A Fuzzy GPSR Route Selection Based on Link Quality and Neighbor Node in VANET

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***Abstract*— Over recent years, a new technology named VANET (Vehicular Ad-hoc Networks) is highly recommended in smart cities and especially in Intelligent Transportation Systems (ITS). The VANET technology relies on the nodes acting like cars without the necessity for any controller or central base station by creating a wireless link among them. It enables cars to send and receive information between themselves and their environment. most VANETs utilize position-based routing protocols because they contain a GPS device. To deal with VANET problems, one solution is Geographic Perimeter Stateless Routing (GPSR) which has been broadly implemented. This paper suggests an effective intelligent fuzzy logic control system; called the FL-QN GPSR routing protocol. The proposed routing protocol incorporates two metrics link quality, and neighbor node to detect the best next-hop node for packet forwarding also updates the format of the Hello message by adding the direction field to be more suitable to our simulation. The OMNeT++ and SUMO simulation tools are both used in parallel to examine the VANET environment. The obtained results of the four simulation experiments in urban environments indicate substantial improvements in the network performance compared to the traditional GPSR and AODV concerning the QoS parameters.**

Keywords*— *FL-QN GPSR, Intelligent Systems, OMNeT++, SUMO, QoS, VANET.

I. INTRODUCTION

Even though VANET is a sub-class of MANET, but in the last ten years, VANET has drawn the attention of researchers all over the globe because of its diverse attribute such as the high mobility of vehicles compared to MANET, which is about 100m, and the frequent changes of topology. The vehicles can connect among each other in (V2V) mode or between a vehicle and infrastructure in (V2I) mode or by mixing the previous two-mode, which is a hybrid mode (V2X) [1]-[3].incorporating the applicable criteria that follow. In VANET, the routing protocol is divided into five categories: topology-based routing, position-based routing, cluster-based routing, geo-cast routing, and broadcast routing [4], [5].

Position-based routing (PBR) takes the geographical position of the nodes using GPS or any other device that can give the location of a node wirelessly, so the PBR doesn't have to establish a routing table for the entire network, it only requires to know the location of the neighbor node using a GPS, this is a great advantage which can save a lot of memory space. Position-based routing is a promise for large-scale wireless ad-hoc networks because of its simplicity, scalability, and use of node position information, making it advantageous for wireless networks. Geographical routing functions on the assumption that nodes are aware of their network positions [6], [7].

Geographical-based protocols are divided into three types (a) Non-delay tolerant networks (Non-DTN) which aim to send a packet as quickly as feasible from source to destination, for example, GPSR (Greedy Perimeter Stateless Routing), (b) Delay tolerant networks (DTN) method to improve network performance under frequent link breakage. DTN sends a packet based on the neighboring node's statistics. The transmission is carried out utilizing the Carry-and-Forward mechanism, for example, VADD (Vehicle-Assisted Data Delivery), and (c) Hybrid protocols in which the greedy forwarding and recovery modes are used for packet transmission, for example, GeoDTN+Nav (Geographic DTN Routing with Navigator) [8]. This paper is based on a very famous Non-DTN routing protocol that is (Greedy Perimeter Stateless Routing) GPSR. Since the traditional protocol has many disadvantages such as jumping into perimeter mode that makes the way to the destination very long, to lower the number of hops and chose the next-hop properly the traditional protocol must be enhanced in a way that the protocol performs well in different scenarios.

Many parameters can influence the GPSR performance, we focus here on two-parameter, namely the link quality and the neighbor node, the link quality is very important due to a weak link may lead to a link breakage and the data may be lost, this is happening as the neighbor node is moving far away from the source, and how close the neighbor node to the source is also very important as the node is close lead to a good delivery of the data.

These two parameters are implemented using a fuzzy logic system to obtain the best next-hop selection to improve the performance, it is done in I2V mode, the reason this mode is chosen is that it reduces the packet loss and delay the fuzzy logic controller is embedded in all vehicles and also the RUS to choose the best next-hop according to the two metrics. The simulation is applied in an urban environment where the speed of the vehicles is set to 40km/h.

The remainder of the paper is as follows, section II demonstrates the related work, Section III goes in the deep to show the process of enhancing the GPSR using fuzzy logic, while section IV shows the proposed FL-QN GPSR algorithm, meanwhile section V reveals the simulation tools and result. Finally, draw the conclusion in section VI.

II. RELATED WORK

Many researchers over the past years focused on investigating and improving the GPSR protocol and so many other protocols. In [9]-[11] in their analysis, they highlight several mathematical models to improve the GPSR protocol by offering extra details to establish a strong and stable path in the neighbor's table. Such analytical models can select the optimum route and avoid the nodes that contributed to the previous packets.

In [12] the author shows the enhancement version of the GPSR as GPSR-M the modified version takes the speed, link quality and, direction not only the position as in the traditional version of GPSR, and also the enhancement includes a prediction of the future position and calculating the next-hop weight.

Because moving too fast may cause a vehicle to be out of range and cause communication failure, the solution introduced in [13] MM-GPSR presented the improvement involving both greedy mode and perimeter, for the greedy mode the improvement begins with establishing the authorized communication region, followed by calculating and comparing the cumulative communication duration of neighbor vehicles, and ultimately selecting the neighbor with the maximum period as the next hop. If the node enters the perimeter mode it calculates and comparing the angle between the source and neighbor nodes and selects the node with a minimum angle as the next-hop node forwarder.

As in [14] the suggested method's major goal is to estimate a vehicle's position by using the location information of its nearby vehicles. To obtain precise position, the model vehicle weights using a fuzzy logic system that uses heading information and distance to calculate weight values. While [15] introduced a new routing protocol founded on fuzzy logic systems that might aid in the coordination and analysis of contradictory metrics. To pick the best next-hop for packet forwarding, the proposed routing protocol integrates numerous variables such as achievable throughput, direction, vehicle position, and link quality. Also in [16], the author suggested an intersection routing founded on the fuzzy multi-factor decision (IRFMFD) that makes use of some features.

The structure is split into two sections: vehicular decision control and intersection decision management. Suitable vehicles between two static nodes placed at two intersections derive potential routing paths in the vehicular component by taking distance, neighbor quantity, and relative velocity into account. In the intersection component, the candidate SN was selected from the present intersection's two-hop neighbors, who were linked to the current intersection via a route determined in part one. Also incorporated other criteria to calculate the number of hops in each link and the link life to reach the best scheme.

III. The Enhancement Of GPSR Using A Fuzzy Logic Controller

In this part, we present the enhancement of the GPSR using a fuzzy logic controller (FLC), the choice of the best next-hop node is grounded on two criteria the link quality and neighbor node. The reason for the fuzzy logic selection for the enhancement instead of other methods is that it has a solid academic basis that incorporates approximate, imprecise, and ambiguous information.

Fig. 1 shows the FL-QN GPSR architecture, the Fuzzy Logic Decision System (FL-DS) is in charge of determining the fuzzy score of every nominee forwarding based on the link quality and neighbor node. These two factors work together to pick the best next-hop that is close to the destination and has a high link quality.

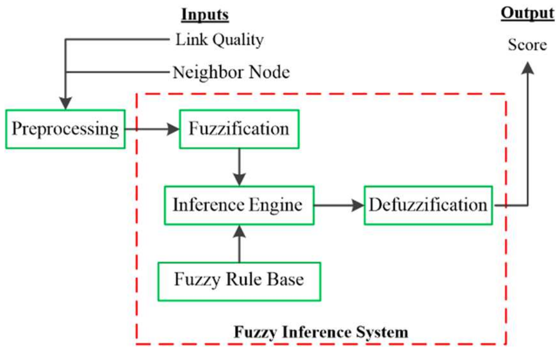


Fig. 1. FL-QN GPSR system architecture

The fuzzy logic decision system in FL-QN GPSR involves four major steps: fuzzification, rule base, inference engine, and defuzzification as shown in Table I. We use the minimum deduction approach for Mamdani. Due to its simplicity, we employ the triangle membership for the following input/output.

TABLE I. THE FUZZY LOGIC CONTROLLER FUNDAMENTAL ELEMENTS

Element	Description
Fuzzification	Transforms a set of crisp input values to a set of fuzzy input values.
Rule Base	The output metric is computed using a set of fuzzy IF-THEN.
Inference Engine	Infers and draws conclusions from fuzzy IF-THEN rules, as well as mapping fuzzy input sets obtained from the Fuzzifier onto fuzzy output sets.
Defuzzification	Conversion and return of a crisp value based on preset output MFs.

TABLE II. INPUT/OUTPUT FUZZY RULES

Input		Output
Link Quality	**Neighbor Node**	**Fuzzy Score**
Low	Low	Very-Low
Low	Medium	Low
Low	High	Medium
Medium	Low	Low
Medium	Medium	Medium
Medium	High	High
High	Low	Medium
High	Medium	High
High	High	Very-High

In the proposed protocol, we consider the GPSR beacon frame, which includes the following extra fields: a) The vehicle direction (b) The link quality, and (c) The neighbor node. Fig. 2 depicts our suggested scheme's redesigned beacon structure.

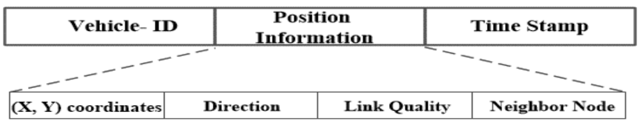


Fig. 2. The Modified Beacon Structure

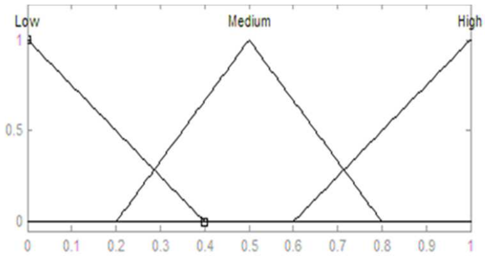
The nodes use the hello packet data to generate a new item in the neighbor table or to update that table. By default, each neighbor has one entry in the GPSR neighbor table. Each item provides the neighbor's (ID) IP address, the time-stamp of the last hello packet received, and the X and Y coordinates. The neighbor table in our method now includes two new fields:

link quality and neighbor node. Each vehicle, as illustrated in Table III, has a neighbors' table (NT) that stores information received from the hello beacon.

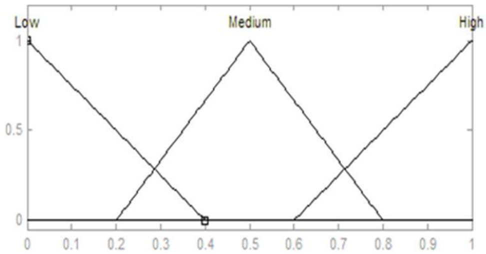
The way to generate a clear numerical value. We choose the center of gravity (COG) method because, in actual-world applications, it is the most used defuzzification methodology. Fig. 3 illustrates the fuzzy score performance membership function and illustrates the relationship between the input and the output variables.

TABLE III. NEIGHBOR TABLE FORMAT

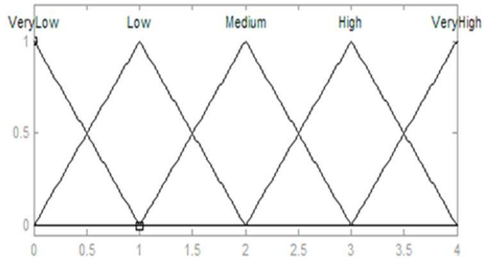
Neighbor's ID
Position (X, Y)
Direction
Link Quality
Neighbor Node
Last Packet Sequence Number
Last HELLO Message Timestamp



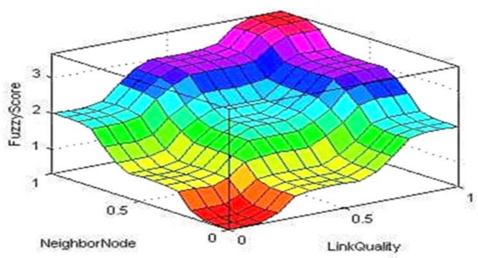
(a) MFs of Input Variable for Link Quality.



(b) MFs of Input Variable for Neighbor node.



(c) Output of MF(Membership Function).



(d) 3D Graph of FIS.

Fig. 3. Fuzzy Inference System of Proposed FLC model FL-QN GPSR

IV. THE PROPOSED FL-QN GPSR ALGORITHM

The proposed algorithm flowchart of FL-QN GPSR is introduced in this part. Based on two network metrics, the neighbor node and the link quality as shown in Equation 1.

$$\text{Link Quality} = \frac{\text{The Received Beacon Packets}}{\text{The Sent Beacon Packets}} \quad (1)$$

In addition, the angle direction must be calculated through Equation 2

$$\varphi_{ID} = \cos^{-1}\frac{((Nv.x*Dv.x)+(Nv.y*Dv.y))}{(\sqrt{(Nv.x^2+Dv.x^2)}*\sqrt{(Nv.y^2+Dv.y^2)})} \quad (2)$$

Where the *Nv* is the neighbor node velocity and *Dv* is the destination node velocity in the proposed arrangement. Criteria 1 are associated with the GPSR (default) distance between two nodes are calculation via Euclidean formula, as in Equation 3.

$$\text{Distance} = \sqrt{(y_1 - y_0)^2 + (x_1 - x_0)^2} \quad (3)$$

Whereas Criteria 2 are constructed on the FLC model to provide a different next-hop choice. To determine the next hop, we can combine the highest Fuzzy Rank$_i$ in the newly updated neighboring table with the nearest GPSR greedy mode to the destination.

The Proposed FL-QN Algorithm

Theory: All Nodes has a GPS
Input: Nodes, Communication Range, Network Map
Output: Best Neighbor Node as next-hop
Stage 1: Characteristics Calculation
For each node N_i **do**
Calculate the position of N_i: (X_i, Y_i)
Calculate the Link Quality of N_i (LQ_i)
Calculate direction of N_i: (Dir_i)
End for
Stage 2: Neighbor Table Establishing
For each node N_i **do**
Create a Hello message
Insert Vehicle ID, link quality, position & direction in the Hello message.
Regularly broadcast Hello message to all the neighbors
End for
Stage 3: Next-Hop Selection ➲ Search Destination is Next-hop:
If Node i is Destination
Forward the packet to the Destination
Criteria 1: Find Closest Distance to Destination
Calculate and Compare the Distance between Destination & all Neighbor N_i (Using Euclidean Formula);
Criteria 2: Use FLC to Find and Tune the Next-Hop using two parameters:
Link Quality & Neighbor Node ➲ Link Quality Ratio = No. of received Beacon /No. of sent Beacon.
Fuzzy_output = Calculate_Fuzzy_Score;
Establish the New Neighbors' Table ➲ Adding Fuzzy_Score_Values of All N_i and Distances of Destination & all Neighbor N_i to Neighbor Table
Search: **if** Rank$_i$ with Highest Fuzzy Score && Closest Distance to Destination
Set Node i as the Next-hop
End if
If Node i address is valid ( )
Transmit the data to Node i; ➲ *Greedy Forwarding*
Else
Recovery Mode ( ) ➲ *Perimeter Forwarding*
End if
End Algorithm

V. Performance Evaluation

A. Simulation tools

We analyze the effectiveness and efficiency of FL-QN GPSR, GPSR, and AODV. The tools that are used to perform this simulation is the network simulator OMNeT++ with the help of two frameworks the INET, and Veins. OMNeT++ is an extensible, modular, component-based C++ simulation library and framework, primarily for building network simulators [17], [18]. In addition, to make the simulation more realistic, the traffic simulator SUMO is used in conjunction with OMNeT++. Fig. 4 depicts the road network for an urban environment constructed using a 3X6 Manhattan grid.

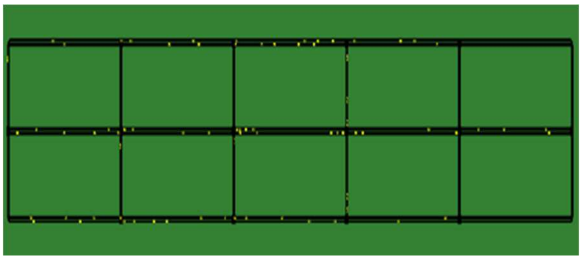


Fig. 4. 3×6 Manhattan Grid

B. Simulation Parameters

The parameters implemented in this scenario are revealed in Table IV.

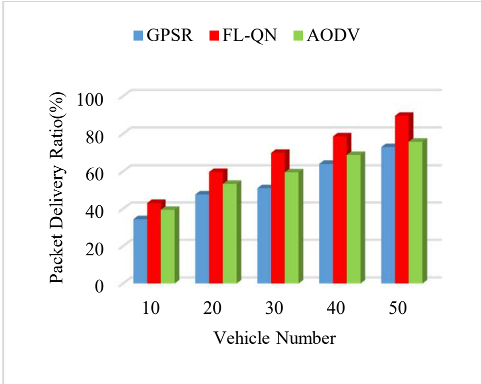
TABLE IV. Simulation Parameter

Parameter	Value or Protocol
OMNeT++version	OMNeT++ V 5.5.1
SUMO version	SUMO 1.6.0
INET version	INET 4.2.1
Veins version	Veins 5.0
Simulation area	2500 x 2500 m
MAC Protocol	IEEE802.11p
Layer 3 addressing	IPv4
Routing Protocol	GPSR & FL-QN GPSR, AODV
Communication mode	I2V
Number of vehicles	10, 20, 30, 40, 50
Vehicle speed	40km/h
Beacon interval	1s
Simulation time	600s
Transmission Range	250m

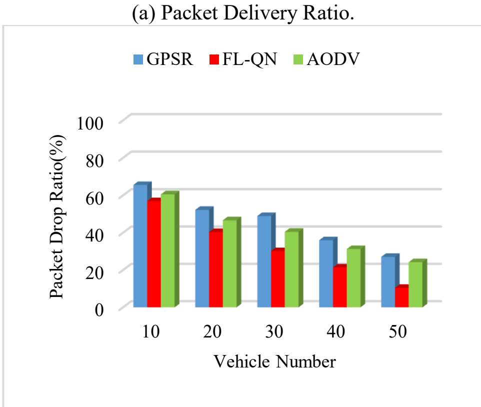
C. Simulation Results

The simulation of GPSR, FL-QN GPSR, and AODV was added to make the comparison more realistic and was investigated with a different number of nodes and also studying the impact of varying the speed value, the communication range, and beacon interval time on the performance of the AODV, GPSR and FL-QN GPSR. The proposed Fuzzy GPSR can provide good and reasonable results compared to existing works, such as a mathematical model in [11] and fuzzy logic-based model as in [15]. The maximum vehicle speed in our simulation is 40km/h (11sec/m).

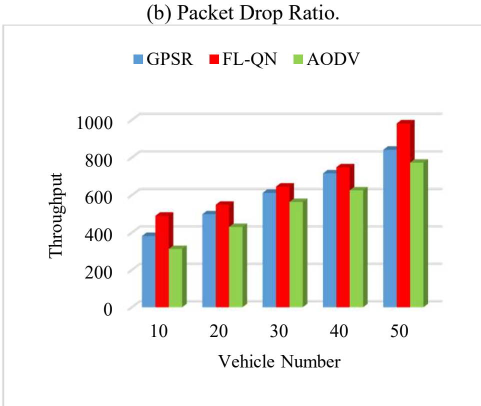
Experimental Case (1): Fig. 5 depicts the scenario with a variable number of vehicles. Fig. 5(a) shows that when node density decreases, so does the packet delivery ratio. In other words, there are not enough reliable and resilient routes being established for packet forwarding. However, when more intermediate nodes become available, i.e., as the number of vehicles increases, so does the estimated packet delivery ratio value.



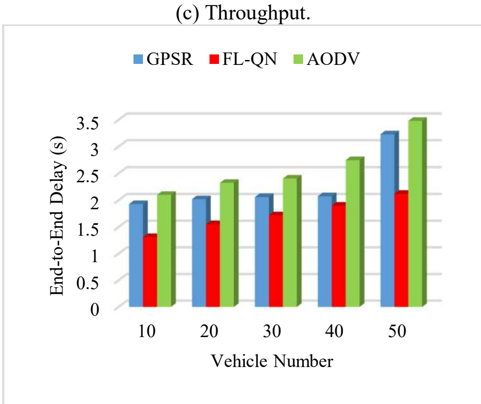
(a) Packet Delivery Ratio.



(b) Packet Drop Ratio.



(c) Throughput.



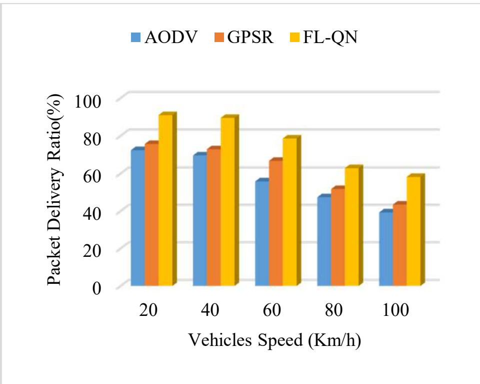
(d) End-to-End Delay.

Fig. 5. GPSR, FL-QN, and AODV Routing Protocols vs the Network Size

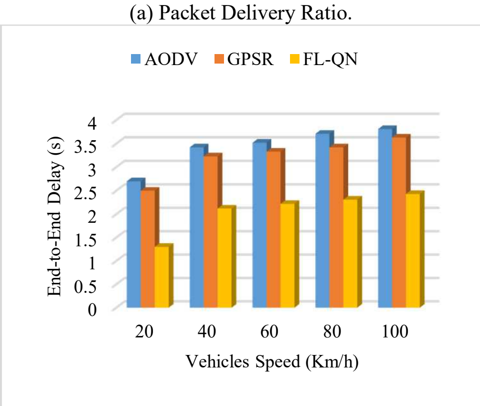
As uncovered in Fig. 5(b), the packet drop ratio lowers as the number of vehicles increases; additionally, as revealed in Fig. 5(c), throughput increases as the number of vehicles increases. Finally, Fig. 5(d) displays the end-to-end latency of AODV, GPSR, and FL-QN GPSR in regards to node count. FL-QN GPSR clearly outperforms GPSR and AODV.

Furthermore, GPSR has the longest end-to-end delay because it is caught in a routing loop between the greedy forwarding and perimeter forwarding transmission techniques compared to FL-QN. When the network topology changes dramatically, FL-QN GPSR can provide more stable and robust pathways that can be dynamically managed using the FLC system. As a result, it is noticeable that the FL-QN GPSR outperforms in its routing metrics.

Experimental Case (2): Fig. 6 shows a scenario of varying the speed values. Fig. 6(a) The FL-QN GPSR is higher than the GPSR and AODV, thus increasing speed has a negative effect on the packet delivery ratio. This is because, in AODV, increasing the speed increases the likelihood of connection failure, which also contributes to packet loss. GPSR performance is degraded further by increasing node mobility, as there are fewer surrounding nodes at greater speeds. Furthermore, when the node's speed increases, FL-QN and GPSR performance degrades due to network disconnection and path instability. The precision with which nodes acquire geographical information is influenced by vehicle speed, which affects GPSR performance but even though using a fuzzy system makes the FL-QN better performance compared to the other protocols.



(a) Packet Delivery Ratio.

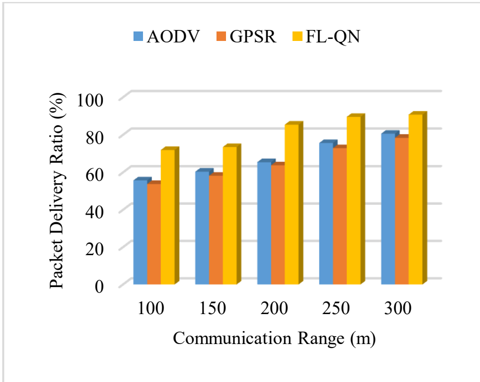


(b) End-to-End Delay.

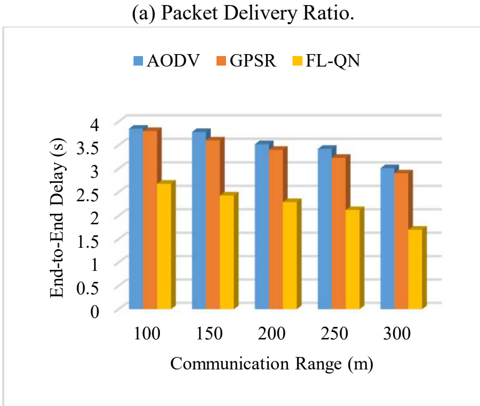
Fig. 6. AODV, GPSR, and FL-QN Routing Protocols vs Vehicles Speed

FL-QN GPSR surpasses AODV and GPSR in terms of the end-to-end delay, as seen in Fig. 6(b) since FL-QN GPSR has a lower end-to-end delay than GPSR and AODV. The effect of speed variation can be addressed by claiming that AODV does not perform effectively at lower speeds and fixed node density due to congestion. This is easily explained by broken links caused by increasing speeds. On the other hand, at lower speeds, the end-to-end latency for GPSR is fairly minimal; but, as speed increases, it increases due to the existence of more void zone possibilities, and the packet enters perimeter forwarding mode. In perimeter forwarding, the right-hand rule is employed to identify the next-hop neighbor, which might result in erroneous and long route selection.

Experimental Case (3): The performance of the AODV, GPSR, and FL-QN can be determined by adjusting the communication range value (100, 150, 200, 250, and 300) m while maintaining a constant speed of 40km/h and limiting the number of cars to 50 during the test. Fig. 7(a) depicts the packet delivery ratio in the protocols. As the communication range value increases, so do the packet delivery ratio for all protocols, however, the packet delivery ratio of FL-QN GPSR is higher than traditional GPSR and AODV because we consider the effects of the parameters of the imprecise link quality of neighbor nodes to select the forwarding node. Fig. 7(b) shows the end-to-end delay in the AODV, GPSR, and FL-QN protocols, demonstrating that increasing the value of communication range results in a decrease in delay because the probability of a neighboring node is high in all protocols, although the FL-QN GPSR outperforms the AODV and the traditional GPSR in the end-to-end delay.



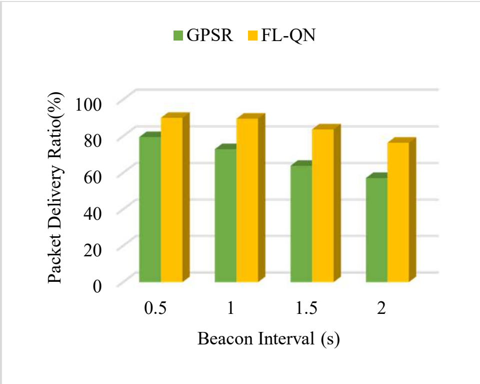
(a) Packet Delivery Ratio.



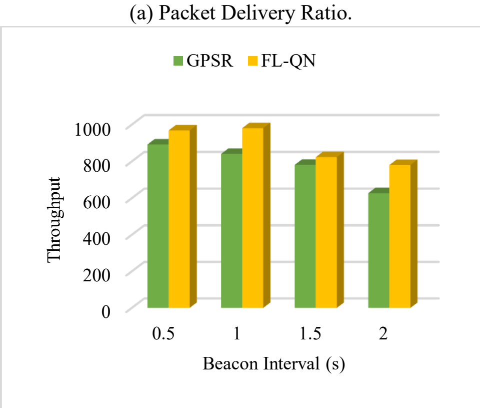
(b) End-to-End Delay.

Fig. 7. AODV, GPSR, and FL-QN Routing Protocols vs the Communication Range

Experimental Case (4): Fig. 8 (a,b) depicts the effect of varying the beacon interval duration on packet delivery ratio and throughput for 50 nodes and a suitable communication range of 250m. It is worth noting that as the beacon interval grows, the accuracy of the neighbor table diminishes; that is, the locations of the neighbor nodes become increasingly outdated, increasing the likelihood of connection failures. As a result, the increase in beacon interval is accompanied by a drop in packet delivery ratio and throughput. In contrast to the existing GPSR protocol, the proposed FL-QN GPSR protocol has a reduced rate of reduction in packet delivery ratio and throughput.



(a) Packet Delivery Ratio.



(b) Throughput.

Fig. 8 GPSR, and FL-QN Routing Protocols vs the Beacon Interval (s).

VI. Conclusion

Vehicle ad-hoc network is a revolutionary innovation emerging in the implementation of intelligent sensors, robust processors, and wireless communication protocols following important technological developments. This technique has been employed in various domains, enabling events and route data to be located at a gathering site known as a base station. The communication operation in VANET depends on how the routing is done better within the network. This study proposes an improvement to the GPSR protocol in which a fuzzy logic controller (FLC) is used to intelligently choose the best next-hop based on link quality and neighbor node in order to reduce the delay and enhance the packet delivery ratio. A new field is also added to the beacon message "Direction field" to boost performance. The simulation results show that our suggested algorithm FL-QN GPSR outperforms the classic GPSR and also the AODV protocol and other existing works in different experimental cases due to the enhancement made that makes this protocol robust toward the different environment changes.

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