases the path length by forwarding the packets away from the destination. The protocol shows poor performance in urban environment as it does not consider the unique characteristics of vehicular network (Lochert et al., 2003).

GPCR (Lochert et al., 2005) considers the urban street as a planar graph to solve the planarization in GPSR. It is a junction based routing protocol where the packet is forwarded to the junction node to take the routing decision on the next direction the packet should follow. The junction nodes are more preferred than the non-junction node while selecting the forwarding node, even though the junction is not geographically closer to destination. Simple greedy approach is adopted to forward the packets between the junctions. However it does not consider the network connectivity and moving direction of vehicles between the road segments. GSR (Lochert et al., 2003) is a topology aware geographical routing protocol to compute the shortest path between the source and destination node. It uses the street map to compute the sequence of junctions through which the packet has to traverse. It does not take into account node mobility and the sparse situation. If the forwarding node does not find any neighbor closer to the junction, then the packet is dropped due to the local maximum. PDGR (Predictive Directional Greedy Routing) (Gong et al., 2007) protocol selects the next hop based on current mobility characteristic and predictable future mobility metric. However the realistic error prone wireless communication channel is not taken into account. The forwarding decision of GPSR is improved in LQ-VV-GPSR (Wang et al., 2012) by considering the quality of communication channel and velocity vector of vehicles. Source node selects the next hop based on the velocity vector and moving direction of nodes. (Okada et al., 2009) proposed an improved forwarding decision by calculating EPD (Expected progress distance), where EPD is obtained based on the quality of wireless link and forwarding distance. VADD (Zhao and Cao, 2008) is designed for sparse networks to guarantee an end-to-end connection based on the idea of store and forward mechanism. The source vehicle stores the message until an optimal neighbor node is found in its vicinity. The packets are forwarded between the junctions based on speed, distance and direction. The performance is improved by selecting the path with lower delay and predicting the moving direction of vehicle by ignoring the environment change in the future. Author in Portable Fuzzy Constraint Q-learning (PFQ-AODV) (Wu et al., 2013) enhances the performance of AODV by considering multiple routing metric such as bandwidth, link quality and relative movement of vehicle. Fuzzy logic is adopted to evaluate the communication link between the vehicles by taking into account of aforementioned parameters. Greedy Perimeter Stateless Routing with Lifetime GPSR-L (Rao et al., 2008) is a modification to the GPSR with route lifetime to determine the link quality. The communication link between the vehicles is estimated for different scenarios of VANET showing enhanced performance in terms of PDR.

Traffic Flow-Oriented Routing (TFOR) (Abbasi et al., 2014) an intersection based geographical routing protocol taken into account of road topology and traffic density to forward the data packet. The real time directional and non-directional traffic density is obtained in an urban environment of VANET to provide the highly connected routing paths with increased packet-delivery ratio by decreasing average delay. Routing between the junctions is performed based on two-hop neighbor information.

Wu (2015) proposed a novel routing protocol considering the multiple routing metric such as route length, vehicle movement and data transmission rate to improve the performance of a routing protocol. The routing algorithm adopts the fuzzy-logic to evaluate the direct link and uses a Q-learning algorithm to find an optimal routing path. Simulations and real-world experiments are carried out to evaluate the proposed protocol. RBVT (Nzouonta et al., 2009) protocol considers real time traffic and junction information to establish the stable road aware routing path between the vehicles. Multi-criteria parameters such as distance between next hop and destination, the transmitter distance and the received power level are considered to select an optimal forwarding node. The protocol had shown improved performance in terms of successful packet delivery ratio (Table 1).

The proposed protocol AMGRP handles the highly dynamic VANET by adopting AHP, a simple mathematical technique to address the routing issues. The routing metric are organized in a hierarchy and examined as a whole after grouping the similar parameters together and also the sub-criteria in each group is examined within itself. The AMGRP uses one-hop node information for forwarding decision reducing the complexity of the protocol. The AMGRP considers different routing metrics and assigns weights obtained through an extensive number of parameter configurations. Therefore the protocol shows an enhanced performance even under dynamic network conditions when compared with the other protocols such as SLD-GEDIR and GPSR.

3. AMGRP overview

The AMGRP is a geographical unicast multi-hop routing protocol for Vehicle to Vehicle (V2V) communication. This work assumes that the vehicles are equipped with GPS and wireless communication devices to facilitate communication between the vehicles. The proposed protocol enhances the data forwarding mechanism in geographical routing by utilizing four routing metrics: mobility, link lifetime, node density and node status. The vehicles maintain a neighbor table to record the one hop neighbor information such as position, speed, buffer queue length and one hop node density. The neighbor table is updated after receiving information from the neighbors via beacon packets (as summarized in Table 2) at predefined intervals. On receiving the beacon packets the source node calculates the average distance, average moving speed, link lifetime and moving angle between the neighbors and stores it along with the rest of the neighbor information. These routing metrics will be utilized by the AHP process to calculate the weight for all the nodes in the neighbor table of source node during the forwarding process. Finally the packet carrier node forwards the packet to the neighbor node with minimum weight. If the packet carrier node faces the local optimum problem i.e. if it has the least weight among its neighbor nodes then the packet is switched to the perimeter mode of routing until a neighbor with less weight is identified. Fig. 1 shows an enhanced forwarding algorithm of AMGRP. The AHP process to compute the weight is shown in Fig. 2.

Table 2
The format for the beacon packet.

Field information	Description
Node ID	The unique node identifier
Time Stamp	Current simulation time
Node Position	The position coordinates (x, y)
Speed	Speed of the vehicle (m/s)
Queue Length	Current size of the buffer queue
Node Density	The number of nodes in the neighbor table
Sequence No	Number of hello messages

3.1. Routing metrics evaluation

VANET is a highly dynamic ad hoc network with predictable mobility parameter. The forwarding decision based on a specific metric may not lead to an efficient routing path toward destination. There are multiple decision criteria which may impact the quality of the routing path. Therefore the following section discusses some of the factors which have been considered for the next hop selection.

3.1.1. Tracking the mobility related information

The mobility metrics such as distance, speed and moving direction between the vehicles have a significant impact on the forwarding decision. This work assumes that each vehicle knows its own position and also the position of the destination. Suppose the position coordinates of a vehicle i is (x_i, y_i), the position coordinates of a source vehicle s is (x_s, y_s), then the distance (D) between the vehicles is computed as follows.

$$D = \sqrt{(x_i - x_s)^2 + (y_i - y_s)^2} \tag{1}$$

The average distance between the vehicles is computed as,

$$D_{avg} = \frac{1}{n}\sum_{i=1}^{n}\sqrt{(x_i - x_s)^2 + (y_i - y_s)^2} \tag{2}$$

where n is the total number of neighbors of s. Then the forwarding vehicle FV is selected considering the average distance of the vehicle as,

$$|D_{FV} - D_{avg}| < |D_i - D_{avg}| \; \forall \text{ neighbor vehicle } i \text{ in } R \tag{3}$$

where R is the radio range.

Let SP_i represent the speed of the vehicle i. The average moving speed of the vehicle SP_{avg} is obtained as,

$$SP_{avg} = \frac{(\sum_{i=1}^{n} SP_i)}{n} \tag{4}$$

Table 1
Comparison of routing protocols of VANETs.

Routing protocols	Forwarding strategy	Intersection-based	Map-aware	Simulation scenario	Recovery strategy	Delay-tolerant (DTN)/ Non-Delay tolerant (Non-DTN)
GPSR	Greedy Forwarding	No	No	Highway	Right-hand rule	Non-DTN
GPCR	Restricted greedy	Yes	No	Urban	Right-hand rule	Non-DTN
GSR	Precomputed Greedy path	Yes	Yes	Urban	Greedy	Non-DTN
PDGR	Predictive directional greedy forwarding	No	No	Highway	Carry and forward	Non-DTN
LQ-VV-GPSR	Improved greedy	No	No	Urban/Highway	Right-hand rule	Non-DTN
VADD	Improved greedy forwarding	Yes	Yes	City	Carry and forward	DTN
PFQ-AODV	Fuzzy constraint Q-learning technique	No	No	Highway/city	Not specified	Non-DTN
GPSR-L	Greedy	No	No	Highway	Right-hand rule	Non-DTN
TFOR	Improved greedy forwarding (traffic density & distance aware)	Yes	Yes	Urban	Carry and forward	DTN
RBVT	Improved greedy forwarding	Yes	Yes	Urban	Greedy	Non-DTN

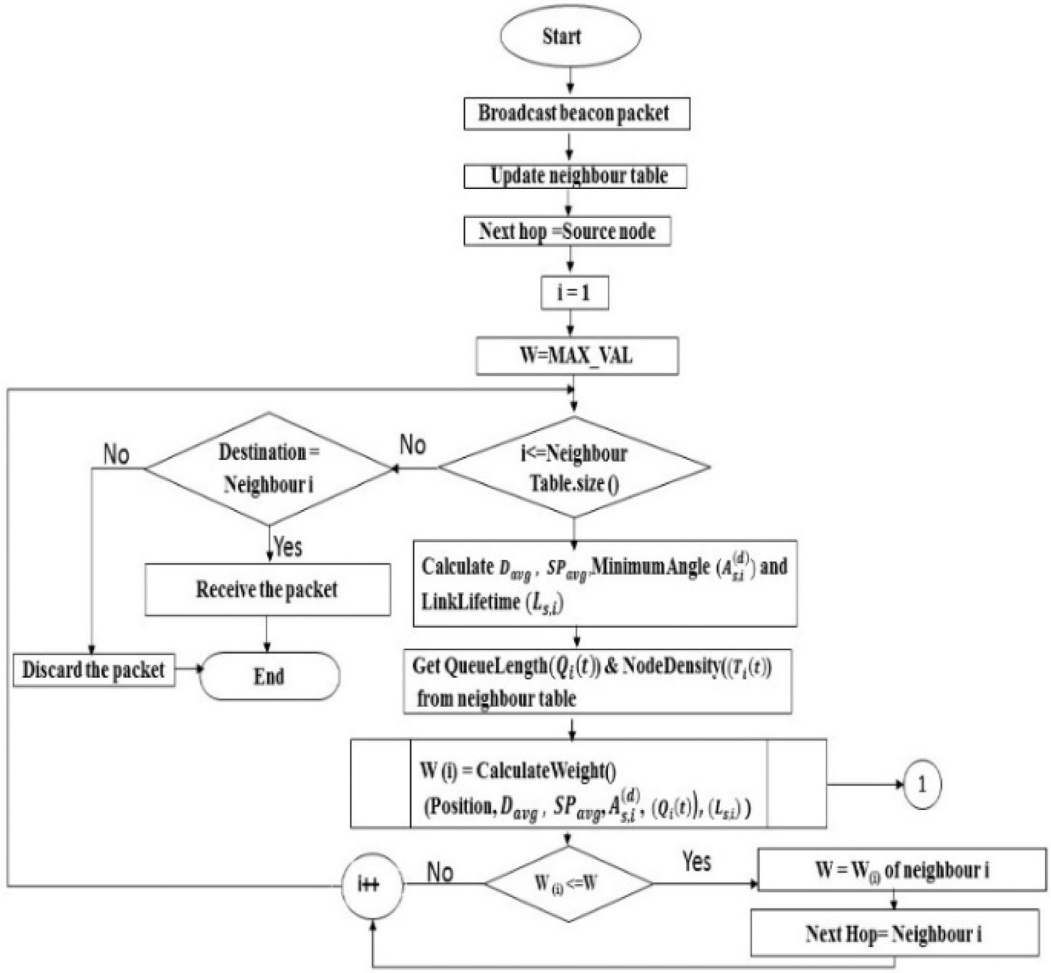

Figure 1. Enhanced forwarding mechanism in AMGRP.

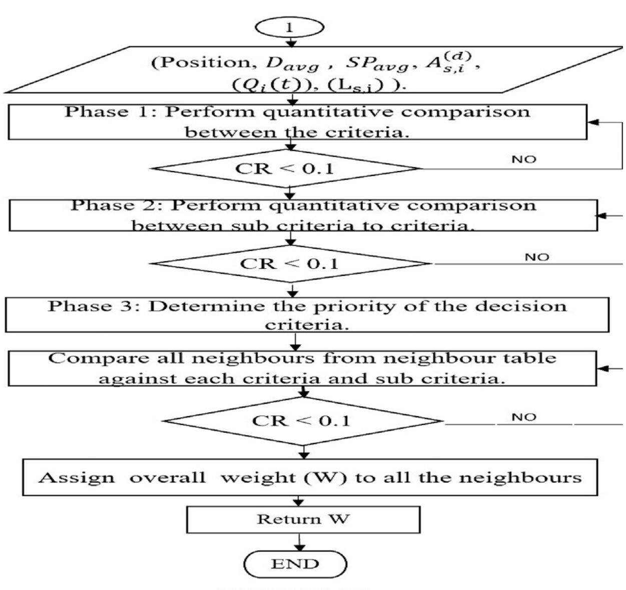

Figure 2. AHP process to compute the weight.

where n is the total number of neighbors of s. Then the forwarding vehicle FV is selected considering the average speed of the vehicle as,

$$|SP_{FV} - SP_{avg}| < |SP_i - SP_{avg}| \ \forall \text{ neighbor vehicle } i \text{ in } R \tag{5}$$

In the geographic routing protocol, if the source node does not consider the moving direction of the nodes, then it could make wrong forwarding decision by sending the packets to the vehicles that is moving against the direction of the destination. Suppose the source vehicle s is at (x_0, y_0), and the destination node is at (x_d, y_d) and the neighbor vehicle i is at (x_i, y_i) then the moving angle between source and neighbor i toward the destination d can be obtained as follows (Xiao et al., 2011).

$$A_{s,i}^{(d)} = \arccos \frac{(x_d - x_0)(x_i - x_0) + (y_d - y_0)(y_i - y_0)}{\sqrt{(x_d - x_0)^2 + (y_d - y_0)^2}\sqrt{(x_i - x_0)^2 + (y_i - y_0)^2}} \tag{6}$$

3.1.2. Estimating the link lifetime

The link lifetime between the nodes is defined as the shortest duration during which two vehicles will remain in communication to transmit the data packets. The link between the vehicles breaks frequently due to the obstacles and varying speed of the vehicles. If the link between the nodes is valid for a short period of time then it could lead to frequent route reconstructions. Suppose the link lifetime is predicted before it breaks then that information can be used as one of the routing metric for the next hop selection. The longer lifetime leads to the stable routing path resulting in a lower packet loss. Let (x_s, y_s), (x_i, y_i) be the coordinates of source node s and neighbor i and their corresponding velocities are given by v_s and v_i, where $v_s < v_i$. Let R be the cation range. Then the link lifetime between s and i is calculated using the Eq. (7) (Taleb et al., 2007). Fig. 3 shows the scenario assumed for the estimation of link lifetime, where d is the distance between the vehicles.

$$L_{s,i} = R - \frac{\sqrt{(x_i - x_s)^2 + (y_i - y_s)^2}}{v_s - v_i} \tag{7}$$

3.1.3. Determine the node status

To quantify the network load, the buffer queue length is considered to avoid packet drops due to congestion at the receiver node. The node is congested if the queue length is small as more data packets need to be processed. To obtain the node status before selecting the next hop, the queue length is beaconed. The average buffer capacity ($Q_i(t)$) can be computed as follows (Zhou et al., 2013).

$$Q_i^{(t)} = \frac{Q_{max} - Q_i^{(t)}}{Q_{max}} \tag{8}$$

where Q_{max} gives the maximum buffer size. In the present work the buffer size is set to 50. $Q_i^{(t)}$ is defined as the number of packets in the buffer queue at time t.

3.1.4. Calculating the one-hop node density

Traffic density is one of the important routing metric to determine the reliable routing path. Intermittent connectivity can be avoided by selecting the next hop with high node density. The vehicles measure the one-hop node density based on number of neighbors in the neighbor table and exchange it through beacon packets for a stable routing path. This reduces the risk of a packet reaching a local maximum. The local node density of neighbor i is denoted as $T_i(t)$ and is computed as follows (Tripp-Barba et al., 2014)

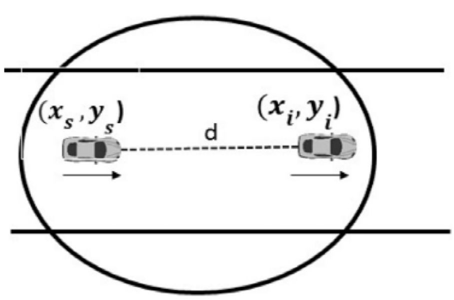

Figure 3. Scenario for link lifetime calculation.

$$T_i(t) = \frac{NeighbourTable.size()}{R} \tag{9}$$

where *NeighbourTable.size*() will compute the total number of neighbors in the neighbor table at timestamp t. The radio range of node i is denoted as R. In Fig. 4 the path taken by the source in GPSR breaks when the forwarding vehicle does not find any neighbor within its vicinity to forward the packet (dashed line) whereas the AMGRP establishes a stable routing path by considering the one hop vehicle density.

3.2. Weighing function

A source node s computes the weight of neighbor node i in consideration with destination node d denoted as $W_{s,i}^{(d)}$ and obtained as,

$$W_{s,i}^{(d)} = p_M M_{s,i}^{(d)} + p_L L_{s,i} + p_Q Q_i^{(t)} + p_T T_i \tag{10}$$

where p_k indicates the relative importance of $k \in \{M, L, Q, T, D, A, S\}$ on the next hop selection which are calculated using the AHP process. In the equation $M_{\mathbf{s,i}}^{(\mathbf{d})}$ accounts for the impact of mobility metric on the forwarding decision of routing protocol and is determined by

$$M_{s,i}^{(d)} = p_D D_{avg} + p_A A_{s,i}^{(d)} + p_S SP_{avg} \tag{11}$$

where D_{avg} is the average distance between the vehicles is computed from the Eq. (2). SP_{avg} gives the average moving speed of the node i obtained from (4). $A_{\mathbf{s,i}}^{(\mathbf{d})}$ is the moving angle between the nodes computed in Eq. (6). $L_{\mathbf{s,i}}$ is the link lifetime estimated using the Eq. (7). $Q_{\mathbf{i}}^{(\mathbf{t})}$ is the buffer queue size and $T_{\mathbf{i}}$ is the one hop node density.

The impact of the aforementioned parameters on the forwarding decision of the AMGRP is evaluated in the following section.

3.3. AHP based forwarding decision making process

The Analytical Hierarchical process (AHP) (Saaty, 1999) is a mathematical tool to deal with intangible multiple criteria during a complex decision making problem. It decomposes the complex problem into a hierarchy of sub-problems to evaluate the relative importance of each criterion (Katsaros et al., 2015). An enhanced solution is obtained by integrating the evaluated criteria into the routing process. The present work adopts the AHP approach to calculate the weight of all individual nodes from the candidate list and to select the candidate with the minimum weight as the most favorable forwarding node.

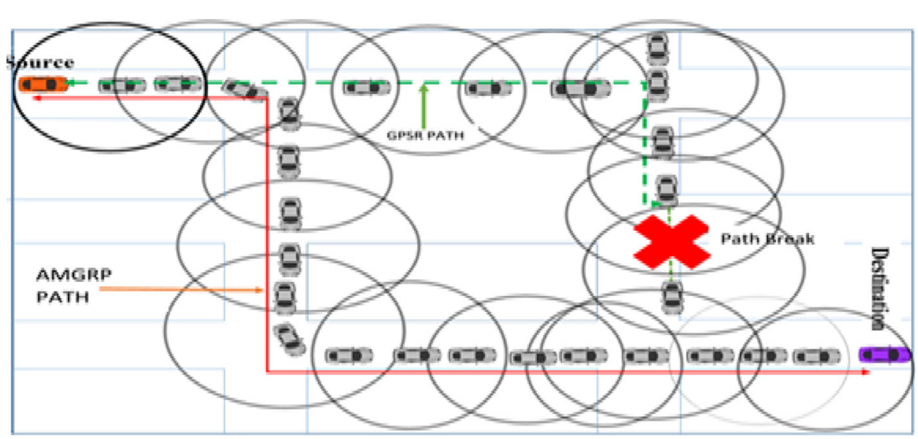

Figure 4. The path taken by the source in AMGRP and in GPRS to reach the destination.

3.3.1. Decompose the problem as a hierarchy

The problem is decomposed into a hierarchy of interrelated decision elements. The objective of work is to choose an efficient forwarding node which is at the top of the hierarchy as shown in Fig. 5. The below level of hierarchy consists of the high level decision factors such as mobility metric, link lifetime, node status and node density contributing to the objective. The next level expands each of these criteria into a more detailed sub-criteria and the bottom level includes the set of neighbor node ($N_1, N_2 \ldots N_k$) as decision alternatives to evaluate within the communication range of the source vehicle.

3.3.2. Construct pair-wise comparison matrix and check for data consistency

In the AHP based approach the comparison matrix $Z = (Z_{i,j})$, $n \times n$ is determined for all decision criteria where, n is the total number of criteria at each level. $Z_{i,j}$ represents the relative importance of criteria i to j. The $Z_{i,j} > 0$ indicates the importance of criteria i to criteria j, $Z_{i,j} = 1$, indicates $i = j$ and $Z_{i,j} = 1/Z_{i,j}$, indicates the reciprocal importance of criteria j relative to criteria i. In the following comparison matrix Z, the $Z_{L,M}$ represents the relative importance of link quality to mobility metric, $Z_{T,L}$ represents the relative importance of node density to link lifetime and $Z_{N,T}$ represents the relative significance of node status to the node density and so on. The values are assigned to these variables from the set {0.2, 0.25, 0.33, 0.5, 1, 3, 5, 2, 4} according to Table 3, which indicates the relative importance between pairs of decision criteria.

$$\mathbf{Z} = \mathbf{Z}_{(\mathbf{i,j})}\mathbf{n} \times \mathbf{n} = \begin{bmatrix} 1 & \boldsymbol{Z_{ML}} & \boldsymbol{Z_{MT}} & \boldsymbol{Z_{MN}} \\ \boldsymbol{Z_{LM}} & 1 & \boldsymbol{Z_{LT}} & \boldsymbol{Z_{LN}} \\ \boldsymbol{Z_{TM}} & \boldsymbol{Z_{TL}} & 1 & \boldsymbol{Z_{TN}} \\ \boldsymbol{Z_{NM}} & \boldsymbol{Z_{NL}} & \boldsymbol{Z_{NT}} & 1 \end{bmatrix} \quad (12)$$

3.3.3. Calculate the relative weights for the decision factors

Once the comparison matrix Z is defined for decision criteria, next step is to calculate the priority vector p which is the normalized Eigen vector of the matrix. The comparison matrix Z is normalized as,

$$\overline{Z_{ij}} = \frac{Z_{ij}}{\sum_{i=1}^{n} Z_{i,j}} \quad (13)$$

The Eigen vector (p_i) is obtained as,

$$p_i = \frac{\sum_{j=1}^{n} \overline{Z_{i,j}}}{n} \quad (14)$$

Table 3
Scales for pair-wise comparison matrix.

$Z_{i,j}$ (intensity)	Description
1	i and j are equally important
3	i is moderately important than j
5	i is strongly important than j
1/3	i is moderately less important than j
1/5	i is strongly less important than j
2, 4	Intermediate values between adjacent scales

where p_i is the priority related to criteria x corresponds to row i. and column j in the comparison matrix Z. The computed Eigen vector p in Fig. 6 indicates the relative ranking of the criteria. It can be observed that mobility metric has higher priority and plays a major role in the decision of next hop selection whereas link lifetime is least important among the four decision criteria.

A comprehensive analysis has been carried out using an extensive number of parameter configurations in order to consider the most effective set of p_k parameters. The impact of various routing metric considered in Eq. (10) are evaluated to identify the relative importance of mobility metric, link lifetime, node status and node density on forwarding decision through comparative matrix Z as shown in (12) and after extensive performance analysis the resultant combination assumed {0.2, 0.3, 0.2, 5, 3, 0.3} for the relative importance of coefficients. This set suggests that the mobility metric is strongly important than link lifetime metric ($Z_{LM} = 0.2$), ($Z_{TM} = 0.33$) indicates that the mobility metric is moderately important than node density, ($Z_{NM} = 0.2$) shows that mobility metric is strongly important than node status. ($Z_{TL} = 5$) indicates node density metric is strongly important than link lifetime related information. ($Z_{NL} = 3$) indicates that the node status is moderately important than link lifetime metric. ($Z_{NL} = 0.3$) indicates node density metric is moderately important than node status. Similarly for the mobility related parameters, the assumed set for {Z_{DA}, Z_{AS}, Z_{DS}} is {5, 0.3, 1}. The values indicate that the distance criteria are strongly important than angle information and distance is equally important to speed whereas the speed is moderately important than angle information. Finally, using these two sets for each group of relative parameters, we can calculate the set of optimal values for the p_K parameters using (14), as shown in Table 4.

3.3.4. Determine the overall AHP score for all the neighbors

Finally the overall AHP score for all individual neighbors from the neighbor list is derived by the sum of the product of its relative

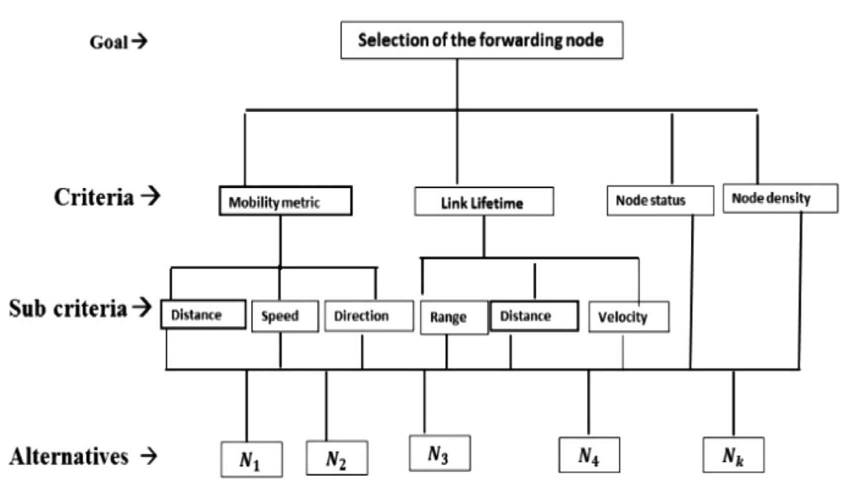

Figure 5. Hierarchical view of the forwarding node selection.

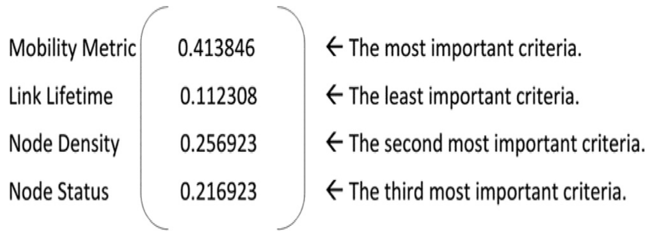

Figure 6. Relative ranking of the criteria.

Table 4
Optimal value for p_k parameters.

Parameters	Values
p_M	0.4138
p_D	0.5247
p_Q	0.2169
p_L	0.1123
p_A	0.1416
p_S	0.3338
p_T	0.2569

priority in each criteria and the relative priority of respective criteria is given as,

$$N_k = \sum_{i=1}^{r}\sum_{j=1}^{q_i} W_i * W_{ij} * N_{ijk} \tag{15}$$

where N_k is the final weight assigned to the kth neighbor. r indicated the number of routing criteria group. q_i, is the sub criteria under criteria i. W_i is the weight of the ith criteria group. W_{ij} is the weight for the jth criteria belonging to the ith criteria group and N_{ijk} is the score of the kth neighbor for the jth criteria in the ith criteria group.

3.3.5. Consistency checking

The consistency checking is performed as in (Jose and Teresa, 2006) to check whether the comparison matrix Z is consistent or not. In the present work Eigen value $\lambda_{max} = 4.15572655$ and $CR = 0.0576765 < 0.1$ indicates that e comparison matrix Z is consistent.

4. Performance evaluation

4.1. Simulation setup

The road network and route information (speed limits, traffic lights, junctions, road directions, etc.) of urban region in Bengaluru covering an area of 2000 m × 1500 m has been downscaled from Open Street Map (OSM) using JOSM for the simulation study. The downscaled data are processed with SUMO which is an open-source realistic microscopic traffic simulator capable of modeling the microscopic mobility of the vehicles and behavior of individual drivers. The mobility model parameters are summarized in Table 5.

The vehicles movement trace file obtained from traffic simulator is imported to network simulator OMNET++ together with INET framework for simulating the proposed protocol AMGRP. The UDPBasicBurst traffic is considered for randomly chosen 10 source and destination flows. Every source sends 2 UDPBasicBurst traffic per second, and the size of UDPBasicBurst packets is 512 bytes. The Vehicular nodes communicate with each other using the IEEE 802.11p DCF MAC layer. The radio transmission range is set to 250 m and the simulations are run for 400 s. The outcomes of the simulations are averaged over a set of 5 independent runs. The most important simulation parameters are summarized in Table 6.

Table 5
Vehicular mobility model.

Parameters	Description	Values
N	No. of nodes	(50–200) step of 25
A	Max Acceleration	0.8
D	Max deceleration	0.3
Min-speed	Min Velocity	5 m/s
Max-speed	Max Velocity	(5–25) step 5 m/s

4.2. Performance metrics

The AMGRP is compared with SLD-GEDIR and GPSR protocols and the following four network performance metrics are analyzed.

4.2.1. The packet delivery ratio (PDR)

This metric gives the ratio of the delivered packets to the destination to those produced by the source node and is derived as,

$$PDR = \sum_{i=1}^{n}\frac{R_i}{S_i} \tag{16}$$

where n is the number of source, R_i is the number of packet received by ith destination and S_i is the number of packet sent by ith source.

4.2.2. End-to-End delay (E2ED)

This metric represents the average delay experienced by the received data packet to reach the destination. The formula to calculate E2ED is given in Eq. (17).

$$E2ED = \frac{1}{\sum_{i=1}^{n} R_i}\left(\sum_{i=1}^{n}\sum_{j=1}^{R_i} TR_{ij} - TS_{ij}\right) \tag{17}$$

where TR_{ij} is the receiving time of jth packet sent by the ith source at the destination and TS_{ij} is the sending time of jth packet sent by the ith source.

4.2.3. Normalized routing overhead (NRL)

This metric represents the ratio of the total number of control packets against the data packet delivered to the destination during the complete simulation. The formula to calculate NRL is given below.

$$NRL = \frac{1}{n}\left(\sum_{i=1}^{n}\frac{1}{R_i}\left(\sum_{j=1}^{R_i}\sum_{k=1}^{p_{ij}} C_{ijk}\right)\right) \tag{18}$$

where C_{ijk} is the number of control bytes used at kth hop by the jth packet sent by the ith source.

4.2.4. Average hop count (AHC)

This metric represents the average number of hops the packets need to reach their destination and computed as,

Table 6
Network simulation parameters.

Parameters	Values
Simulation Time	400
Number of traffic source	10
Data Packet Length	512 byte
Carrier Frequency	5.8 GHz
Propagation Model	Two-Ray ground model
Physical Layer	IEE802.11p (11 Mbps)
Transmission Power	10 mW
Traffic Type	UDP

$$AHC = \frac{1}{n}\left(\sum_{i=1}^{n}\frac{1}{R_i}\left(\sum_{j=1}^{R_i}\sum_{k=1}^{p_{ij}}H_{ijk}\right)\right) \tag{19}$$

where H_{ijk} indicates the number of kth hop traversed by the jth packet sent by the ith source.

The complexity of the proposed protocol AMGRP is $k \times n$, where k is the number of simple mathematical calculations and n is the number of neighbors whose local information is acquired by the beacon packet. Therefore the complexity of the AMGRP is O (n).

4.3. Simulation results and analysis

The impact of traffic density and vehicle speed on the performance of the proposed protocol AMGRP over SLD-GEDIR and GPSR is evaluated in an urban environment of VANETs.

4.3.1. Impact of varying node density on the performance of the protocols

In the simulation setup to study the impact of traffic density, the average mobility speed is fixed to 15 m per second but the number of nodes is varied from 50 to 250 in steps of 25 to represent different node densities. The obtained numerical results are plotted in Fig. 7(a–d).

The PDR of AMGRP, SLD-GEDIR and GPSR plotted in Fig. 7(a) shows that as the node density increases the successful data packet delivery ratio also increases. The reason is that as the network becomes more connected the chances of getting into void problems are less, hence the PDR increases consistently with an increased node density. The simulation results show that when the road consists of about 17–34 vehicles per km^2 the average packet delivery ratio of AMGRP is from 5.3% to 6.7% more than SLD-GEDIR and from 27.3% to 31.1% more than GPSR. This is because when the network is sparsely distributed the probability of meeting a vehicle to forward the data packet in the identified segment area is low. In contrast, when the traffic distribution is about 75–85 vehicles per km^2 the PDR of AMGRP is from 4.8% to 7.3% more than SLD-GEDIR and from 29.6% to 32% more than GPSR since AMGRP considers the network status in order to avoid the highly congested node for the next-hop selection.

Fig. 7(b) shows the average delay of UDPBasicBurst packets that have been received at the destination with different node densities. With about 17–34 vehicles per km^2 on the simulated road topology the latency of AMGRP is 3.5–5.5% less than SLD-GEDIR and 28.69% less than GPSR. It shows that when the network is sparsely connected the SLD-GEDIR experiences slight increase in the average latency due to higher chances of missing the vehicles in the segment region. On the other hand with about 70–85 vehicles per km^2 the latency of AMGRP is 7.3% less than SLD-GEDIR and 36.9% less than GPSR. The proposed protocol AMGRP performs efficiently by employing AHP engine in the heterogeneous traffic condition where higher priority is given to node density and the node status after mobility metric. When the network is moderately dense with about 35–65 vehicles per km^2 the SLD-GEDIR shows a slight improvement with 2.8% less than AMGRP in average delay due to sufficient connectivity within the segment.

The excess traffic of control packets generated by the routing protocols is shown in Fig. 7(c). The rate of control message is pro-

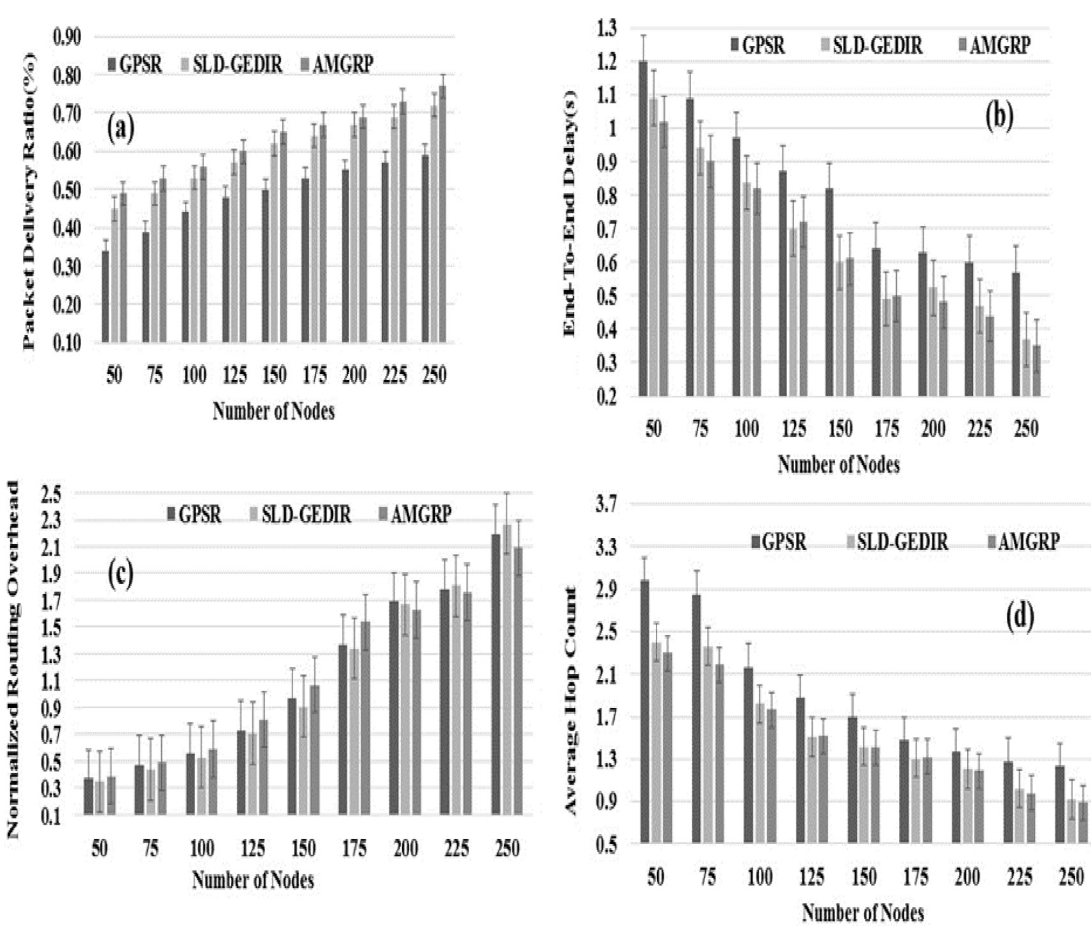

Figure 7. Impact of varying node density on (a) PDR, (b) E2E Delay, (c) NRL and (d) AHC.

portional to the number of vehicles in the network. The AMGRP has more control overhead compared to the simulated protocols because the nodes need to continuously update the neighbor with more number of information parameters. The size of the control packet is higher in AMGRP than the other two protocols resulting in an increase in the control overhead. In a traffic of about 17–35 vehicles per km^2 the routing overhead of the AMGRP is increased to be between 10.3% and 13.5% when compared with SLD-GEDIR and from 8.7% to 12.3% when compared with GPSR. But in a high dense network with about 75–85 vehicles per km^2 the routing overhead of AMGRP gradually decreases by a margin of 4.38–6.43% than the routing overhead of the SLD-GEDIR and from 7% to 11% less than GPSR since node status is considered as one of the routing metric for avoided congestion.

The average number of hops required to deliver the data packets from source to destination is shown in Fig. 7(d). Average number of hops traversed by the successfully delivered messages is reduced as the node density increases. In a sparse connected environment with about 17–35 vehicles per km^2 the number of hops traversed in AMGRP is lesser by 3.8–5.57% than SLD-GEDIR and by 23–25% than GPSR. The AHP technique adopted in AMGRP selects the next hop giving considerable priority to the one-hop node density. When there are about 36–50 vehicles per km^2 considered as a moderate connectivity, there is no significant difference between AMGRP and SLD-GEDIR protocol. In a dense condition of about 75–85 vehicles per km^2 the average hop count of AMGRP is reduced by about 3.4% and 27.5% when compared with SLD-GEDIR and GPSR respectively. The AMGRP reduces the packet drop considerable by avoiding the nodes with higher buffer queue length.

4.3.2. Impact of varying node mobility on the performance of the protocols

To study the impact of vehicles speed on network performance metrics we fix the number of nodes to 150 and vary the average mobility speed from 5 to 25 m/s in steps of 5 m/s and the obtained results are shown in Fig. 8(a–d).

The frequent network partition caused due to high speed vehicular nodes deteriorates the performance of the protocols as shown in Fig. 8(a). The increased speed of the vehicles degrades the performance of all the three protocols as nodes will remain in the communication for a very short period of time which may not be sufficient to forward all the data packets. When the maximum node speed is about 90 km/h the average PDR of AMGRP shows to be from 5.3% to 8.1% more than SLD-GEDIR and 26.8% to 31.78% more than GPSR. This proves AMGRP establishes stable routing path as higher priority is given to the mobility metric. The average moving speed of the vehicle and the average distance between the vehicles are considered to be the sub criteria of mobility metric are calculated and the forwarding vehicle close to this calculated value is considered as the next hop. The performance of GPSR degrades for the varying vehicle speed because it might select a stale neighbor to forward the data packet as it considers only the position of the vehicles. When the vehicles are moving in a moderate speed there is no significant improvement between the AMGRP and SLD_GEDIR.

Fig. 8(b) shows the average delay of UDPBasicBurst packets that have been received at the destination for the varying vehicle speed in an urban environment. High speed vehicular nodes often switch into perimeter mode of routing resulting in a higher delay. When the vehicles are moving in a maximum speed of about 18 km/h, the average delay in SLD-GEDIR is reduced from 5.2% to 7.8% less than the AMGRP. When the maximum speed of the vehicles is considered to be about 90 km/h the average delay in AMGRP is seen to be reduced as 4.8–5.9% less than SLD-GEDIR and 21.6–25.7% less than GPSR. The routing path is established in AMGRP by considering the average moving speed and distance between the vehicles as crucial factors.

Fig. 8(c) plots the routing overhead of all the three protocols at various speed and shows that the routing overhead increases as the speed of the vehicle increases. A network with high mobility vehicles encounters frequent network fragmentation and increased routing overheads. The AMGRP shows comparatively increased routing overhead than the other protocols when the vehicles are

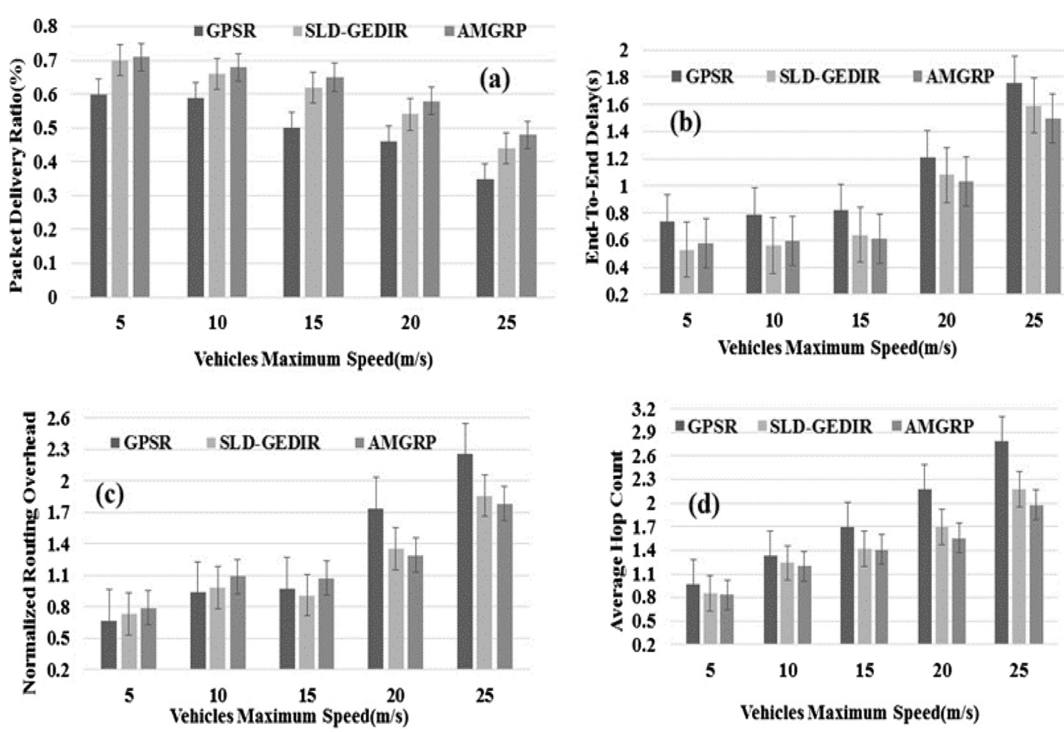

Figure 8. Impact of varying node mobility on (a) PDR, (b) E2E Delay, (c) NRL and (d) AHC.

moving at about 18 km/h speed. It is increased from 5.3% to 7.4% more than SLD-GEDIR and from 6.8% to 10.2% more than GPSR, whereas, the AHP technique adopted in AMGRP to select the next hop enhances the performance in a highly dynamic network by giving equal priority to average moving speed and distance in a mobility metric group. Henceforth, when the speed of the vehicles was about 90 km/h, the routing overhead of AMGRP is reduced by a margin of 4.8–6.4% than the routing overhead of the SLD-GEDIR and from 3.7% to 5.7% than GPSR. The SLD-GEDIR might show a high rate of link breakage within the vehicles in the considered segment with high velocity vehicles.

The average number of hops the protocols has taken to deliver the data packets for varying node mobility is plotted in Fig. 8(d). The hop count increases for the considered protocols due to the instability in the routing path with fast moving vehicles. There is not much significant improvement when the vehicles are moving slowly with a maximum speed of about 18 km/h, whereas when the speed is about 90 km/h the proposed AMGRP is taking less number of average hops to reach the destination by selecting the forwarding node with vehicles moving in average speed and distance thereby avoiding frequent switching to recovery strategy. The average hop count in AMGRP is from 5.8% to 7.2% less than SLD-GEDIR and from 21.8% to 24.2% less than GPSR. It can be noted that in SLD-GEDIR vehicles in a segment might move out of its communication range in a highly dynamic network leading to frequent link disruptions.

5. Conclusion

The dynamic nature of VANET suggests using more number of routing criteria to understand and calculate a reliable routing path. In the present work an enhancement to the existing GPSR routing protocol is proposed to route the data packets to more directed nodes in a less congestion and more stable routing path. The impact of various routing metrics such as link lifetime, predictable mobility, node status and node density on forwarding decision is instigated in a systematic framework to make an effective geographical forwarding decision. An AHP mechanism is employed to combine multiple decision criteria into a single weighing function thereby enhancing the routing protocol over a number of metrics. The simulation is carried out in a realistic urban scenario with obstacle modeling to indicate the improved performance of the proposed AMGRP routing mechanism when compared with GPSR and SLD-GEDIR routing protocols.

Acknowledgements

The authors would like to thank the web sources for OMNET++/INET (http://www.omnetpp.org/), SUMO (http://sourceforge.net/projects/sumo/) and JOSM (https://josm.openstreetmap.de/) software's and the anonymous reviewers for their valuable comments and suggestions that helped to improve the quality of paper.

References

Abbasi, I.A. et al., 2014. A traffic flow-oriented routing protocol for VANETs. EURASIP Journal on Wireless Communications and Networking 1, 1–14.
Bernsen, J., Manivannan, D., 2009. Unicast routing protocols for vehicular ad hoc networks: A critical comparison and classification. Pervasive Mobile Comput. 5 (1), 1–18.
Gong, Jiayu, Xu, Cheng-Zhong, Holle, James, 2007. Predictive directional greedy routing in vehicular ad hoc networks. Distributed Computing Systems Workshops, (ICDCSW'07). 27th IEEE International Conference. pp. 2–2.
Jose, A.A., Teresa, L., 2006. Consistency in the analytic hierarchy process: a new approach. Int. J. Uncertainty Fuzziness Knowledge-Based Syst. 14 (4), 445–459.
Kaiwartya, O., Kumar, S., Lobiyal, D.K., Abdullah, A.H., Hassan, A.N., 2014. Performance improvement in geographic routing for vehicular Ad Hoc networks. Sensors 14 (12), 22342–22371.
Karp, B., Kung, H.T., 2000. GPSR: greedy perimeter stateless routing for wireless networks Proceedings of 6th Annual Int. Conf. Mobile Comput. Netw, New York, NY, USA, pp. 243–254.
Katsaros, K., Dianati, M., Sun, Z., Tafazolli, R., 2015. An evaluation of routing in vehicular networks using analytic hierarchy process. Wireless Commun. Mobile Comput.
Little, Agarwal, Chau, T.D.C., Figueroa, A.J., Ganick, M., Lobo, A.J., Rich, T., 2010. Directional communication system for short-range vehicular communications. In: Proceeding of 2nd IEEE Vehicular Networking Conf. (VNC 2010), December 15, pp. 231–238.
Lochert, C., Hartenstein, H., Tian, J., Füßler, H., Hermann, D., Mauve. M., 2003. A routing strategy for vehicular ad-hoc networks in city environments. Proceedings of IEEE IV'03. Columbus. pp. 156–161.
Lochert, C., Mauve, M., Füßler, H., Hartenstein, H., 2005. Geographic routing in city scenarios. SIGMOBILE Mobile Comput. Commun. Rev 9 (1), 69–72.
Nzouonta, J., Rajgure, N., Wang, G., Borcea, C., 2009. VANET routing on city roads using real-time vehicular traffic information. IEEE Trans. Veh. Technol. 58 (7), 3609–3626.
Okada, Hiraku, Takano, A., Mase, K., 2009. A proposal of link metric for next-hop forwarding methods in vehicular ad hoc networks. In 6th IEEE Conference on Consumer Communications and Networking. pp. 1–5.
Research and Innovative Technology Administration (RITA), Intelligent Transportation Systems [online]. Available: http://www.itsoverview.its.dot.gov/.
Rao, S.A., Pai, M., Boussedjra, M., Mouzna, J., 2008. GPSR-L: greedy perimeter stateless routing with lifetime for VANETS. In: 8th International Conference on ITS Telecommunications, ITST (IEEE 2008). pp. 299–304.
Saaty, Thomas L., 1999. How to make a decision: the analytic hierarchy process. Eur. J. Oper. Res. 48 (1), 9–26.
Sharef, B.T., Alsaqour, R.A., Ismail, M., 2014. Vehicular communication ad hoc routing protocols: a survey. J. Netw. Comput. Appl., 363–396
Tripp-Barba, C., Urquiza-Aguiar, L., Igartua, M.A., RebolloMonedero, D., de la Cruz Llopis, L.J., Mezher, A.M., 2014. A multimetric, map-aware routing protocol for VANETs in urban areas. Sensors 14 (2), 2199–2224.
Taleb, T., Sakhaee, E., Jamalipour, A., Hashimoto, K., Kato, N., Nemoto, Y., 2007. A stable routing protocol to support ITS services in VANET networks. IEEE Trans. Veh. Technol. 56 (6), 3337–3347.
Wang, Hao., Tan, G., Yang, J., 2012. An improved VANET intelligent forward decision-making routing algorithm. J. Netw. 7 (10), 1546–1553.
Wu, Celimuge, Ohzahata, Satoshi, Kato, Toshihiko, 2013. Flexible, portable, and practicable solution for routing in VANETs: a fuzzy constraint Q-learning approach. IEEE Transactions on Vehicular Technology, 4251–4263.
Wu, Celimuge, 2015. Toward practical and intelligent routing in vehicular ad hoc networks. IEEE Trans. Veh. Technol. 64 (12), 5503–5519.
Xiao, Degui, Peng, Lixiang, Asogwa, Clement Ogugua, Huang, Lei, 2011. An improved GPSR routing protocol. Int. J. Adv. Comput. Technol. 3 (5).
Zhao, J., Cao, G., 2008. VADD: vehicle-assisted data delivery in vehicular ad hoc networks. IEEE Trans. Veh. Technol. 57 (3), 1910–1922.
Zhou, J., Xu, H., Qin, Z., Peng, Y., Lei, C., 2013. Ad hoc on-demand multipath distance vector routing protocol based on node state. Commun. Netw. 5 (03), 408.