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Enhancing routing efficiency in highway environments of vehicular ad hoc networks through fuzzy logic-based protocols

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ABSTRACT

The predictive directional greedy routing (PDGR) protocol is widely utilized in highway settings within vehicular ad hoc networks (VANETs). However, PDGR encounters a notable challenge when packets lack a suitable vehicle directionally, leading to network disconnections. This triggers a shift to carry and forward recovery mode due to outdated neighbor information in the vehicle's neighbor table (VNT). To address this, our study proposes an improved fuzzy logic-based improved PDGR (IPDGR). This novel algorithm dynamically adjusts beaconing intervals based on real-time network dynamics. Through comprehensive evaluation using VANET simulators, IPDGR demonstrates superior performance compared to PDGR and directional greedy routing (DGR) protocols across various metrics including Inconsistency of vehicle's neighbor's table (IVNT), packet delivery ratio (PDR), routing path length (RPL), and number of hole problem occurrence (NHPO).

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1. INTRODUCTION

In vehicular ad hoc networks (VANETs), vehicles can directly communicate with each other. Both safety and non-safety applications in VANETs often necessitate the utilization of multi-hop communication, as highlighted in [1]–[5]. Particularly in highway environments, where multi-hop communication becomes crucial, the efficiency of routing algorithms becomes paramount due to the high mobility of vehicles. In the context of VANETs, position-based routing protocols are gaining prominence over topology-based routing protocols, primarily due to the widespread availability and advancement of global positioning system (GPS) devices. These protocols base their forwarding decisions on the geographic location information of neighboring vehicles stored in the vehicle neighborhood table (VNT), as outlined in [6]–[8]. Incorrect position information can result in erroneous forwarding decisions, consequently leading to suboptimal routing protocol performance and, subsequently, a diminished VANET performance. Therefore, there arises a necessity to dynamically adjust packet interval times based on the prevailing network movement conditions, as discussed in [9]–[11].

The location information accuracy level depends on the beacon sending frequency. High mobility in highway environments results in rapid changes in node location. This results in incorrect information in VNT [12]. Thus, the beacon transmitting rate should be as small as possible to have accurate information in VNT. Such an approach increases communication overhead and decreases the performance of the VANET. Additionally, as beaconing takes a long time to be performed; false information will be increased eventually in VNT. This negatively affects the performance of the VANET in terms of packet delivery ratio (PDR). This instigates the necessity for a dynamic updating approach [13]. Indeed, it is crucial to tune the beaconing osculation based on the speed of nodes in VANET. In the literature [14]–[18], several solutions were proposed that adopted position-based routing protocols to enhance the sending of data packets between vehicles over VANET, but these solutions do not consider stale information in VNT. This paper presumes that all participating nodes travel with varying velocities during the communication process. In this case, stale information in VNT is increased due to the incurs wrong selection of the next hop. Generally speaking, for the VANET environment, geographic approaches are more appropriate compared to topology-based protocols [5], [6].

Gong *et al.* [19] propose a protocol named directional greedy routing (DGR). DGR is a unicast position-based designed for highway environments. To determine the position of the intended final packet target destination, the DGR algorithm needs to position finder and stable maps. Furthermore, DGR supposes that all participating nodes are appraised for their speed and motion direction. To communicate with the final target, the DGR algorithm sends the data packets hop-by-hop using directional greedy forwarding (DGF). With DGF, a source vehicle that has a data packet to be forwarded selects a vehicle that is closest to the destination and is moving in the destination's direction. Furthermore, if the packet holder does not have a vehicle in the direction of the destination, then it applies carry and forward recovery mode. The DGR algorithm's main goal is to decrease loop problem appearance during the sending of the data packet process. However, achieving these objectives results in more hops that incur more delay. Afterwards, to enhance the overall performance of the DGR routing protocol, several solutions were presented.

Gong *et al.* [19] introduced probabilistic distance-geographic routing (PDGR), a unicast overlay geographical-based routing protocol designed to utilize both current and predictable future information for forwarding packets to their destinations. PDGR utilizes static digital maps (DGPS) to obtain geographical locations, and participating vehicles constantly broadcast beacon messages at fixed intervals. Consequently, each node constructs its VNT based on the information gleaned from these beacons. PDGR employs two primary strategies for discovering the next forwarding vehicle: direction first forwarding (DFF) and position first forwarding (PFF). By leveraging both current and anticipated future information, PDGR calculates a weighted score for both current and potential future neighbors. In cases where a packet encounters a void, PDGR employs a carry and forward recovery mode until it locates the next vehicle moving in the direction of the destination. However, a significant limitation of PDGR is the potential for network disconnection if a predicted node is chosen as the next relay node, which may fall out of the sender's range.

However, both methodologies failed to account for the accuracy levels of nodes during movement, leading to the frequent occurrence of the void problem due to high dynamics in both protocols. Consequently, the carry and forward recovery method must be applied frequently. The primary cause of the void problem lies in the presence of stale information in the VNT, thereby diminishing the overall network performance. Additionally, both DGR and PDGR assume vehicles move at a constant speed, which is often not the case in the VANET environment. Moreover, both protocols utilize a fixed interval time for removing a neighbor from a VNT. In DGR and PDGR, the entry lifetime of neighbors is set as three times the beacon message frequency period. However, pre-determining the entry period in advance is impractical in VANET and may adversely affect the routing protocol's performance. This study's primary contribution is to ensure the accuracy of information in the VNT, aiming to enhance the reliability and scalability of PDGR within the VANET domain. The proposed approach involves adjusting the beacon interval based on the nodes' motion characteristics. The novel approach introduces a fuzzy logic-based beaconing scheme (FLBS) to achieve optimal routing. The remainder of this study is structured as follows: section 2 reviews related position-based routing studies in VANETs. Section 3 provides a detailed explanation of the proposed improved PDGR (IPDGR). Section 4 describes the evaluation of the proposed routing scheme, including cropped results and accompanying discussions. Finally, section 5 concludes this paper's findings.

2. OBJECTIVES AND ARCHITECTURE OF THE PROPOSED IMPROVED PDGR

This section explores and presents the design of the proposed routing protocol IPDGR. The overall goal of the IPDGR algorithm is to dynamically ensure and maintain up-to-date nodes' status information in a

VNT. The proposal is mainly to hire a fuzzy logic controller [20] in its design. Thus, the intended performance of the proposal can be thoroughly improved and can attain its objective. This section presents an adopted method to send beacons that is compatible with the VANET environment. The adopted method is based on the fuzzy logic controller (FLC) called the FLBS. By applying the FLBS approach, a vehicle uses FLC to decide when the new beacon must be transmitted. The overall goal of FLBS is to dynamically ensure up-to-date VNT. The construction of the FLBS relies on the relation between the vehicles' velocity and the next localization process. Compared with the deployed approach in PDGR, the proposed FLBS algorithm is expected to decrease the stale information in vehicles' VNT. That can increase the reliability of the underlying proposed protocol. Moreover, void problem occurrence can be prevented or decreased to the lowest rate. FLBS can be used as a general scheme that can apply to most unicast position-based routing protocols in highway environments.

Ordinarily, when a vehicle is moving fast with unfixed speed, location variation can be attained quickly, the localization process and updating are repeated frequently, and vice versa. With the FLBS algorithm, the frequency of the check time decision depends on FLC. Vehicle speed (*ves*) and inspection time (*bett*) are used as input variables and as output parameters sequentially. Therefore, FLBS chooses the appropriate *bett* based on *ves* metric by using FLC. Recall that FLC is adapted with the *bett* that using *ves*, this adaptation fulfills a suitable trade-off between reasonable accuracy tolerance, and stale position information in VNT. The FLC is adapted to control the examination process by the FLBS algorithm.

2.1. Transforming Input of vehicle speed into fuzzy logic

The *ves* input variable has five ranges that will be fuzzified to five fuzzy groups. As advised by [21] the contiguous groups interfered by a quarter to half percent. The *ves* fuzzy groups take names that describe its condition such as very low (VL), low (L), medium (M), high (H), and very high (VH). The *ves* is fuzzified between *ves*-min=0 m/s and *ves*-max=40 m/s. Table 1 and Figure 1 show the *ves* input variable ranges and groups.

Table 1. Fuzzy sets of *ves* input Variable

ves range m/s	Fuzzy sets
5–13	Very low (vl)
6.3–19.5	Low (l)
13.25–26.75	Medium (m)
20.5–33.7	High (h)
27–35	very high (vh)

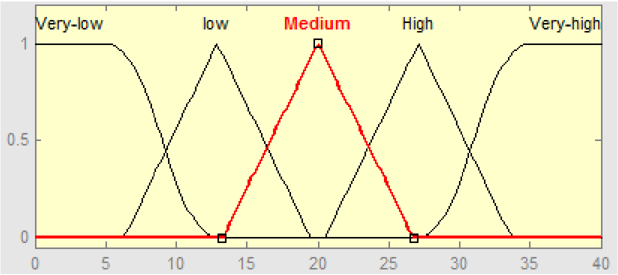

Figure 1. Membership functions of a *ves* input variable

The candid equations for *ves* membership functions are as (1) to (5):

$$ves_{vl}=\begin{cases} 1 & x\le x5 \\ 1-2\left(\frac{x-5}{13-5}\right)^2 & 5\le x\le\frac{5+13}{2} \\ 0 & x\ge 13 \end{cases} \tag{1}$$

$$ves_{l}=\begin{cases} \left(\frac{x-6.3}{12.9-6.3}\right) & 6.3\le x\le 12.9 \\ \left(\frac{19.5-x}{19.5-12.9}\right) & 12.9\le x\le 19.5 \\ 0 & otherwise \end{cases} \tag{2}$$

$$ves_m = \begin{cases} \left(\frac{x-13.25}{20-13.25}\right) & 13.25 \le x \le 20 \\ \left(\frac{26.75-x}{26.75-20}\right) & 20 \le x \le 26.75 \\ 0 & otherwise \end{cases} \tag{3}$$

$$ves_h = \begin{cases} \left(\frac{x-20.5}{27.1-20.5}\right) & 20.5 \le x \le 27.1 \\ \left(\frac{33.7-x}{33.7-27.1}\right) & 27.1 \le x \le 33.7 \\ 0 & otherwise \end{cases} \tag{4}$$

$$ves_{vl} = \begin{cases} 0 & x \le 27 \\ 2\left(\frac{x-27}{35-27}\right)^2 & 27 \le x \le \frac{27+35}{2} \\ 1-2\left(\frac{x-35}{35-27}\right)^2 & \frac{27+35}{2} \le x \le 35 \\ 1 & x \ge 35 \end{cases} \tag{5}$$

2.2. Fuzzy beaconing time output transformation

The fuzzy beaconing time (*bett*) encompasses an output variable with five sets, each labeled to reflect its respective duration: “very short” (VS), “short” (S), “medium” (M), “long” (L), and “very long” (VL). This study operates under the assumption that the longest possible beaconing interval time is 10 sec. Consequently, the *bett* is fuzzified within the range of *bett*-min=0 and *bett*-max=10 seconds. Table 2 and Figure 2 depict the ranges and groupings of the *bett* output variable.

Table 2. Fuzzy sets for *bett* output variable

Bett range m/s	Fuzzy sets
0–3.16	Very short (vs)
1.6–4.9	Short (s)
3.3–6.7	Medium (m)
5.1–8.3	Long (l)
6.84–10	Very long (vl)

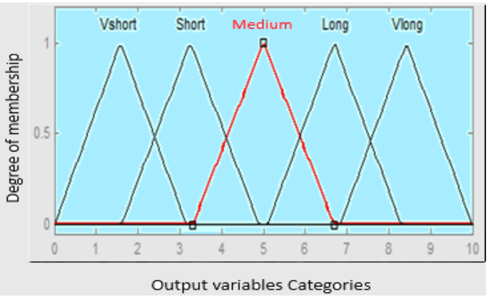

Figure 2. Membership functions for *bett* output variable

The candid functions for *bett* membership functions as (6) to (10):

$$bett_{vs} = \begin{cases} \left(\frac{x-0}{1.58-0}\right) & 0 \le x \le 1.58 \\ \left(\frac{3.16-x}{3.16-1.58}\right) & 1.58 \le x \le 3.16 \\ 0 & otherwise \end{cases} \tag{6}$$

$$bett_s = \begin{cases} \left(\frac{x-1.6}{3.25-1.6}\right) & 1.6 \le x \le 3.25 \\ \left(\frac{4.9-x}{4.9-3.25}\right) & 3.25 \le x \le 4.9 \\ 0 & otherwise \end{cases} \tag{7}$$

$$bett_m = \begin{cases} \left(\frac{x-3.3}{5-3.3}\right) & 3.3 \le x \le 5 \\ \left(\frac{6.7-x}{6.7-5}\right) & 5 \le x \le 6.7 \\ 0 & otherwise \end{cases} \tag{8}$$

$$bett_l = \begin{cases} \left(\frac{x-5.1}{6.7-5.1}\right) & 5.1 \le x \le 6.7 \\ \left(\frac{8.3-x}{8.3-6.7}\right) & 6.7 \le x \le 8.3 \\ 0 & otherwise \end{cases} \tag{9}$$

$$bett_{vl} = \begin{cases} \left(\frac{x-6.8}{8.4-6.8}\right) & 6.8 \le x \le 8.4 \\ \left(\frac{10-x}{10-8.4}\right) & 8.4 \le x \le 10 \\ 0 & otherwise \end{cases} \tag{10}$$

2.3. Fuzzy rule system and fuzzy inference

The proposed algorithm depends on the changes on vehicle speed *ves* as a fuzzy input variable. Next, the proposed algorithm utilizes 5 proposed IF-THEN rules. The five rules used by fuzzy inference to convoy vehicle speed input groups into beaconing time output groups. The goal of using the defuzzifier is to element collect the fuzzy group into one value. This work uses the fuzzy Mamdani logic method [22] which is one of the most defuzzification methods (inference process). This method is regularly applied in applications. Table 3 shows the 5 suggested fuzzy rules to attain this goal that is used in this work.

Table 3. IF-THEN rules for beaconing computation approach

Rule	Vehicle speed (*ves*)	Beaconing time (*bett*)
1	Very low	Very long
2	Low	Long
3	Medium	Medium
4	High	Short
5	Very high	Very short

3. EVALUATION METHODOLOGY

This study leverages an enhanced network simulator to assess the proposed methodology. The enhancement process commenced with a comprehensive understanding of both directional greedy routing (DGR) [19] and predictive directional greedy routing (PDGR) [19]. Subsequently, the proposal was developed, drawing from genuine insights into the algorithms and software implementation of DGR and PDGR protocols using C++ within the network simulator. Transitioning to the evaluation phase, all three protocols DGR, PDGR, and the proposed IPDGR were implemented, considering various settings specific to the VANET environment. Table 3 outlines the simulation parameters tailored for highway scenarios. This section proceeds to evaluate the performance of the proposed IPDGR routing protocol in NS-2.34 in comparison to DGR and PDGR.

3.1. Simulation parameters

Table 4 describes the simulation parameters for the highway environment using the NS2.34 simulator. The scenario spans a wide area with many vehicles, each having a transmission range and movement speed. The simulation includes details on traffic type, packet size, and network protocols.

Table 4. Simulation parameters for highway environment

Simulation	NS2.34
Scenario area	5,000×5,000 m
Subject	Version and dimensions
Simulation	NS2.34
Scenario area	5,000×5,000 m
Simulation time	300 Seconds
Vehicles	200
Transmission range	250 m
Movement model	Modified random waypoint
Minimum speed value	60 km/h
Maximum speed value	140 km/h
Hello packet size	12 bytes
Hello packet interval	1.5 second
Density between nodes	5 vehicles every 130 m
MAC layer protocol	IEEE 802.11 DCF
Traffic type	Cbr /udp
Packet size	512 bytes
Channel bandwidth	2 Mbps
Radio propagation model	Two ray ground model

3.2. Simulation setup

Table 4 outlines the simulation setup utilized in this study, leveraging the NS-2.34 simulator for conducting a series of experiments. The choice of NS-2.34 stems from its widespread adoption as a simulator for VANET research. Additionally, we utilize the modified random waypoint mobility mode (MRWP) [22]. This model ensures a moderate speed value relative to the desired average speed compared to the traditional random waypoint (RWP) model. Two distinct scenarios are examined: the first involves vehicles traveling in the same direction (source vehicle, intermediate vehicles, and destination vehicle), while the second scenario features the source and destination vehicles traveling in opposing directions, with intermediate vehicles moving in both directions. In each scenario, 10 pairs of source-destination are randomly selected. Our evaluation focuses on key routing metrics including PDR, routing path length (RPL), inconsistency of vehicle's neighbor's table (IVNT), and number of hole problem occurrence (NHPO). These metrics are selected based on the specific requirements of the solution. It's crucial to highlight that data exchange occurs between vehicles across different hops, aiming for maximal delivery and minimal occurrence of voids compared to alternative protocols. Detailed explanations for each metric are provided below. PDR (11) is used to calculate the PDR [23], [24].

$$PDR = \left(\frac{\sum_{m=1}^{n} eived\ packets\ at\ destination\ vehicle}{\sum_{m=1}^{n} received\ packets\ at\ destination\ vehicle}\right) * 100\% \tag{11}$$

where *n* is the number of nodes. RPL (12) is used to calculate PRL [24], [25]:

$$RPL = \sum_{m=1}^{n} NHRP - \sum_{m=1}^{n} NHSP\ (optimal\ path) \tag{12}$$

where *n* is the number of nodes.

Inconsistent IVNT: To elaborate on the IVNT metric, consider node i's degree at time t, denoted as $V(i,t)$, representing the total number of neighbors within its transmission range. Additionally, let $V*(i,t)$ denote the number of neighbors listed in the node's IVNT at time t (13), as presented in reference [25], is employed to compute the IVNT at time t.

$$INM = \left(\frac{|V\ (i.t\ ) -\ \ V*(i.t\ )|}{V\ (i.t\ )}\right) * 100\% \tag{13}$$

where, $V\ (i,t)$ is vehicle *i* degree at time *t*, $V*(i,t)$ is the number of neighbors listed in VNT at time *t*.

NHPO (14) is utilized to determine the NHPO throughout the simulation duration for all received packets at all destination sides, as detailed in references [23], [24].

$$NHPO = \sum_{n=1}^{p} Numbero\ f\ hole\ problemoccurance \tag{14}$$

From (14), P represents the total number of received packets at the destination side that experienced a hole problem during the simulation period, while n represents the total number of nodes.

4. SIMULATION COMPARISON AND DISCUSSION

The simulation was executed 10 times for each scenario, with results obtained by averaging the emulation outcomes. In the first scenario, all vehicles move in the same direction. In the second scenario, intermediate vehicles travel in multiple directions, with the source and destination vehicles moving in opposite directions.

4.1. Scenario 1 results: all vehicles moving in the same direction

This scenario discusses the impact of vehicle speed on the performance of DGR, PDGR, and IPDGR routing protocol solution, terms of IVNT, RPL, PDR, and NHPO routing metrics are chosen based on the required solution which is presented in Figures 3 to 6. A comparison in Figure 3 shows that the IPDGR protocol reduces the PDR ratio by about 17.4% and 22.2% over PDGR and DGR protocols respectively. As shown in Figure 4, as speed increases, DGR and PDGR have smaller PDR. The implicit reasons are assorted. DGR, considers both geographic position and motion direction when selecting the next hop. Also, it considers the packet holder’s current neighbors to calculate the weighted score for selecting the next hop. Therefore, it is clear that the selected next hop may no longer in VNT. Wrong selection incurs more packet loss. PDGR considers the packet holder’s future neighbors to calculate the weighted score for selecting the next hop. It relies on a conventional beaconing approach to make its prediction. Thus, this increases stale information in VNT due to increments in the vehicle speed.

Figure 4 illustrates a comparison where the IPDGR protocol demonstrates a notable reduction in the RPL ratio by approximately 23% and 34% when compared to the PDGR and DGR protocols, respectively. In Figure 6, a notable increase in hop count is observed at a vehicle speed of 110, which is evident in both DGR and PDGR protocols, consequently leading to longer RPL. This surge in hop count can be attributed to the incorrect selection of the next relay node, resulting in the continued predominance of recovery mode forwarding over greedy forwarding in both protocols. This phenomenon is exacerbated by the acceleration of vehicle speeds, leading to a corresponding increase in stale information within the VNT. In contrast, the RPL of IPDGR remains unaffected by the acceleration of vehicle speeds. With IPDGR, as vehicle speeds increase, the stale information within the VNT decreases due to the FLBS, resulting in a more accurate selection of the next forwarder. Consequently, the predominance of greedy forwarding over recovery mode forwarding progressively increases. As the majority of forwarding is accomplished greedily, this facilitates a rapid reduction in the length of the routing path, as evidenced by the decrease in hop count.

Figure 5 illustrates the average IVNT ratio across the IPDGR, PDGR, and DGR protocols relative to vehicle speed. The protocol exhibiting the lowest IVNT ratio is considered the most favorable. A comparison presented in Figure 7 indicates that the IPDGR protocol outperforms both PDGR and DGR protocols, reducing the IVNT ratio by approximately 44% and 52%, respectively. Under speeds below 80 km/hr, all protocols demonstrate reasonable average IVNT values. However, as speeds exceed 90 km/hr, IPDGR exhibits notable advantages over PDGR and DGR. This advantage is particularly evident in scenarios characterized by high topology changes, facilitated by IPDGR's innovative beaconing features. Through IPDGR's new beaconing approach, the beacon packet transmission rate increases, attributed to the utilization of the FLBS scheme. Leveraging FLBS for beacon transmission enhances the accuracy of information within VNT entries, consequently decreasing the IVNT rate.

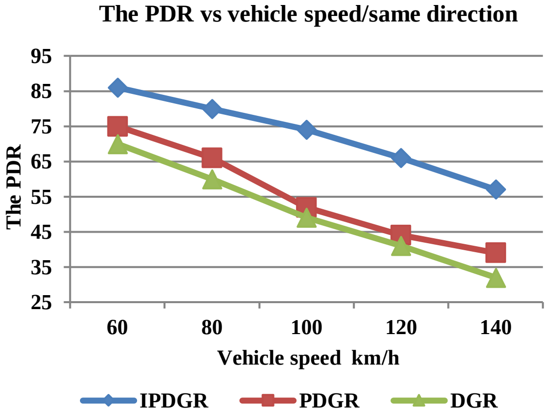

Figure 3. PDR via vehicle speed

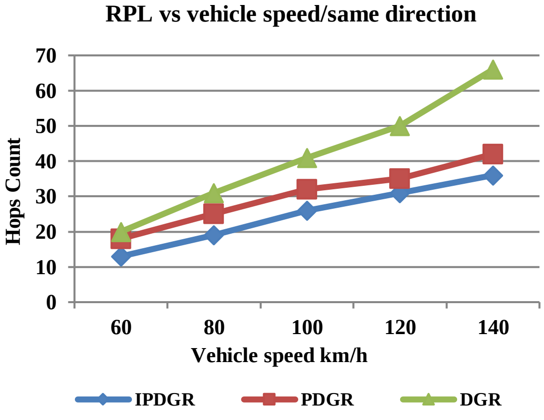

Figure 4. RPL via vehicle speed

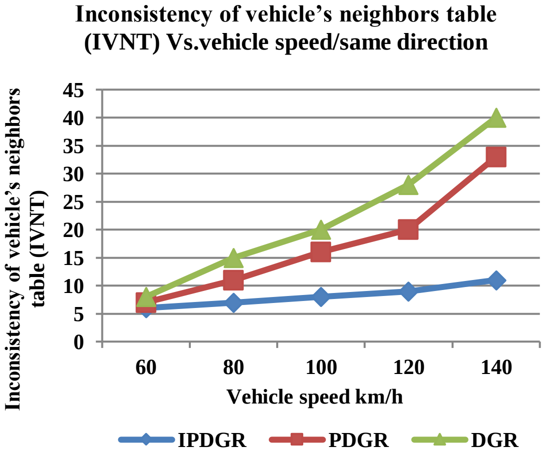

Figure 5. IVNT via vehicle speed

Figure 6 illustrates the NHPO relative to the speed of vehicle movement for the IPDGR, PDGR, and DGR protocols, with the protocol exhibiting fewer NHPOs considered superior. Meanwhile, Figure 8 demonstrates that the FLBS algorithm employed in the IPDGR protocol reduces the average NHPO by approximately 22% and 28% compared to PDGR and DGR respectively. In Figure 5, it is evident that as vehicle velocity increases, data transmission encounters more NHPOs when using PDGR and DGR protocols. However, PDGR exhibits a relatively better performance than DGR due to its predictive approach. Conversely, IPDGR demonstrates superior performance, experiencing the least NHPOs. This enhancement in IPDGR is attributed to the incorporation of the FLBS algorithm's novel features.

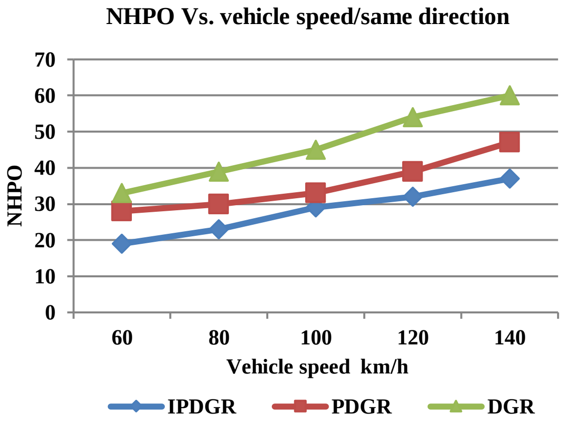

Figure 6. NHPO via vehicle speed

4.2. Scenario 2 results: Source vehicle and destination vehicle moving in the opposite direction

This scenario discusses the impact of vehicle speed on the routing performance of proposed improved and conventional PDGR in terms of PDR, RPL, IVNT, and NHPO routing metrics are chosen based on the required solution which are presented in Figure 7 to 10. A comparison in Figure 7 shows that the IPDGR protocol reduces the PDR ratio by about 21% and 25% over PDGR and DGR protocols respectively. As shown in Figure 9, as speed increases, DGR and PDGR have smaller PDR. The implicit reasons are assorted. DGR, considers both geographic position and motion direction when selecting the next hop. Also, it considers the packet holder’s current neighbors to calculate the weighted score for selecting the next hop. But it didn’t consider neighbors opposite movement direction. Therefore, it is clear that the selected next hop may no longer be in VNT. Wrong selection incurs more packet loss. PDGR considers the packet holder’s future neighbors to calculate the weighted score for selecting the next hop. It relies on a conventional beaconing approach to make its prediction. Also, it did not consider neighbors opposite movement directions. Thus, this increases stale information in VNT due to increments in the vehicle speed.

Figure 8 indicates that the IPDGR protocol outperforms both PDGR and DGR protocols by reducing the RPL ratio by approximately 32% and 38% respectively. In Figure 10, despite the vehicle velocity varying at the same rate as the constant bit rate (CBR) and vehicle numbers, there is a notable increase in the average number of hops in the recovery mode, particularly at a vehicle speed of 90. This increase is primarily attributed to the high disconnection between communicating vehicles caused by the opposite motion direction of intermediate nodes. Consequently, there is a significant increase in hop count, resulting in a longer RPL. Moreover, selecting the next hop with a different direction of motion leads to a higher average number of hops, increasing the likelihood of packet drops along the route. Notably, IPDGR exhibits a lower average number of hops compared to the other protocols, owing to its novel beaconing extension.

In Figure 9, it is evident that as vehicle speed increases, the topology undergoes rapid changes, particularly considering the opposite motion direction of intermediate vehicles. All protocols maintain an acceptable mean of IVNT when the vehicle speed is below 65 km/hr, owing to various factors. DGR, for instance, considers the current vehicle neighbors in IVNT based on a long beaconing time approach. Conversely, PDGR anticipates near-future neighbors using a predictive approach, albeit still relying on long-term beaconing. This approach enhances accuracy in VNT, leading to decreased IVNT compared to DGR. However, as the speed surpasses 70 km/hr, IPDGR demonstrates superiority over both PDGR and DGR protocols. IPDGR leverages its new features to outperform, reducing the IVNT ratio by approximately 35% and 38% compared to PDGR and DGR protocols respectively. The FLBS scheme plays a crucial role in this improvement, increasing the beacon packet sending rate and consequently contributing to the reduction in the IVNT rate.

The findings depicted in Figure 10 illustrate the impact on the IPDGR, PDGR, and DGR protocols when considering the motion of intermediate vehicles in all directions. Concurrently, Figure 10 reveals that the utilization of the IPDGR protocol reduces the average NHPO by approximately 31% and 40% compared to PDGR and DGR respectively. Additionally, the figure indicates that as vehicle velocity increases, the forwarded packets encounter more NHPOs when employing PDGR and DGR protocols. This effect is more pronounced with DGR compared to PDGR, owing to its prediction algorithm. IPDGR exhibits superior performance over PDGR and DGR due to its novel FLC algorithm.

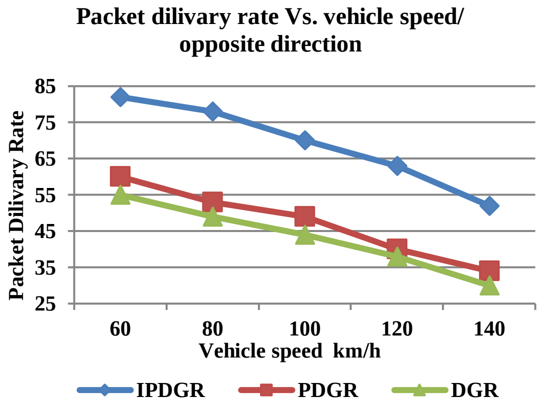

Figure 7. PDR via vehicle speed

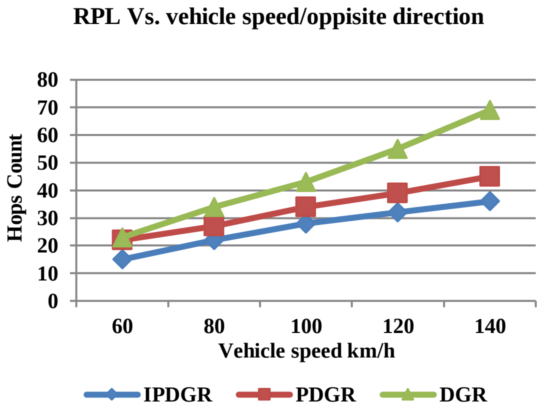

Figure 8. RPL via vehicle speed

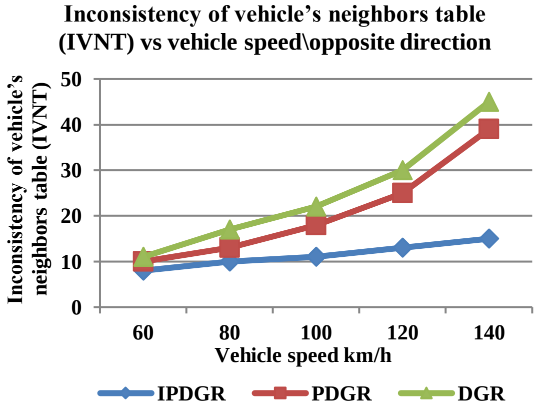

Figure 9. IVNT via vehicle speed

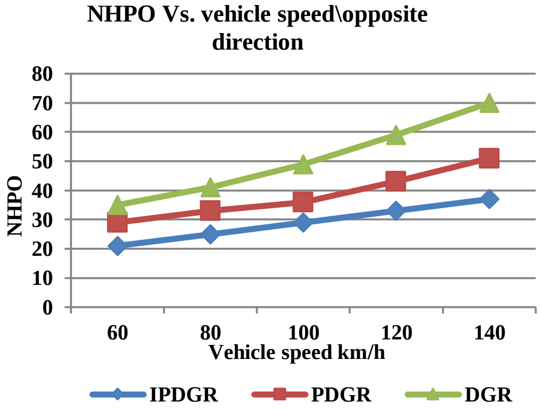

Figure 10. NHPO via vehicle speed

5. CONCLUSION

In conclusion, this study presents the IPDGR, a refined version of the conventional PDGR protocol. IPDGR focuses on enhancing the beaconing process by dynamically adjusting beaconing intervals based on vehicle speed, facilitated by a fuzzy logic controller. This enhancement aims to optimize beaconing efficiency while minimizing overhead. The evaluation of IPDGR's performance compared to traditional PDGR and DGR protocols was conducted using a bespoke simulation tool designed for VANET scenarios. Two distinct scenarios were examined: one where all vehicles moved in the same direction, and another where intermediate vehicles traveled in multiple directions while the source and destination vehicles moved in opposite directions. Results of the evaluation highlighted IPDGR's superior performance across key routing metrics, including PDR, RPL, Inconsistency of IVNT, and NHPO. These metrics were selected based on their relevance to the targeted solution. Overall, IPDGR demonstrated notable improvements over conventional PDGR and DGR protocols, showcasing its potential to enhance routing efficiency and reliability in VANET environments.

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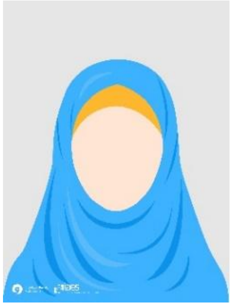

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