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Improving Performance of Opportunistic Routing Protocol using Fuzzy Logic for Vehicular Ad-hoc Networks in Highways

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Abstract
Vehicular ad-hoc networks (VANETS) is an emerging technology with an extensive capability in various applications including the vehicles safety, traffic management, and intelligent transportation systems. Considering the high mobility of vehicles and their inhomogeneous distributions, designing an efficient routing protocol seems necessary. Given the fact that a road is crowded at some sections and is not crowded at the others, the routing protocol should be able to dynamically make decisions. On the other hand, the VANET environment is vulnerable at the time of data transmission. Broadcast routing, similar to opportunistic routing, could offer a better efficiency compared to the other protocols. In this paper, the fuzzy logic opportunistic routing (FLOR) protocol is presented, in which the packet rebroadcasting decision-making process is carried out through the fuzzy logic system along with the three input parameters of packet advancement, local density, and number of duplicated delivered packets. The rebroadcasting procedures use the values for these parameters as inputs to the fuzzy logic system to resolve the issue of multi-casting, considering the crowded and sparse zones. The NS-2 simulator is used to evaluate the performance of the proposed FLOR protocol in terms of the packet delivery ratio, end-to-end delay, and network throughput compared with the existing protocols such as FLOODING, P-PERSISTENCE, and FUZZBR. The performance comparison also emphasizes on an effective utilization of the resources. Simulations on highway environment show that the proposed protocol has a better QoS efficiency compared with the above published methods in the literature.

Keywords: *Opportunistic Routing, Fuzzy Logic System, Rebroadcasting.*

1. Introduction
Given the importance of vehicular ad-hoc networks (VANETs), it is necessary to have efficient methods for disseminating information between vehicles. In this regard, and in order to improve the information dissemination process, many inter-vehicle network routing protocols have been evaluated. However, no method compatible with the natural characteristics of vehicular networks has yet been provided with the capability of meeting all the requirements related to different applications in such networks. Due to the dynamic nature of vehicles and their movement at high speeds, continuous network interruptions and partitioning will occur in inter-vehicle networks. Node density will also vary according to the location conditions and at different times. The rate of connection interruptions and the links formed among vehicles will increase by decreasing the network density. Such challenges have caused to create many research areas related to inter-vehicle networks. Most of the routing techniques offered for mobile ad-hoc networks refer to unicast data transfer [1, 2], so they are not suitable for applications sensitive to inter-vehicles network delay including multi-media messaging and alert messages. The opportunistic routing strategy is one of the most appropriate methods that allow to dynamically decide for selecting the relay node during the routing process [3, 4]. In fact, instead of pre-defined rebroadcasting, the opportunistic

routing utilizes a set of candidate nodes. This multiple set of nodes present among the neighbors is defined as sending set [4]. Therefore, choosing an appropriate criterion to select the rebroadcasting node in opportunistic routing can improve the performance of inter-vehicle network characteristics. In addition, the car following model is limited to roads and highways. Hence, it is critical for drivers to know the vehicle position and direction in order to make better decisions and to avoid link disconnection. In order to obtain this information, the beacon messages will be used periodically between neighbors. These updates are very costly in many ways. Each update leads to increase the bandwidth usage, packet advancement delay, and increase the collision risk in the media access layer [5]. Packet collision will cause packet loss, which can affect routing efficiency, and consequently, a crowded condition occurs when the channel is used by vehicles. As a result, collisions will occur by increasing car densities, which can also lead to increase congestion within the network. This crowded condition in the network causes to increase in pocket loss and delay, and consequently, to decrease the system functionality [6, 7]. In this work, to solve this problem, beacon messages were not used in the opportunistic routing protocol and were introduced as a fault-tolerant protocol for vehicular networks that use the wireless channel broadcast feature and helps to improve the network performance during data forwarding. Additionally, the number of duplicated packets, packet advancement toward destination, and density are used as the prioritization criteria for rebroadcasting nodes. In this way, the packets are transferred with the least amount of consumed resources and provide appropriate performance considering opportunistic routing schemes. In our proposed method, it is not necessary to send beacon packets to keep informed of the status of neighbors and the density of the network, and therefore, to calculate these parameters; this leads to reduce the congestions and packet loss. Given the above-mentioned items, a fuzzy protocol is presented in this paper for decision-making on rebroadcasting the packets and their routings to the destination. This fuzzy protocol uses three input parameters with the objective of proper decision-making for rebroadcasting. Given the importance of the advancement of the packet, the variation and local density of the vehicles and controlling duplicate packets in the network, these three variables are chosen as the inputs to the fuzzy system for a proper decision-making. In fact, the routing tries to choose the rebroadcasting nodes with the maximum advancement towards the destination. Moreover, the local density of a parameter is dynamic in the network. Routing should make proper decisions considering the density. Finally, the number of duplications of the packets cause congestions and collisions in the network for which the routing should have required to control. Consequently, routing and packet rebroadcasting use fuzzy decision-making with these three parameters. For this purpose and in order to overcome the shortcomings in the previous works and to select the appropriate routes for rebroadcasting, we exploited the fuzzy logic to combine the concepts of (i) packet advancement to reduce delay between links, (ii) local density to afford with communicational rapid changes leading to reduced rebroadcasting and increased throughput, and (iii) choosing nodes with the least number of received duplicate packets. By applying the fuzzy logic on the rebroadcasting node, the best node is selected amongst the relays set, which finally leads to create routes with a higher throughput, lower end-to-end delay, and favorable data delivery rate.

The remaining sections of this paper are as follow. Related works are reviewed in Section 2. In Section 3, the proposed protocol is presented. In Section 4, the simulation results are shown, and finally, the conclusions are made in Section 5.

2. Related works

The multi-hop broadcasting provides a reliable communication mechanism for delivering the messages in VANETs. Given the unique features of VANETs, several routing solutions have been proposed for these networks. Their main characteristics include being dynamic, high-mobility, and responsive to variable density of the network. The density of the network is one of the effective parameters involved in delivering the packet to the destination. For instance, for low-density VANETs, the routing protocols often require a compromise between reliability and latency [8]. Multicast routing has recently drawn the attention of the researchers. In this protocol, a packet is sent to all vehicles in the network in a flooding manner. Different protocols have been proposed in the recent years for the efficiency of broadcast communications and reliable transmissions that are known as smart flooding protocols [9]. The objective of presenting these protocols is to reduce the number of the multicast packets and an efficient use of the bandwidth in the network. Flooded transmission of the data is a protocol for sending a data packet from a source to all of its neighboring nodes. The first protocol for the flooded transmission is the simple flooding protocol [10], in which when a packet is generated and sent from a node, the receiving node rebroadcasts the packet. *In order t*o prevent multiple rebroadcasting of the same packet, each node contains a list of delivered data packets and their lifetimes. Nevertheless, this protocol leads to the multi-broadcast storm issue and the performance of the network gradually deteriorates, particularly in the scenarios with a high density. Distance-based protocols are the routing protocols that use geographical data for enhancing the performance of the data rebroadcasting in a network. In [11], a multi-hop multicast routing strategy named as DADCE has been presented. This protocol uses the criterion of distance to choose a sender node. In this scheme, the closest node that receives the packet rebroadcasts the message once again. Furthermore, the density of the nodes and the fading parameter are considered to calculate the quality of the channel. The goal is to determine a threshold value consistent with the environmental conditions. The value of the threshold is calculated based on Equation (1) as:

$$D_c\left(N\right)=D_{max}-\beta e^{aN} \tag{1}$$

where, Dc is the decision cut-off; N is the local density; and D_{max} , a, and β are the parameters dependent on the quality of the channel and the broadcasting of the nodes. In fact, the performance of this routing protocol depends on a number of local parameters such as the node density, broadcasting, and quality of the wireless channel. The opportunistic routing protocol behaves the same as the multicast protocol. Opportunistic routing is a protocol for increasing the efficiency in wireless networks that has the ability to cope with the unreliable nature of wireless connections [4]. In figure 1, the sender node multi-broadcasts the data packets at time t to its n neighboring sets. The receiver nodes forward the packets based on the considered criteria.

Some of the current receiver nodes are defined as the sender set (i.e. relay nodes). Then all members of the sender set that have successfully received the packet perform the rebroadcasting (relaying) operation. In the opportunistic protocol, there are several factors that can be used for broadcast packets.

Based upon these factors, the opportunistic fuzzy routing would be different form each other. Nevertheless, all of these definitions are common in one point: "A node that sends a packet through an opportunistic protocol does not have a pre-defined strategy for choosing the next hop for guaranteeing the delivery to the destination but this is carried out instantaneously and the decisions are made based on the current situation". The important challenge of routing protocols in VANETs is that they suffer from frequent interruptions and delay in delivering the packets. In order to cope with this issue, the geographical opportunistic routing protocol is introduced based on the joint link state and forwarding quality (LFGOR). In order to determine the candidate set of sender nodes in LFGOR, a combination of filtering and prioritization is used, in which the information regarding the location, link state, and sender node quality are taken into account. Overall, this protocol has an acceptable latency [13]. Routing protocols are challenging for highly mobile networks. Therefore, an opportunistic routing called LADOR (Location and Direction Aware Opportunistic Routing) is introduced, in which the transmission is carried out through the carry-and-forward mechanism. LADOR has two steps including 1) the step of choosing the neighboring nodes 2) determining the message priority for transmission. In this protocol, not only the delivery rate is increased, but flooding and traffic streams are avoided as well [14].

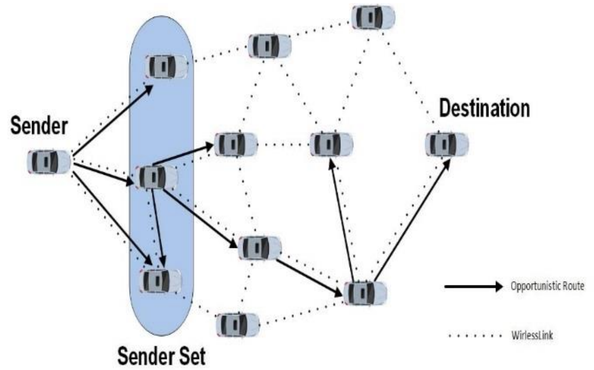

Figure 1. An example of packet forwarding using opportunistic routing.

A fuzzy logic-based method has been proposed in [15] for inter-vehicle networks taking into account the mobility parameters, distance from neighboring nodes, and signal strength. The method is intended to broadcast alert massages in the network; it introduces the whole network as the destination; its goal is to maximize the number of received data packets in all the possible directions. It also does not consider the forwarding parameters and the number of duplicated packets in the network. Considering that the forwarding parameter between the nodes will increase the system throughput and network delivery rates, by taking into account the relay nodes in different sections due to the hidden terminal problem, the proposed method will have data broadcasting redundancy. In opportunistic routing, the node rebroadcasting criterion could be the packet advancement or node density. Selecting a proper criterion or the superiority of a criterion over the others is an important issue that could affect the rebroadcasting performance. In order to solve this issue, one could use the fuzzy logic for a better decision-making. Authors in [16] have purposed a novel intelligent forwarding-based stable and reliable data dissemination scheme. Link stability is described mathematically, by which vehicles choose the next forwarding node. Then a greedy algorithm is presented to transmit the data from source to destination. Recently, the fuzzy logic decision-making system has been used to help the node to make the decision for rebroadcasting in terms of some of the receiver-based routing protocols. Such solutions have been presented in [17, 18]. In [17], each vehicle has a fuzzy logic system that uses cover, connectivity, and mobility factors for making decisions regarding the rebroadcasting or removing the delivered packet. A similar solution has been proposed in [18], where a fuzzy logic system has been used in making decision on whether a vehicle is suitable for rebroadcasting. The required inputs for this system are the coverage and mobility factors that have been similarly computed in [17]. A set of candidate vehicles for rebroadcasting have been generated based on the decision suitable for fuzzy logic system and the vehicles with the maximum value of coverage within the set making the decision on rebroadcasting.

In [19], the authors have proposed a stable routing protocol based on the fuzzy logic system, which can deliver alert messages with minimum delay and improve the stability of cluster structure by generating only a small number of clusters in the network. In this work, the fuzzy logic system has been used to create the clusters and select a cluster head for each cluster. This method also considers distance, relative mobility, packet loss, and average end-to-end delay as inputs to the fuzzy decision-making system.

The proposed approach is based on 4 metrics of neighboring nodes to select cluster head. In [21], the authors have presented a new data delivery protocol for vehicular networks in urban environments that could enhance the routing performance without using GPS. The fuzzy rule-based wireless transmission protocol is designed for the optimization of choosing the rebroadcast parameters considering several factors including the speed of the vehicle, driving direction, number of hops, and connectivity time. In [22], the author has presented a novel adaptive fuzzy multiple attribute decision routing (AFMADR) scheme, by which a packet carrier is supposed to be a decision-maker in the selection of a target for the next hop transmission with more factors to be considered. The AFMADR scheme consists of four steps. Firstly, the candidate vehicles are characterized by four attributes including the distance, direction, road density, and location to obtain a fuzzy attribute score of each attribute. A fuzzy performance score will be produced for each candidate based on the fuzzy attribute score and their real-time weights. Lastly, a route decision is made by choosing a candidate with the highest performance score as the target for the next hop transmission. The mobility and signal strength received in [15] select the nodes among the sending set as the packet rebroadcaster that is closer to the sender node; it leads to increase the number of steps, and therefore, has a higher delay. Finally, considering the deficiencies in the previous works and the challenges faced in vehicular ad-hoc networks arising from their natural nature, it is essential to provide a new benchmark that takes into account a suitable channel model and more realistic traffic patterns reflecting the real behavior of vehicles in the environment for opportunistic routing. It should consider the intrinsic features of a vehicular ad-hoc network to increase the network performance such as the delivery rates, throughput latency, and end-to-end delay reduction.

3. Proposed protocol

Most routing strategies attempt to provide appropriate paths between the nodes and to minimize the time required to fix the interruptions occurring in network connections. However, factors such as speed and position of the nodes and the distance between them, the reliability of the links between the nodes, and the delay between the links may have important and serious impacts on the path stability. In highways, data delivery is difficult due to the lack of stable connectivity and high mobility of the vehicles, which lead to sparse or dense zones in the network at different times. Therefore, a protocol should be presented that could properly perform the routing for the delivery of the packet to the destination. We used the concept of density, the number of duplicate packets, and packet advancement, which seem to be major essential factors in the paths for real-time services as a new criterion for opportunistic routing in order to address the mentioned deficiencies and more compatibility with vehicular ad-hoc network features.

In the proposed protocol, three factors of advancement, local density of the vehicles, and the number of duplicated delivered packets are calculated, which are based on the calculated values and using the fuzzy logic, the receiver vehicle decides whether to perform the rebroadcasting operation or discard the delivered packet. These three factors, as the inputs of the fuzzy logic, are described in the following sub-sections.

3.1. Fuzzy logic

Basically, routing is difficult in inter-vehicle networks due to the high mobility of the vehicles, and selecting a proper route depends on the network environment. Fuzzy systems could be highly flexible by changing the membership function and the set of fuzzy rules, and could be employed in different scenarios. The fuzzy logic theory was introduced by L. Zade as a logic describing propositions with some degrees of facts and lies. The fuzzy system procedure includes the three steps of fuzzification, fuzzy inference engine, and defuzzification. In the fuzzification part, the numerical values of the input variables are transformed into a fuzzy set. In the fuzzy inference engine, a set of fuzzy rules in the form of if-then are transformed into outputs, and in the defuzzification part, the fuzzy output is transformed into an exact number. In this paper, the three functions of advancement membership function, density, and number of duplicate packets are used as inputs to the fuzzy logic-based rebroadcast system.

Figure 2 illustrates the fuzzy control system. A vehicle uses the advancement membership function for calculating the values of close, intermediate, and far as the values for the parameter of the advancement of the packet. In other words, when the distance of the receiver of the packet from the sender (in m) is longer than a specified threshold, the membership function assigns the far value to it, and on the contrary, when this distance is shorter than a specified threshold, the close value is assigned to this parameter; otherwise, the intermediate value will be the value of this function. The membership function for the density and the number of duplicate packets use the values of high, medium, and low for calculating the value of their parameters.

Therefore, when the number of sending nodes for a packet is higher than a specified threshold, a high value is assigned to the membership function of density, and when the number of these senders are lower than a specified threshold, the value low is assigned, and finally, the membership function of the number of duplications at the receiver counts the number of delivered packets, and if this number is higher than a threshold value according to the definition of the function, the high value is assigned to it, and if it is lower than a threshold value, the low value is assigned to it. The fuzzy inference method is a max-min method. In other words, the AND fuzzy operator takes the minimum value of the precedents [23]. Based on the fuzzy value of the input variables and using the if-then rules, the rules of this fuzzy system and the status of the vehicle are defined as rebroadcasting or non-broadcasting in table 1.

3.1.1. Packet advancement membership function

This parameter shows the advancement of a packet towards the destination, i.e. the a_{ij} parameter calculates the distance between the ith sender nodes from one of its rebroadcast candidates (i.e. jth vehicle). The advancement of the packet is defined as:

$$d_{ij} = D_{id} - D_{jd} \tag{2}$$

$$a_{ij} = f(x)\begin{cases} \dfrac{d_{ij}}{r} & 0 < d_{ij} < r \\ 0 & otherwise \end{cases} \tag{3}$$

Where r is the maximum communication range, and D_{id} and D_{jd} are the distances between the ith and jth vehicles to destination d, respectively. The optimization of the advancement of the packet, despite the other two parameters, leads to the rebroadcasting in the further nodes to the receiver in the sending set. Considering that the transmission range $r = 300\,m$ is taken into account, the close value shows that the distance between the receiver and the sender is larger than the specified value, i.e. the criterion packet has a good advancement and is closer to the destination and it should perform the rebroadcasting operation. When the distance between these two values is taken to be intermediate in which case one could not decide based on its value whether the node has performed the rebroadcasting. The membership function of advancement is illustrated in figure 3 for the proposed fuzzy logic rebroadcasting protocol.

3.1.2. Density membership function

The number of neighboring vehicles is used for calculation of density. When a vehicle wants to rebroadcast a packet, it puts its specifications as the sender in its header. In this way, whenever a vehicle receives a packet, it stores the header information of the delivered packet including the packet ID and the sender's identification number in its buffer. Then the receiver's buffer is searched based on the ID of the delivered packet to examine the number of different senders of the packet, i.e. how many times this packet with this ID have been received by different senders as the neighbors. In case the number of delivered packets from different neighbors is lower than a threshold, the low value is assigned to this parameter and the local density of the network is in uncrowded condition. Consequently, the receiver vehicle should perform the rebroadcasting operation.

When the number of neighbors is higher than a specified threshold, the value of this parameter is high, i.e. the local density of the network is high, and the rebroadcasting node should not perform the rebroadcasting; otherwise, the medium value is assigned to it.

The local density is normalized by the number of id packet senders divided to the average number of vehicles in transmission range, e.g. 300 m in the movement patterns (Fleet Net). In other words, according to the density of the network, one could not decide whether the rebroadcasting operation should be performed. The density membership function is illustrated in figure 4 for this proposed fuzzy logic rebroadcasting protocol.

3.1.3. Membership function for number of duplicate packets

In calculating this parameter, the number of duplicate packets is used such that when a vehicle receives a packet, it searches for its specific ID in its own buffer to determine how many times this packet is delivered, i.e. the number of duplicates for the packet is determined.

If this is the first time that the packet is delivered, the value of this parameter is set to low and the rebroadcasting operation for this packet is carried out by the receiver node.

In case the number of deliveries is higher than the specified threshold, the value of this parameter is set to high, and in order to prevent sending duplicate packets, this packet should not be rebroadcasted, and in the range between these values, the value of this parameter is set to medium, in which case, one could not explicitly specify if the packet should be rebroadcasted given the number of duplicate deliveries of the packets.

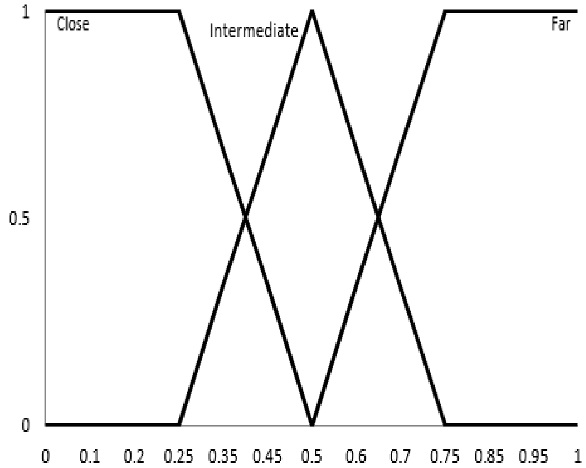

Figure 3. Membership function for the packet advancement.

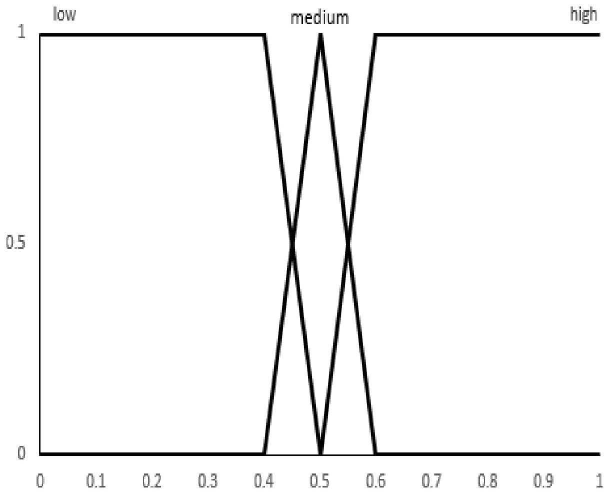

Figure 4. Membership function for local density.

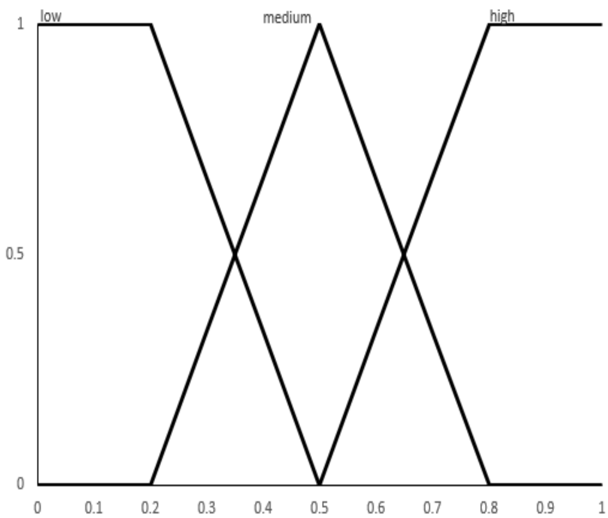

Figure 5. Membership function for factor of the number of duplicate delivered packets.

We obtain the number of duplicate packet ID from the total received packet ID and the total received packets. Fuzzy logic is used in order to resolve this uncertainty issue. The membership function for the number of duplicate packets is illustrated in figure 5 for the proposed fuzzy logic rebroadcast protocol. In this work, the center of gravity (COG) is used, which is known to be the most popular defuzzification method, extensively used in real applications.

3.2. Fuzzy Logic Opportunistic Routing (FLOR) Protocol

Broadcasting data packets is the basis for the opportunistic routing protocol. This type of data transmission is utilized in order to increase the probability of at least one node having the potential of receiving a packet. Figure 6 shows the application of packets broadcasting in data transmission through opportunistic routing. In this figure, sender S wants to send packets to destination D. Paths N1, N2, and N3 provide different routes to the destination (path 1, path 2, and path 3).

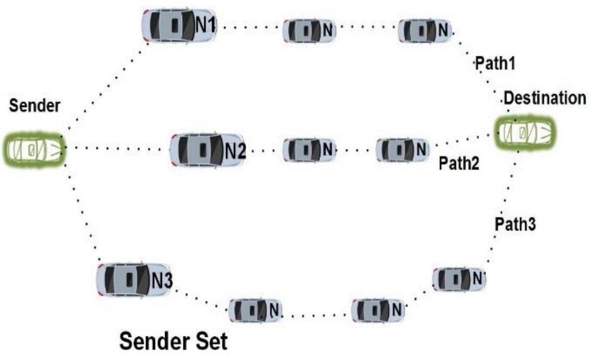

Figure 6. Rebroadcasting using opportunistic routing.

Using the normal routing, origin $sender$ chooses one of these three sender paths as the next hop, and then sends the packet through them in the form of unicast. In the opportunistic routing strategy, the data packet is sent to all three neighbors (or some of them) with rebroadcast receiving ability. In fact, opportunistic routing broadcasts a data packet instead of a pre-determined rebroadcaster to a set of broadcasting candidates. In general, the opportunistic routing operation consists of three main steps as:

- Selecting the set of rebroadcasting candidates;
- Data multi-casting to the candidate rebroadcasters;
- Data transmission.

In this protocol, the opportunistic routing protocol is used with a slight difference. In the classical opportunistic routing protocol, packet rebroadcasting is carried out by the candidate set in case of failure of the members in sending by the other members of the set. However, in the FLOR protocol, given the fact that being in uncrowded zones, duplicate transmissions could help delivering the data packets in the destination. Therefore, considering the fuzzy decisions, a number of members of the set of candidates could perform the rebroadcasting operation. In fact, rebroadcasting operation is adaptable with respect to the density of the environment and other parameters, which in turn, the duplicate packets could be controlled. In this protocol, the set of candidates are selected among the nodes that are in the transmission range and in front of the sender. In the proposed protocol, when a packet is received by each node, it initially uses the packet advancement of the sender in the packet header to examine if the sender's location is in a proper location (the nodes behind the sender are neglected). One of the unique features of the proposed protocol is that beacon packets are not required to know the status of the neighbors or calculating the local density of the network. Using these data packets in the network environment leads to congestions, collisions, and inefficient use of the bandwidth. Furthermore, management and time of the delivery of the packet is one of the issues in routing protocols. Through a dynamic technique, we can manage rebroadcasted packets based on network criteria. We can consider composition of three consisting of advancement of packet, local density, and number of duplicate delivered packet as inputs of fuzzy system. In order to describe the proposed protocol, the following example is provided. Once the fuzzy values of advancement of packet, local density, and number of duplicate delivered packet factors are calculated, the sender node uses the IF/THEN rules (as defined in Table 1) to calculate the rank of the node. The linguistic variables of the rank are defined as {Rebroadcasting, Non-rebroadcasting}. For example, in table 1, Rule 1 may be expressed as follows:

IF *Packet advancement* is Close, *Density* is Low, and *Number of duplicate packets* is Low, **THEN** Rank is Rebroadcasting.

Now, having the values of the membership functions, one can easily find out which one of the 27 rules of fuzzy logic of table 1 should be executed to lead to the rebroadcasting or not rebroadcasting decision. It is clear that in this complex situation, fuzzy logic is the best solution for making such decisions.

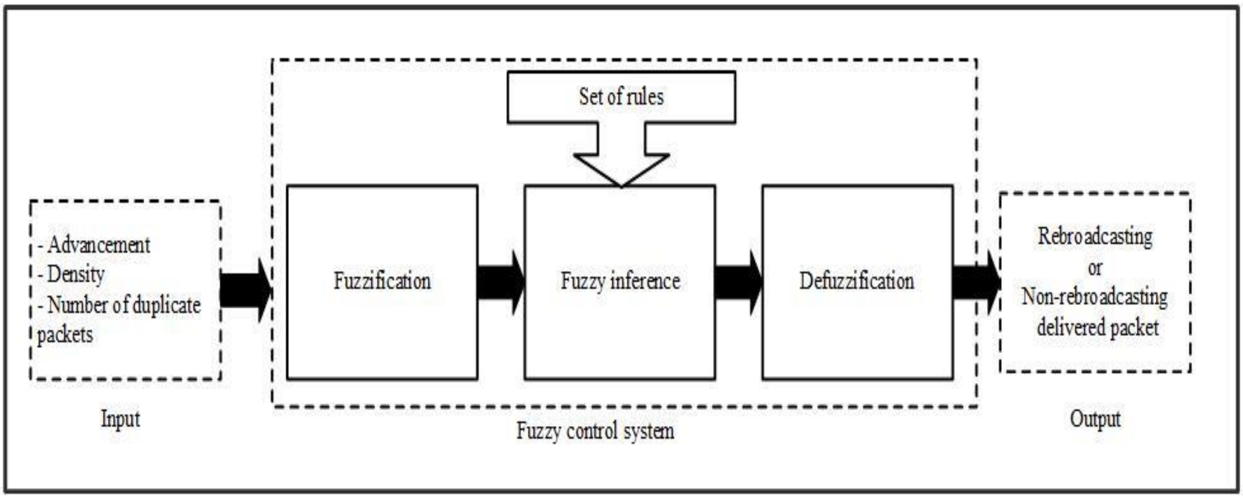

Figure 2. Fuzzy control structure.

Table 1. Defined 27 Fuzzy rules based on fuzzy values of input variables.

Rule	Packet advancement	Density	Number of duplicate packets	Status
Rule 1	Close	Low	Low	Rebroadcasting
Rule 2	Close	Low	Medium	Non-rebroadcasting
Rule 3	Close	Low	High	Non-rebroadcasting
Rule 4	Close	Medium	Low	Rebroadcasting
Rule 5	Close	Medium	Medium	Non-rebroadcasting
Rule 6	Close	Medium	High	Non-rebroadcasting
Rule 7	Close	High	Low	Rebroadcasting
Rule 8	Close	High	Medium	Non-rebroadcasting
Rule 9	Close	High	High	Non-rebroadcasting
Rule 10	Intermediate	Low	Low	Rebroadcasting
Rule 11	Intermediate	Low	Medium	Rebroadcasting
Rule 12	Intermediate	Low	High	Non-rebroadcasting
Rule 13	Intermediate	Medium	Low	Rebroadcasting
Rule 14	Intermediate	Medium	Medium	Rebroadcasting
Rule 15	Intermediate	Medium	High	Non-rebroadcasting
Rule 16	Intermediate	High	Low	Rebroadcasting
Rule 17	Intermediate	High	Medium	Non-rebroadcasting
Rule 18	Intermediate	High	High	Non-rebroadcasting
Rule 19	Far	Low	Low	Rebroadcasting
Rule 20	Far	Low	Medium	Rebroadcasting
Rule 21	Far	Low	High	Non-rebroadcasting
Rule 22	Far	Medium	Low	Rebroadcasting
Rule 23	Far	Medium	Medium	Rebroadcasting
Rule 24	Far	Medium	High	Non-rebroadcasting
Rule 25	Far	High	Low	Rebroadcasting
Rule 26	Far	High	Medium	Non-rebroadcasting
Rule 27	Far	High	High	Non-rebroadcasting

Algorithm 1: pseudo-code of proposed method (FLOR)

S: *Source Node*
BN: *Broadcasting Node*
CRS: *Total Number of Neighbors of BN*
Node_id: *sender's identification number*
1. Set BN = S
2. Define fuzzy sets for Advancement from BN, Density relative to BN, and Duplicate packages received as input and Rebroadcast or not Rebroadcast as output variables.
3. Define fuzzy rules in the form of IF-THEN statements with the help of various Input parameter values.
4. If destination vehicular is in transmission range of BN, then packet received at destination (exit).
5. **For** Each member of CRS **do** {
    6. Input three parameter numerical data into fuzzy system.
    7. Generate fuzzy values by using fuzzy Membership Functions (Advancement from BN, Density relative to BN, Duplicate packages received) defined in step 2 for each input metrics.
    8. Input the fuzzy values obtained in step 7 to fuzzy inference system.
    9. Map the fuzzy values to pre-defined IF-THEN rules obtained in step 3 and use 27 the rules together to obtain fuzzy output whose indicate Rebroadcast or not Rebroadcast.
    10. Convert the fuzzy system output into a numerical value using the defuzzification method

}// **end of for loop**
11. Update BN = Next Neighbor
12. Repeat steps 4 to 11 until to packet receive in destination.
13. End

4. Simulation results

The efficiency of the proposed protocol is evaluated using NS-2 (v. 2.35) simulator, a C++ based simulation tool. The simulation is carried out using the parameters listed in table 2. In order to perform the evaluation, Fleet Net [27], which is a generator for the real movement patterns of the cars in highway environments, is used, which is very different from that of urban areas [12].

Table 2. Simulation parameters.

Simulation parameter	Value
Simulator	**Ns-2 (v. 2.35)**
Simulation area	**15,000 m × 15 m**
Number of nodes	**108, 236, 340, 459**
Transmission range	**300 m**
Channel data rate	**2 Mbps**
Traffic generate type	**CBR**
Packet size	**512 bytes**
Minimum. Speed	**50 km/h**
Maximum. Speed	**224 km/h**
Simulation time	**60 s**
Hello interval	**0 s**
Queue length	**50 packets**
Radio propagation model	**V2V–Nakagami**
Mac layer	**DCF of IEEE 802.11**

Furthermore, in the performed tests, a microscopic method is used and the movements and locations of each car are determined through Fleet Net model [24, 25]. This model not only takes the characteristics of the cars into account, but it also considers the behavior of the drivers such as lane change, traffic laws, paying attention to traffic signs or reducing the speed in road curves. Also the built-in simulation tool for the driver's behavior for Daimler Chrysler called FARSI in Fleet Net is utilized.

FARSI simulator shows the actual speed, distance, as well as the macroscopic characteristics such as the traffic stream and using the lane. Hence, FARSI guarantees that the movement pattern of the vehicle in Fleet Net is as real as possible [24]. In this paper, the scenario of a highway with the length of 15 km and width of 15 m is considered. The vehicles move in two directions with speeds in the range of 50-224 km/h, and could change their lanes as well. However, it is assumed that the data transmission is carried out by the vehicles in their movement direction. In order to model the wireless channels in a realistic manner, the V2V channel model proposed in [26] is used, which generates the fading effect of Nakagami.

The Nakagami propagation model was used to simulate the channel fading, and its parameters are shown in table 3. For each parameter, the first value indicates the parameter value used in the freeway scenarios, and the value between the parentheses indicates the parameter value used in the street scenarios. We used these parameter values because they modeled a realistic wireless channel for VANETs [27].

Table 3. Parameters of the propagation environment model Nakagami.

GAMMA0_	GAMMA1_	GAMMA2_	D0_GAMMA_	D1_GAMMA_
1.9 (2.0)	3.8 (2.0)	3.8 (2.0)	200 (200)	500 (500)
m0_	m1_	m2_	d0_m_	d0_m_
1.5 (1)	0.75 (1)	0.75 (1)	80 (80)	200 (200)

A constant bitrate (CBR) is used to generate the traffic. Each vehicle has a transmission range of 300 m for a channel data rate of 2 Megabits per second [28]. It is worth mentioning that although there are numerous propagation models for evaluation of VANETs [24], the above-mentioned models have well-established parameters, needed in the simulations. Five performance criteria are used for the evaluation of the network performance:

- *Packet delivery ratio (PDR)* shows the ratio of the successfully delivered packets in the destination to the total number of generated packets by the source vehicle.

- *Average end-to-end delay (AE2ED)* shows the average latency between the sources to their destinations for the packets, which are correctly delivered in the destination normalized by the number of the packets that are correctly delivered. The lower the average end-to-end delay is, the more performance increases. D_{AE2E} can be measured by Equation 4.

$$D_{AE2E} = \frac{1}{N_{PSR}} \sum_{i=1}^{N_{PSR}} \left(T_r^i - T_S^i \right) \tag{4}$$

With:

$$N_{PSR} = \frac{\sum N_{RP}}{\sum N_{SP}} \tag{5}$$

In the above equations, D_{AE2E} is the average end-to-end delay, N_{PSR} is the number of packets successfully received to the neighbor, T_r^i is the reception time of packet I, T_S^i is the sent time of packet i, N_{SP} is the number of packets to send, and N_{RP} is the number of received packets.

- *Packet loss ratio (PLR)* shows the ratio of discarded packets to the total number of delivered packets. This is represented mathematically by Equation 6:

$$P_{PLR} = \frac{\sum N_{SP} - \sum N_{RP}}{\sum N_{SP}} \tag{6}$$

- *Number of messages per data packet* shows that the number of generated messages (data messages sent by all nodes across the network) indicates the number of data packets generated by the source nodes.

- *Average throughput* shows the average number of received data in the vehicles in bits per second.

In this paper, the performance of our proposed FLOR protocol is compared against the three known protocols of flooding protocol [9], p-persistence protocol [26], and FUZZBR protocol [15] in two different simulation scenarios. 1) Different nodes are considered for network performance evaluation, and 2) In this scenario, the evaluation of the network is performed with different traffic loads. The two different scenarios have been used in the simulation with the following parameters:

• Number of vehicles as variables in the network.

• Changing the rate of generating traffic on the network.

4.1. Evaluation of Performance Criteria for Number of Different Vehicles in Network

In this scenario, Fleet Net generates the vehicle mobility patterns for four different numbers of vehicles, i.e. 108, 236, 340, and 512 with a rate of one data packet per second (Table 4). The above number of vehicles are also used in comparisons between the proposed FLOR and the three other protocols. In order to obtain a significant comparison of the results, different speeds of vehicles are also used.

Table 4. Detailed specifications of the vehicles in three different scenarios.

Number of vehicles	Minimum speed (Km/h)	Maximum speed (Km/h)	Average speed (Km/h)
108	73	224	128
236	71	185	122
340	63	200	122
459	52	220	122

The distance from the source to the destination is the same in all simulations but could change during the simulation given the speed of the vehicles. Figure 7 shows the PDR results for the simulations of this scenario. The packet delivery rate is reduced by increasing the number of nodes in Flooding. This is because with increasing density, rebroadcasting is performed by many nodes, and it increases the collisions and reduces the volume of the received packets. Due to reducing the number of rebroadcasting, the packet delivery rate in the p-persistence method is better than the Flooding method. However, as a probabilistic method is used in p-persistence, the number of rebroadcasting increases with increasing number of nodes, which leads to a reduced performance.

Packet delivery rates in FUZZBR is better than the two previous methods. In this method, the delivery rate does not change considerably by increasing the number of nodes.

As previously noted, the number of rebroadcasting packets is also increased by increasing density. As a result, the number of lost packets decreases. In the proposed method (FLOR), by controlling the number of rebroadcasting packets, as well as by taking into account the density, the packet delivery rates are increased by increasing the number of nodes.

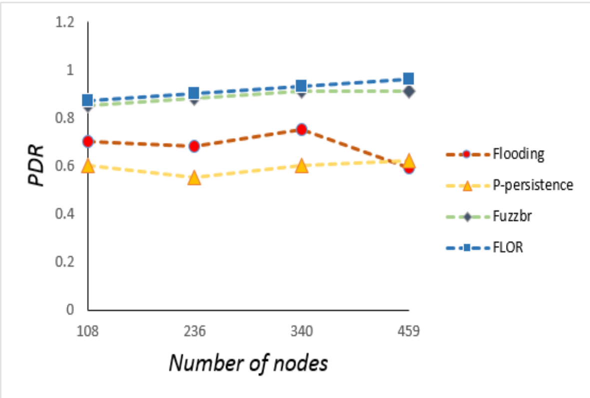

Figure 7. Packet delivery ration for different numbers of vehicles.

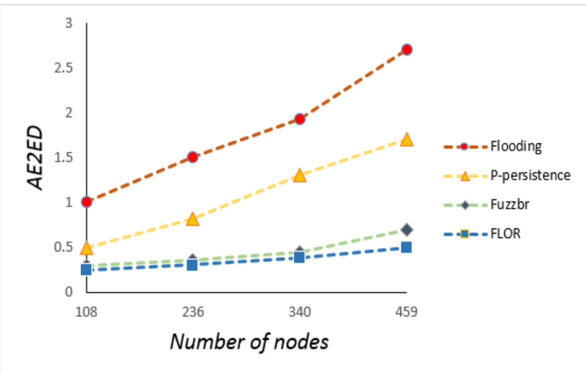

Figure 8. End-to-end latency for different numbers of vehicles.

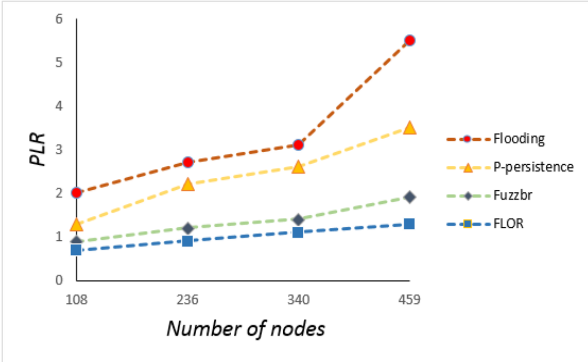

Figure 9. PLR for different numbers of vehicles.

Furthermore, PDRs of the proposed protocol are higher than the other protocols in all cases. Figure 8 shows the E2E latency for testing the protocol for three different number of vehicles. In flooding, with increasing node densities, the delay increases dramatically because rebroadcasting of the duplicate packets is increased as a result of increased density, and consequently, more collisions occur. This, in turn, leads to packet loss with more advancement. In the p-persistence method, the delay is increased by increasing the number of nodes, as in spite of the use of possible rebroadcasting, it cannot fully control rebroadcasting. In FUZZBR, given the fact that the sender selects the rebroadcaster according to the distance between vehicles, the node movement, and signal strength, the selected rebroadcasting nodes receive a non-duplicate packet. This will reduce the delay. Moreover, in this method, the delay is increased by increasing the density and the number of beacon packets. In the proposed method (FLOR), the number of duplicate packets is decreased sharply with respect to the selected parameters. Furthermore, the delay does not significantly change after increasing the density since in the proposed method, the beacon is not used.

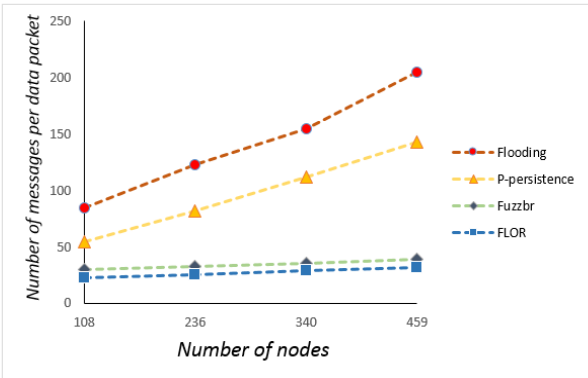

Figure 10. Number of messages per data packet for various numbers of nodes.

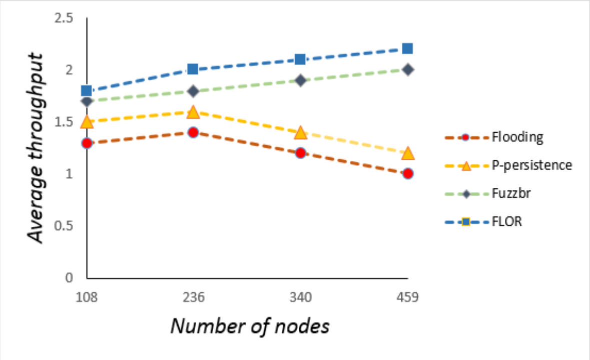

Figure 11. Network throughput for different numbers of vehicles.

Figure 9 shows the PLR values for various protocols. In this figure, it is clear that when the network is in a sparse state, the number of real deliveries at the destination is low and FLOR has better outputs than the flooding protocol. When the network becomes denser, since the number of deliveries are high at the destination, as well as due to high density, the number of lost packets are increased. According to the figure, the proposed protocol has better outputs than the other protocols. Figure 10 demonstrates the number of messages per data packet in testing the proposed protocol. Given the fact that in flooding each node rebroadcasts a packet at least once, the number of extra generated packets is very high. As a result of using possible rebroadcast, the p-persistence method has less duplicate packets.
However, it still cannot prevent the production of duplicate packages completely. In the FUZZBR method, given the fact that only certain nodes rebroadcasts, the number of duplicate packets decreases. In the proposed method, as the number of duplicate packages is used as a parameter, the generation of duplicate packets significantly decreases in the network. Meanwhile, in FUZZBR and FLOR, the increase in the number of nodes does not lead to significant changes in density because only the specified nodes rebroadcast a data message. Figure 11 illustrates the throughput in testing the proposed protocol, and it emphasizes on the fact that in the uncrowded state of the network where routing is difficult, the FLOR protocol can properly operate. This is because when the number of nodes is low, the farther node in the rebroadcasting set is selected based on the defined criteria, which is a specific feature of our proposed method. In other words, for low density, the advancement parameter is more beneficial. Furthermore, for a crowded state, due to the high number of nodes and duplicate packets, this protocol properly delivers the packets to the destination, which reflects the fact that this protocol is dynamic and adaptive. The simulation results indicate the superior performance of the proposed method in some cases over the other protocols.

4.2. Evaluation of performance criteria for Traffic Generation Rate as a variable in Network

In order to evaluate the impact of the generated packet traffic rate on the performance of the proposed protocol, using the CBR traffic, the packet generation rate is made variable from 1 to 10 packets per second and the number of vehicles is set to 266. Note that by increasing the data packet generation rate in s, it leads to an increased collision rate and decreases the packet delivery ratio, and therefore, the packet delivery ratio for each one of the four protocols decreases. However, as shown in figure 12, the packet delivery ratio of the proposed FLOR protocol is the best of all at higher traffic generation rates.

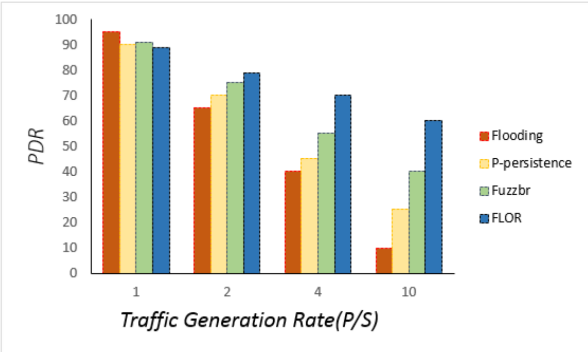

Figure 12. Packet delivery ratio for different traffic generation rates.

Figure 13 shows the end-to-end delay for different traffic generation rates in a network. As the traffic generation rate increases, the delay also increases. By increasing traffic, in addition to the increase in the channel access time, the collisions will also increase, which ultimately increase the end-to end delay.

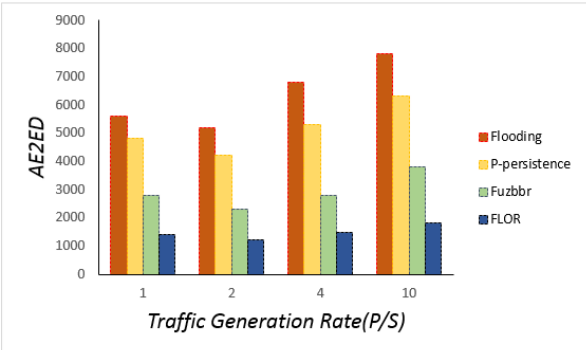

Figure 13. Average end-to-end delay for different traffic generation rates.

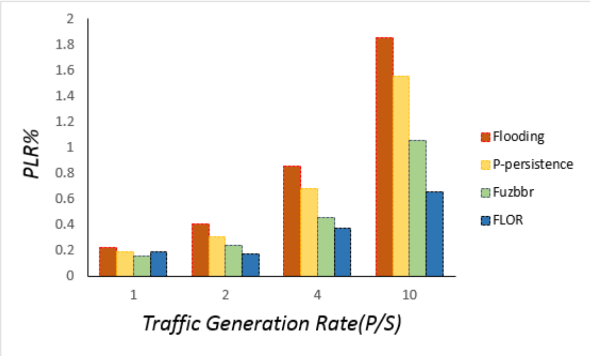

Figure 14. Packet loss ratio for different traffic generation rates.

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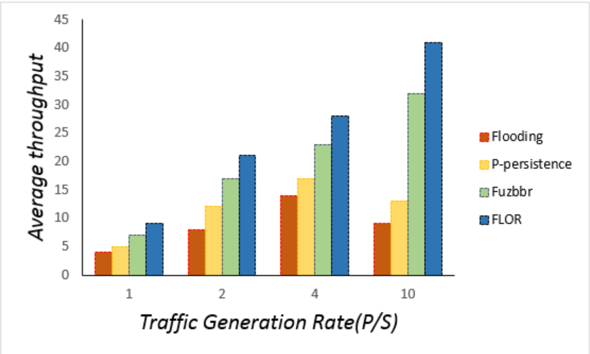

Figure 15. Throughput for different traffic generation rates.

Due to the absence of fuzzy decision-making, the delay of the flooding and P-persistence methods is much more than the other methods, which indicate how much the fuzzy system can affect the delay reduction. The node density parameter of fuzzy functions reduces the delay over the FUZZBR method because the packets are less likely to collide and be retransmitted. Figure 14 shows the lost packets ratio only including data packets. The fuzzy allows rebroadcasting a candidate relay from among the CRS members, which is less likely to collide and reduce the number of duplicate packets. In figure 15, the throughputs of the four protocols are shown versus the variation in the packet generation rate. It is obvious that as much as the packet generation rate increases, the throughput will also increase. The FLOR protocol provides a higher throughput than the other protocols because of its more efficient packet delivery and reduced collision rate. Although the throughput of the FUZZBR protocol is closer to the FLOR protocol, it is not to be forgotten that FUZZBR delivers packets with a higher delay to the destination (Figs. 12 and 13).

The FLOR method is also compared with a similar proposed protocol that uses evidence theory [29]. These methods can also be applied to newer ideas[30]. Since the simulation values are the same, no significant difference was observed in the results. This shows that the proposed method in the scenario of different traffic generation rates is not very different from the other one.

5. Conclusion

A smart opportunistic routing protocol for VANET networks has been proposed, which uses the fuzzy logic and takes the local properties into account. In the proposed protocol, each vehicle after receiving a message decides whether to rebroadcast the received message. The decision on rebroadcasting is made by the fuzzy logic system using the packet advancement, local density, and number of duplicated delivered packets factors. Fuzzy logic systems are effective tools for resolving the multi-criteria conflicts and better evaluation of the options. The results of the simulations for the real movements of the vehicles in Fleet Net, carried out using NS-2 simulator, show that using the fuzzy logic with three membership functions improves the routing performance. The proposed protocol has a better performance compared to that of flooding, P-persistence and FUZZBR protocols in terms of PDR, E2E latency, and throughput in four simulation scenarios with different numbers of vehicles.

References

[1] Liu. J, Wan. J, Wang. Q, Deng. P, Keliang Zhou & Qiao. Y (2015). A survey on position-based routing for vehicular ad hoc networks, Telecommunication Systems, vol. 62, no. 1, pp. 15-30.

[2] Saleh. L, Gamel. S. A, Abo-Al-Ez. K. M & Khaled. M (2016), A Reliable Routing Protocol for Vehicular Ad-hoc Networks, Computers & Electrical Engineering, Elsevier,

[3] Chakchouk. N (2015). A Survey on Opportunistic Routing in Wireless Communication Networks, IEEE Communications Surveys & Tutorials, vol. 17, no. 4, pp. 2214-2241.

[4] Zhang. X, Cao. X, Yan. L &. Sung. D. K. (2016), A Street-Centric Opportunistic Routing Protocol Based on Link Correlation for Urban Vanets, IEEE Transactions on Mobile Computing, vol. 15, no. 7, pp. 1586-1599.

[5] Naderi. M, Zargari. F, & Ghanbari. M (2019). Adaptive beacon broadcast in opportunistic routing for VANETS, Ad-Hoc Networks, Elsevier, vol. 86, pp. 119-130.

[6] Ghosh. T & Mitra. S (2012). Congestion control by dynamic sharing of bandwidth among vehicles in VANET, Intelligent Systems Design and Applications (ISDA), 2012 12th International Conference on, pp. 291-296.

[7] Singh. R. K & Tyagi. N. (2012). Challenges of Routing In Vehicular Ad Hoc Networks: A Survey, IJECCE, vol. 3, no. 1, pp. 126-132.

[8] Abdrabou. A, Liang. B, & Zhuang. W. (2013). Delay analysis for sparse vehicular sensor networks with reliability considerations, IEEE Trans. Wireless Commun., vol. 12, no. 9, pp. 4402–4413, Sep.

[9] Naderi. M, Zargari. F, Sadatpour. V & Ghanbari. M, (2017). A 3-Parameter Routing Cost Function for Improving Opportunistic Routing Performance in VANETs, Wireless Personal Communications, Volume 97, pp. 109–123.

[10] Muhlethaler, P, Laouiti. A, &. Toor. Y, (2007). Comparison of Flooding Techniques for Safety Applications in VANETs, in Telecommunications. ITST'07. 7th International Conference on ITS, 2007, pp. 1–6.

[11] Slavik. M & Mahgoub. I. (2010). Spatial Distribution and Channel Quality, Adaptive Protocol for Multihop Wireless Broadcast Routing in VANET, IEEE Transaction on Mobile Computing, vol. 12, no. 4, pp. 722-734.

[12] Qadri. N, Altaf. M, Fleury. M & Ghanbari. M. (2010). Robust video communication over an urban VANET, Journal of Mobile Information Systems, vol. 6, no. 3, pp. 259-280.

[13] Weiwei, D., Changle, L. & Zhifang, M. (2016). Joint Link State and Forwarding Quality: A Novel Geographic Opportunistic Routing in VANETs, in proceeding 2016 International Conference on Computer, Information and Telecommunication Systems (CITS), Kunming, China, pp. 1-5.

[14] Barootkar M, Ghaffarpour Rahbar. A, & Sabaei, M. (2016). LDAOR Location and Direction Aware Opportunistic Routing in Vehicular Ad hoc Networks, Journal of Telecommunications And Information Technology, vol. 1, no. 1, pp. 68–83.

[15] Celimuge, W., Satoshi O. & Toshihiko K. (2012). VANET Broadcast Protocol Based on Fuzzy Logic and Lightweight Retransmission Mechanism, IEICE Transactions on Communications, vol. E95B, no. 2, pp. 415-425.

[16] Sulistyo S. & Alam S. (2018). SINR and throughput improvement for VANET using fuzzy power control. Int J Commun Syst. (2018); e3579. https://doi.org/10.1002/dac.3579.

[17] Limouchi. E, Mahgoub I, & Alwakeel. A (2016). Fuzzy logic-based broadcast in vehicular ad hoc networks. In IEEE Vehicular Technology Conference (VTC-Fall), pp. 1-5.

[18] Limouchi. E, & Mahgoub. I. (2016). BEFLAB: Bandwidth efficient fuzzy logic-assisted broadcast for VANET.In 2016 IEEE Symposium Series on Computational Intelligence (SSCI), Athens, Greece pp. 1-8.

[19] Marzak, B., El Moumni, S., Benlahmar, E., Ait-Mlouk, A & Talea, M. (2018), Stable routing protocol based on fuzzy logic system in vehicular ad hoc networks. Int J Commun Syst, 31:e3587. https://doi.org/ 10.1002/dac.3587.

[20] Zhou, Y., Li, H., Shi, Ch., Lu, N. & Cheng, N. (2018).A Fuzzy-Rule Based Data Delivery Scheme in VANETs with Intelligent Speed Prediction and Relay Selection, Wireless Communications and Mobile Computing, vol. 2018, Article ID 7637059, pp. 1- 15.

[21] Li, G., Ma, M., Liu, Ch. & Shu, Y. (2015). Adaptive fuzzy multiple attribute decision routing in VANETs, Int. J. Commun. Syst, https://doi.org/ 10.1002/dac.3014.

[22] Li, G., Ma, M., Liu, C., & Shu, Y. (2017), Adaptive fuzzy multiple attribute decision routing in VANETs, Int. J. Commun. Syst., 30: e3014.

[23] Pappis. C. P. & Siettos, C. I. (2005). Search Methodologies: Introductory Tutorials in Optimization and Decision Support Techniques. Boston, MA: Springer US, ch. Fuzzy Reasoning, pp. 437–474. [Online]. Available: http://dx.doi.org/10.1007/0-387-28356-0 15.

[24] Fueßler, H., Mauve, M., Hartenstein, H., Kasemann, M., & Vollmer, D. (2002). A comparison of routing strategies for vehicular ad hoc networks. Technical Report TR-02-003, Department of Computer Science, University of Mannheim.

[25] Dib, G. (2009), Vehicle-to-vehicle channel simulation in a network simulator. Pittsburgh: Information Networking Institute, Carnegie Mellon University.

[26] Wisitpongphan, N, Tonguz, O. K, Parikh. j. S, Mudalige, p., Bai, f, & Sadekar, V. (2007). Broadcast storm mitigation techniques in Vehicular ad hoc networks, IEEE Wireless Communications, pp. 84-94.

[27] Wu. C, Ohzahata. S, & Kato, T. (2013). Flexible, Portable, and Practicable Solution for Routing in VANETs: A Fuzzy Constraint Q-Learning Approach, IEEE Transactions on Vehicular Technology, vol. 62, no. 9, pp. 4251–4263.

[28] Qadri, N, Fleury. M, Altaf. M. & Ghanbari. M. (2010). Multi-source video streaming in a wireless vehicular ad hoc network, IET Communications, vol. 4, no. 11, pp.1300-1311.

[29] Azimi Kashani. A, Ghanbari, M. & Rahmani. A. M. (2019), Improving the performance of opportunistic routing protocol using the evidence theory for VANETs in highways, IET Communications, vol. 13, no. 20, pp. 3360-3368.

[30] Yarinezhad. R. & Sarabi. A. (2019). A New Routing Algorithm for Vehicular Ad-hoc Networks based on Glowworm Swarm Optimization Algorithm, Journal of Artificial Intelligence & Data Mining (JAIDM), vol. 7, no. 1, pp. 69-76.

نشریه هوش مصنوعی و داده کاوی

بهبود عملکرد پروتکل مسیریابی فرصت طلب با استفاده از منطق فازی برای شبکه‌های بین خودرویی در بزرگراه‌ها

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چکیده:

شبکه‌های بین خودرویی (VANETS) یک فناوری نو ظهور با قابلیت گسترده در برنامه‌های مختلف از جمله ایمنی وسایل نقلیه، مدیریت ترافیک و سیستم‌های حمل و نقل هوشمند است. با توجه به تحرک زیاد و سایل نقلیه و توزیع نامتجانس آنها، طراحی پروتکل مسیریابی کارآمد ضروری به نظر می‌رسد. با توجه به اینکه جاده‌ها در بعضی از قسمت‌ها شلوغ است و در سایر قسمت‌ها خلوت است، پروتکل مسیریابی باید بتواند به صورت پویا تصمیم‌گیری کند. از طرف دیگر، محیط VANET در زمان انتقال داده آسیب پذیر است. مسیریابی پخش، شبیه به مسیریابی فرصت طلبانه، می‌تواند در مقایسه با پروتکل‌های دیگر، بازده بهتری را ارائه دهد. در این مقاله پروتکل مسیریابی فرصت طلب منطقی فازی (FLOR) ارائه شده است، که در آن فرآیند تصمیم‌گیری مجدد بسته از طریق سیستم منطق فازی به همراه سه پارامتر ورودی پیشرفت بسته، چگالی محلی و تعداد تکرار انجام می شود. بسته‌های تحویل داده شده از روش‌های انتقال مجدد و مقادیر این پارامترها به عنوان ورودی به سیستم منطق فازی برای حل مسئله چند ریختی با توجه به مناطق شلوغ و خلوت استفاده می‌کند. شبیه ساز NS-2 برای ارزیابی عملکرد پروتکل پیشنهادی FLOR از نظر نسبت تحویل بسته، تأخیر انتهایی به انتها و توان شبکه در مقایسه با پروتکل‌های موجود مانند FLOODING، P-PERSISTENCE و FUZZBR استفاده می‌کند. مقایسه عملکرد همچنین بر استفاده مؤثر از منابع تأکید دارد. شبیه سازی‌های موجود در محیط بزرگراه نشان می‌دهد که پروتکل پیشنهادی در مقایسه با روش‌های منتشر شده فوق، از راندمان QoS بهتری برخوردار است.

کلمات کلیدی: مسیریابی فرصت طلبانه، سیستم منطف فازی, بازپخش, شیکه‌های بین خودرویی.